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RADIO FREQUENCY INTERACTIONS WITH AIR CARGO CONTAINER MATERIALS FOR REAL TIME COLD CHAIN MONITORING

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ABSTRACT Transportation is an important part of the supply chain as goods are being transported over thousands of kilometres from their production sites to consumers thanks to increasing globalization. Many perishable items, most of which are temperature sensitive, need to be transported by air due to their short shelf life. Today's regulations do not allow RFID to be utilized inside aircrafts during flight, but the need for real time cold chain management is pushing the air cargo industry to investigate the capabilities of this technology. Since, environmental conditions highly influence the RFID system's outcome, it is mandatory to understand the RF behaviour around air cargo materials. For this study, three frequencies (433MHz, 915MHz and 2.45GHz) and five aircraft container (ULD) materials (Aluminum, Duralite, Herculite, Kevlar® and Lexan®) were evaluated inside an anechoic chamber. Two tests were performed to detect the signal strength at various points in the measurement space under different configurations to observe the effects of aircraft container materials on RF wave propagation. The results of this study showed that the signal transmission through Aluminum was poor due to the fact that most of the energy was reflected from the surface which caused variations in signal strength in front of the sample. On the contrary, RF waves propagated easily through all four of the other materials, allowing most of the energy to be available behind the samples while a very small amount was reflected. Thusly, all tested materials except Aluminum are RF-lucent and should have no significant interference for any RFID system between 433MHz and 2.45GHz.

Keywords: air cargo, cold chain monitoring, container, material properties, RFID, radio frequency identification, wave propagation.

INTRODUCTION Products, such as food, pharmaceuticals and flowers, are at high risk of perishing from various adversities along the cold chain. The parties involved should control when possible, and at the very least monitor the conditions of the goods in order to ensure their quality and to comply with all legal requirements. Among environmental parameters during transport, temperature is the most important in maintaining the shelf life of the products (Nunes et al., 2006; Zweig, 2006; Jedermann et al., 2009).

Cold chain With today's globalization, there is a growing need for fresh products to be delivered year round all over the world, thus, temperature sensitive items are likely to be shipped by air because of their relatively short shelf life. Unfortunately, a faster transit time does not always imply controlled temperature throughout transportation. In contrast, during airport operations, loading, unloading, air transportation or warehouse storage, perishable goods often suffer from temperature abuse either due to difficulties in controlling the temperature, absence of refrigerated facilities, or lack of information about produce characteristics and needs (Nunes et al., 2003). On approximately 2.6 million tons of perishables air freighted in 2008, nearly 30% is estimated to be lost due to handling and temperature abuse (Catto-Smith, 2006). In a previous study, Emond et al. (1999) showed that the environmental conditions during airport operations could, in fact, be very far from the optimum for fruits and vegetables. Moreover, in a strawberry quality study, Nunes et al. (2003) showed that greater losses in quality occurred during simulation of the airport handling operations, in-flight, and retail display than during warehouse storage at the grower, truck transportation to or from the airport, or during backroom storage at the supermarket.

Temperature monitoring Currently, most digital temperature loggers have to be connected to a host device to download data, and as a result, have limited real-time data interactivity, which result in after-the-fact analysis for claims, loss in quality and related issues. Radio frequency identification (RFID) temperature loggers function wirelessly which allows for real-time information transfer. Active or semi-passive RFID tags can support one or many sensors as well as the unique ID that RFID technology provides by design. The RFID tag, with associated hardware and software will add the benefit of having the item scanned on receipt, so that if an alert (alert triggers are programmable prior to shipping) is active, the receiver knows immediately (not after-the-fact) that there is a potential problem with the shipment and can spend the time required on specific shipments rather than going through random inspections (Jedermann et al., 2007). Many studies have already shown the effectiveness of RFID in monitoring product temperature during transit (Emond, 2007; Jedermann and Lang, 2007; Jedermann et al., 2007; Ketzenberg and Bloemhof-Ruwaard, 2009).

RFID technology Although RFID's effectiveness has been proven for many cases, the technology is not flawless. Certain materials, like metals and water-based liquids, are challenging for RFID systems (Foster and Burberry, 1999; Emond, 2008) and are generally referred to as being RF-Opaque. The behaviour of radio frequency around metal has been studied extensively (Dobkin and Weigand, 2005; Griffin et al., 2006; Prothro et al., 2006; Sydanheimo et al., 2006). Because aluminum is a very good conductor (conductivity 38 MS/m), incident electromagnetic wave totally reflects from the metallic surface with a phase reversal (Cheng, 1993; Reitz et al., 1993). Moreover, metallic surface of the object in the vicinity of an antenna changes its radiation pattern, input impedance, radiation efficiency and resonant frequency. These changes depend on the size and shape of the metallic object and also on the distance of the antenna from the object (Raumonen, 2003; Mo and Zhang, 2007). Mo and Zhang (2007) also demonstrated that RFID tags placed 1/4 wavelength away from the metallic surface enhances the readability of the tags.

Not only metallic materials, but also dielectrics (or electrical insulators) cause reflections. Other materials will affect part of the incident energy and transmit the rest. The exact amount of transmission and reflection is also dependant on the angle of incidence, material thickness, and dielectric properties (Blaunstein and Christodoulou, 2007). On the other hand, little or no reflection occurs when electromagnetic waves penetrate directly through objects such as paper, non conductive plastics or textiles (Penttilä et al., 2006). These materials, including most composites, are non-absorbing and possess low refractive indexes. Such materials are generally referred to as being RF-lucent.

Air Cargo While the world is talking about climate change, the airline industry is looking at ways to be more fuel efficient to minimize their operational costs as well as their impact on the environment. One way to do so is to reduce the weight, and minimizing weight without compromising the business volume is feasible by using lighter containers, or ULDs (Unit Load Device). Composite ULDs can save up to 25% of the tare weight of a traditional aluminum ULD (Nordisk, 2010). For illustration: A Boeing 747-400 aircraft, equipped with 16 standard aluminum LD-3s normally has a total of 1216kg empty container weight. Alternatively, by using ultra light composite LD-3 containers, the combined empty container weight total would be approximately 880kg. Furthermore, composites containers are easier to repair and require fewer visits to a repair station than aluminum units (Saunders, 2003). Kevlar® ULDs are constantly replacing older aluminum containers and account for approximately 39% of a major airline's ULD fleet. Aluminum ULDs still add up to 43% of their fleet, whereas Lexan® containers count for the remaining 18%.

This study focuses on the air transportation part of the cold chain. RFID is not yet a widespread technology in the transportation industry, but its potential value makes it worth the investigation effort. The goal of this study is to explore the possibility of real time temperature monitoring during air cargo operations by researching the effect of container wall materials on RF propagation. Five different ULD materials were chosen for this study: Aluminum, Duralite, Herculite, Kevlar® and Lexan®. Due to the fact that the RF behaviour of materials depend on size, shape and thickness, all samples used for this study were collected from an airline container maintenance facility and therefore represent the true properties for each material. Initial hypotheses are that only Aluminum samples will not allow RF transmission, whereas all other materials will transmit radio waves with negligible interference.

MATERIALS AND METHODS Three radio frequencies (433MHz, 915MHz and 2.45GHz) were tested against five different air cargo materials as described in the introduction: Aluminum, Duralite, Herculite, Kevlar® and Lexan®. Duralite is a thick fibreglass woven composite. Herculite (or Twintex® P PP) is a thermoplastic glass reinforcement panel made of commingled E-Glass and thermoplastic filaments. Kevlar® is made with high strength para-aramid fiber and Lexan® is a translucent polycarbonate. Each sample was a square sheet of 0.305m long sides and thicknesses of 1.00, 1.80, 1.00, 0.50 and 1.80mm respectively.

This series of tests were performed inside an anechoic chamber of dimensions 2.05m high, 1.90m wide and 2.70m deep. The wall materials were Eccosorb VHP-12-NRL and Eccosorb FS-100-NRL (Emerson & Cuming Microwave Products N.V., Westerlo, Belgium), a solid, pyramidal shaped, carbon loaded urethane foam absorber.

Each frequency was generated by an RF signal generator (Agilent N9310A, Agilent Technologies, Santa Clara, CA); power supply (XTR 33-25, Xantrex technology, Burnaby, BC, Canada); and power amplifiers (5803039A and 5303081, Ophir RF, Los Angeles, CA). This equipment was located outside of the anechoic chamber during testing. The RF output of this system was conveyed to the anechoic chamber via a 50m long LMR-400 low-loss cable. Each frequency was tested with a particular set of emitter and receiver antennas (Table 1) and only one frequency was tested at a time.

Table 1. Specifications of the six antennas used.

Frequency	Antenna	Polarization	Gain	Model & Manufacturer
433 MHz	Emitter	Circular	9 dBi	SPA 430, Huber + Suhner AG, Essex, VT
	Receiver	Linear (omni)	0 dBi	B-368-1, How Tsen Intl. Electronics Metal Co.,Ltd. Shin Wu Hsiang, Tao Yuan Hsien, Taiwan
915 MHz	Emitter	Circular	8 dBi	SPA 915, Huber + Suhner AG, Essex, VT
	Receiver	Linear (omni)	2.5 dBi	EXR902TN, Laird Technologies, Schaumburg, IL
2.45 GHz	Emitter	Circular	6 dBi	2AC-001, Alien Technology, Morgan Hill, CA
	Receiver	Linear (omni)	8 dBi	MRN-24008SM3, AntennaWorld, Miami, FL

Two tests were administered to determine the effects of the materials on RF propagation. For all tests, the received signal was measured with a spectrum analyzer (RSA3303B, Tektronix, Beaverton, OR), also kept outside the door of the anechoic chamber during testing. The definition of a data point in this experiment is a 200 sample average of the peak signal power observed at each tested frequency. One frequency was tested at a time and all data were analysed with reference to the control data point (no material sample present).

Test 1 The goal of this test was to quantify the reflection and absorption characteristics of each material. Inside the chamber, the emitting antenna, receiver antenna and material samples were arranged in a row on a Plexiglas table with a Styrofoam plate to help hold everything in place (Figure 1). The table was centered in the room 0.38m above the floor, just over the anechoic chamber surface material responsible from absorbing outside RF radiation. The emitting antenna was positioned vertically, beaming towards the back of the room. The receiving antenna was also positioned vertically with specific intervals based on the radiation wavelength (at $\lambda/2$, $3\lambda/4$, $\lambda+\lambda/4$ or $\lambda+\lambda/2$), and the material sample was positioned at λ in front of the emitting antenna.

Wavelength in meters is calculated as; $$\lambda = \frac{c}{f} \quad (1)$$

Where c is the speed of light in m/s and f is the frequency in Hz. In other words, the sample was 0.692m from the 433MHz antenna; 0.328m away from the 915MHz antenna; or 0.125m away from the 2.45GHz antenna. The respective receiver antennas were consecutively placed ¼ and ½ wavelengths away from the sample, on both sides (figure 1).

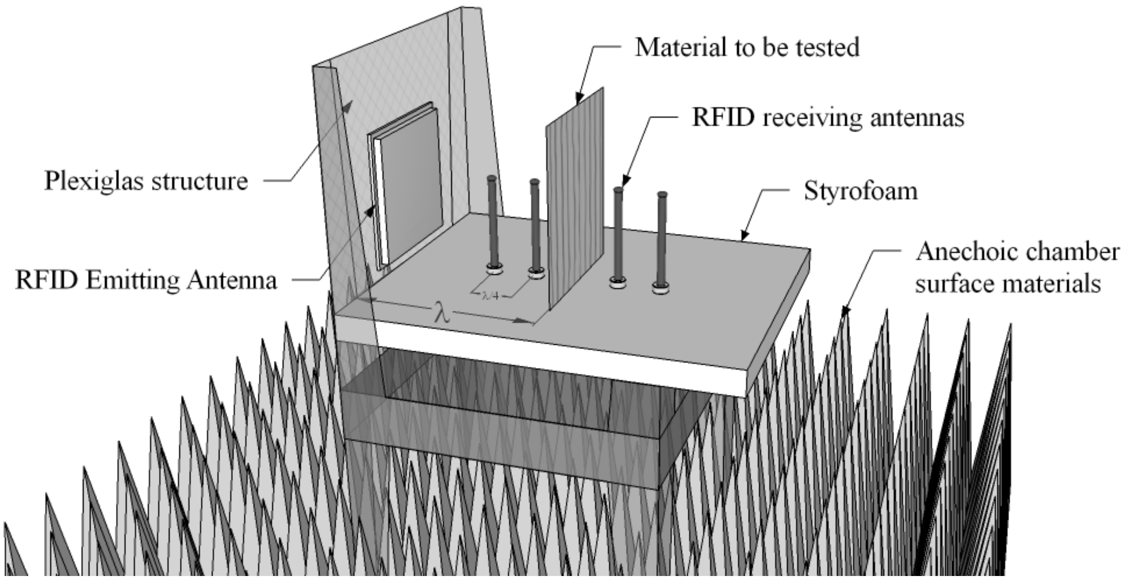

Figure 1. Diagram of the anechoic chamber setup for test 1. Note that four receiver antennas are shown for illustrative purposes as only one receiver antenna is used at a time for each test.

Ideally, test 1 should have been accomplished with infinite planes of each sample. Reality is different, and material availability was limiting. This design is interesting in the way that it procures information on more aspects of radio frequency behaviour, like wave scattering and diffraction around sharp obstacles. In reality, those effects exist and are inevitable components in RFID applications.

Test 2 In order to achieve a more uniform dataset, the goal of this test was to isolate the receiver antenna from the knife-edge diffraction effect. The sample was framed with a solid, pyramidal shaped carbon loaded urethane foam absorber (anechoic chamber wall material). The foam pyramids were glued onto a 0.05m thick Styrofoam sheet and were positioned to leave the center part of the 0.305m by 0.305m square empty to place the samples as shown in Figure 2a. The samples were again positioned one wavelength away from the emitting antennas, and the receiver antenna was taped behind the sample (Figure 2b). Three repetitions of each data point were performed for statistical analysis.

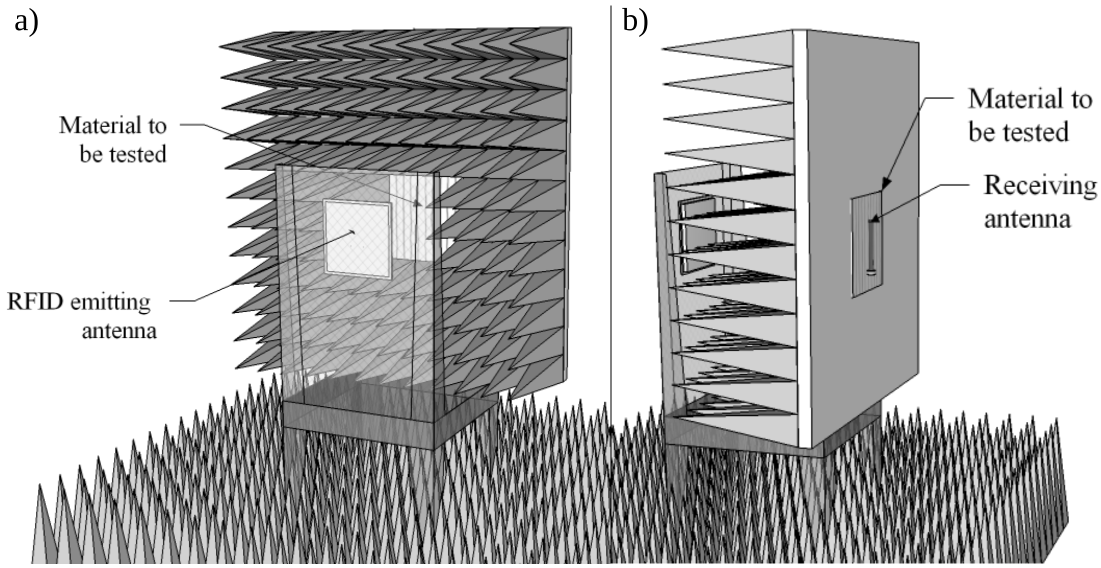

Figure 2. Anechoic chamber set-up for test 2. (a) The sample material is surrounded by pyramidal shaped, carbon loaded urethane foam absorber and is placed one wavelength from the emitting antenna. (b) The receiver antenna is taped behind the material sample.

Statistical analysis consisted of one-way ANOVA to show significant differences between the materials for each frequency. Multiple comparisons of means were performed with Bonferroni adjustments. All statistical analyses were computed using SAS 9.1 (SAS Institute Inc. 2003).

RESULTS AND DISCUSSION

Test 1 The results showed a very strong effect for Aluminum on RF transmission, and minimal interaction for all other sample materials. All comparisons were made between the control and each sample. Table 2 shows values obtained for the control measurements (no material present), whereas Table 3 illustrates the signal deviations from the control (control subtracted from each signal strength measurement). Receiver antenna positions are measured from the emitting antenna and sample materials are positioned at λ.

433MHz Results show weaker signal levels in front of the Aluminum sample at λ/2 (-1.52dBm) and higher signal strength at 3λ/4 (+2.39dBm) (Tables 2-3). This confirms the observation made by Mo and Zhang (2007), which is when an electromagnetic wave hits a metallic surface, it reflects with a 180° phase reversal. This causes signal cancellation at λ/2 and signal amplification at λ/4 from the metallic surface. In our case, λ/4 from the Aluminum sample is 3λ/4 distance from the emitting antenna. All other samples show no considerable loss or gain from reflections when the receiver antenna was positioned in front of the samples (within ±0.09dBm from control). As far as signal transmission through the samples, it is understandable that only the Aluminum sample offers considerable signal blocking, with signal loss of -5.45dBm at λ+λ/4 and -2.70dBm at λ+λ/2. All other materials were within ±0.50dBm from the control.

915MHz In this part of the experiment, signal strength in front of the Aluminum sample is increased in both λ/2 and 3λ/4 cases, although the increase is greater at 3λ/4 (+7.11 vs. +3.98). This could be caused by signal scattering since the plate size (0.305m) is slightly smaller but very close to the wavelength at 915MHz (0.325m). Since for the case of

915MHz the wavelength and the dimensions of the material (obstacle) are of similar sizes, the set-up is in the resonance range (Finkenzeller, 2003). Therefore, the behaviour of RF radiation may not follow traditional rules such as the one stated by Mo and Zhang due to the unpredictable nature of edge diffractions (Longhurst, 1967) as well as resonance. Signal is also slightly reflected from of other materials, Lexan® being the second most reflecting with +1.18dBm gain. In the case of signal transmission, similar results are observed as with 433MHz, except the signal loss is greater, with -19.70 and -11.74 at λ+λ/4 and λ+λ/2 respectively. All other materials are within ±0.17dBm of the control.

2.45GHz Results for this part of the experiment follow Mo and Zhang's theory of wave reflection with a loss of -6.86dBm and a gain of +2.81dBm at λ/2 and 3λ/4 respectively. All other materials are within ±0.58dBm of the control. Moreover, the signal loss behind the samples is obvious with -37.99dBm at λ+λ/4 and -34.37dBm at λ+λ/2, all other materials being within ±0.55dBm of the control.

Table 2. Signal strength measurements (dBm) for control (no sample), test 1. Receiver antenna positions are measured from the emitting antenna.

Frequencies	Receiver antenna positions			
	λ/2	**3λ/4**	**λ+λ/4**	**λ+λ/2**
433MHz	11.07	9.25	8.65	1.80
915MHz	13.90	11.03	7.97	6.15
2.45GHz	8.94	7.85	6.64	6.12

Table 3. Signal strength deviation (dBm) from control (no sample) for test 1. Receiver antenna positions are measured from the emitting antenna and sample materials are positioned at λ.

Frequencies	Materials	Receiver antenna positions			
		λ/2	**3λ/4**	**λ+λ/4**	**λ+λ/2**
433 MHz	Aluminum	-1.52	2.39	-5.45	-2.70
	Duralite	0.02	0.09	0.02	0.18
	Herculite	-0.03	0.02	0.15	0.50
	Kevlar®	-0.02	0.02	0.09	0.40
	Lexan®	0.01	-0.02	0.08	0.14
915 MHz	Aluminum	3.98	7.11	-19.70	-11.74
	Duralite	1.09	0.40	0.17	0.12
	Herculite	0.84	0.30	0.08	0.03
	Kevlar®	0.96	0.32	0.09	0.00
	Lexan®	1.18	0.16	0.17	0.10
2.45 GHz	Aluminum	-6.86	2.81	-37.99	-34.37
	Duralite	0.22	0.38	-0.32	-0.10
	Herculite	-0.17	0.54	-0.51	-0.50
	Kevlar®	-0.15	0.30	-0.55	-0.16
	Lexan®	-0.07	0.58	-0.29	-0.23

Looking at signal transmission behind the Aluminum sample, it is noticeable that the signal loss increases with the frequency. This is caused by the ratio of the wavelengths and the materials sample size. At 433MHz, the wavelength is more than two times longer than the sample size (0.692m and 0.305m respectively); at 915MHz, both dimensions are similar (λ = 0.325m); and at 2.45GHz, the wavelength is about half of the sample size (λ=0.125m). When a radio wave impinges an obstacle larger than its wavelength, reflection occurs. However, when a wave hits an obstacle smaller than its wavelength, scattering occurs and wave patterns are redirected with random phase and amplitude (Blaunstein and Christodoulou, 2007).

It is also noticeable that there is minor signal amplification behind the non metallic samples at 433MHz and 915MHz. This can be explained by the fact that the sample size is smaller than the wavelengths, which allows waves to travel around the materials' edges. This effect is known as the knife-edge diffraction and explains the redirection of electromagnetic waves when they hit a solid obstacle such as the edge of the material sample in this experiment (Kumar et al., 2007). Knife-edge diffraction is described by Huygens-Fresnel principle which states that such an obstruction (the edge of the material in this case) will act as a secondary source of RF radiation (Longhurst, 1967). Depending on the wavelength of the electromagnetic signal, the effects of this secondary source can be observed at different points in the measurement field, in this case, amplification behind the non-metallic samples, however, the discussion of this phenomenon in greater detail is beyond the scope of this text.

Test 2 When six treatments (material samples) are compared, all results are reported as significant when $P < 0.05$ and the Aluminum sample is the only one significantly different from the others for all three frequencies.

Table 4. Signal strength measurements (mean±SD) (dBm) for control, plus signal strength deviation between material samples and control at three frequencies for test 2 (n=3).

Materials	Frequencies		
	433 MHz	**915 MHz**	**2.45 GHz**
Control	3.83±0.05	9.53±0.05	6.96±0.01
Aluminum	-15.16±0.06	-20.49±0.18	-35.47±0.23
Duralite	-0.05±0.03	-0.21±0.01	-0.19±0.03
Herculite	-0.04±0.03	-0.29±0.02	-0.33±0.01
Kevlar®	-0.01±0.01	-0.35±0.01	-0.37±0.01
Lexan®	-0.06±0.04	-0.53±0.65	0.07±0.03

Due to the nature of the second experiment it would be expected to obtain higher attenuation at lower frequencies because shorter wavelengths will travel more easily inside the open frame within the foam absorber material. However, one should note that this observation will be affected by two important parameters: the electromagnetic properties of the container samples as well as the absorbtion profile of the urethane foam absorber, which is proportional to the frequency (Eccosorb, 2008). For instance, for free air (control) the signal strength at 433MHz is 3.83dBm whereas the signal strength at 915MHz is 9.53dBm. This clearly shows the attenuation from the wavelength dimension at lower frequency as expected. However, at 2.45GHz, the signal power is attenuated to 6.96dBm, which is explained by the fact that the foam absorber material has higher absorption coefficients at higher frequencies.

CONCLUSION This test demonstrated the effects of five commonly used air cargo container wall materials on RF propagation at three different frequencies. The reflection and absorption characteristics of each material were quantified. Two different test setups were utilized to analyze the characteristics of RF propagation in greater detail for each material and the results from both experiments showed a very strong effect of Aluminum on RF transmission and minimal interaction for all other sample materials as expected. The use of non-metallic containers for air transportation of perishable products should make real time temperature monitoring possible by allowing RF waves to transmit through the wall surface effortlessly.

REFERENCES

Blaunstein, N. and C. G. Christodoulou. 2007. Radio propagation and adaptive antennas for wireless communication links : terrestrial, atmospheric and ionospheric. Hoboken, N.J.: Wiley-Interscience.

Business Wire. 2002. U.S. Federal Aviation Administration -FAA- Approves Telair International Blast-Resistant Baggage Container. Available at: www.allbusiness.com. Accessed 15 February 2010.

Catto-Smith, C. 2006. Thermal protection of perishable air cargo during ground handling. In International symposium on fresh produce supply chain management.

Cheng, D. K. 1993. In Fundamentals of Engineering Electromagnetics, 304-330. ed. Anonymous , Prentice Hall.

Dobkin, D. M. and S. M. Weigand. 2005. Environmental effects on RFID tag antennas. Microwave Symposium Digest, 2005 IEEE MTT-S International.

Eccosorb. 2008. Eccosorb® VHP-NRL Very high performance broadband pyramidal absorber. . Available at: www.eccosorb.com. Accessed 19 January 2010.

Emond, J. P. 2007. Quantifying RFID's cold chain benefits. In RFID Journal LIVE! 2007 Conference.

Emond, J. P. 2008. The cold chain. In RFID Technology and Applications, 144. ed. S. B. Miles, Sarma, S. E. and Williams, J. R., New York, NY, USA: Cambridge University press.

Emond, J. P., F. Mercier and M. C. N. Nunes. 1999. In-flight temperature conditions in the holds of a widebody aircraft. In Proceedings of the 20th InternationalCongress of Refrigeration, Paper No. 281.

Finkenzeller, K. 2003. RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification. New York, NY, USA: John Wiley & Sons, Inc.

Foster, P. R. and R. A. Burberry. 1999. Antenna problems in RFID systems. IEE Colloquium on RFID Technology 3/1-3/5.

Griffin, J. D., G. D. Durgin, A. Haldi and B. Kippelen. 2006. RF Tag Antenna Performance on Various Materials Using Radio Link Budgets. Antennas and Wireless Propagation Letters, IEEE 5(1): 247-250.

Jedermann, R. and W. Lang. 2007. Semi-passive RFID and beyond: steps towards automated quality tracing in the food chain. Int. J. Radio Frequency Identification 1(3): 247-259.

Jedermann, R., J. P. Emond and W. Lang. 2007. Shelf life prediction by intelligent RFID Technical limits of model accuracy. In International Conference on Dynamics in

Logistics.
Jedermann, R., L. Ruiz-Garcia and W. Lang. 2009. Spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. Computers and Electronics in Agriculture 65(2): 145-154.
Ketzenberg, M. E. and J. M. Bloemhof-Ruwaard. 2009. The Value of RFID Technology Enabled Information to Manage Perishables. ERIM Report Series Reference No. ERS-2009-020-LIS.
Kumar, R., S. K. Kaura, A. K. Sharma, D. P. Chhachhia and A. K. Aggarwal. 2007. Knife-edge diffraction pattern as an interference phenomenon: An experimental reality. Optics & Laser Technology 39(2): 256-261.
Longhurst, R. S. 1967. Geometrical and physical optics. 2nd ed. London: Longman.
Mo, L. and H. J. Zhang. 2007. RFID Antenna near the surface of metal. 2007 International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications803-806.
Nordisk. 2010. Nordisk Ultralite. Available at: www.nordisk-aviation.com. Accessed 19 January 2010.
Nunes, M. C. N., J. P. Emond and J. K. Brecht. 2003. Quality of strawberries as affected by temperature abuse during ground, in-flight and retail handling operations. In 239-246. Acta Hort. (ISHS).
Nunes, M. C. N., J. P. Emond, K. V. Chau, M. Rauth, S. Dea and W. Pelletier. 2006. Effects of in-store conditions on the quality of fresh fruits and vegetables. 262.
Penttilä, K., M. Keskilammi, L. Sydänheimo and M. Kivikoski. 2006. Radio frequency technology for automated manufacturing and logistics control. Part 2: RFID antenna utilisation in industrial applications. The International Journal of Advanced Manufacturing Technology 31(1): 116-124.
Prothro, J. T., G. D. Durgin and J. D. Griffin. 2006. The effects of a metal ground plane on RFID tag antennas. Antennas and Propagation Society International Symposium 2006, IEEE3241-3244.
Raumonen, P., L. Sydanheimo, L. Ukkonen, M. Keskilammi and M. Kivikoski. 2003. Folded dipole antenna near metal plate. Antennas and Propagation Society International Symposium, 2003. IEEE 1848-851 vol.1.
Reitz, J. R., R. W. Christy and F. J. Milford. 1993. Monochromatic waves in bounded regions. In Foundations of electromagnetic theory, 441-469. ed. Anonymous , Reading, Mass.: Addison-Wesley.
Saunders, B. 2003. Award-winning blast resistant cargo container at Dubai air show spotlight. Available at: www.zawya.com. Accessed 14 February 2010.
Sydänheimo, L., L. Ukkonen and M. Kivikoski. 2006. Effects of size and shape of metallic objects on performance of passive radio frequency identification. The International Journal of Advanced Manufacturing Technology 30(9): 897-905.
Zweig, S. E. 2006. Advances in vaccine stability monitoring technology. Vaccine 24(33-34): 5977-5985.