RF Hot-Zone Location Within Rectangular Confined Spaces

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Abstract

The use of radio frequency (RF) has adequately enhanced our lives through its applications in communications, weather systems, navigation, maintenance works, medicine and manufacturing. The technology is however not without its drawbacks in that exposure may sometimes be above the exposure limits set by International Standards and require shrewd management practises to avoid the associated risks.

Ray tracing models have been extensively used to track RF propagation inside and outside of buildings to predict RF signal loss but the complexities of the environment, personnel, obstacles and other artefacts render it near impossible to accurately determine the location and intensity with any certainty. One environment for consideration which may not be as complex as buildings is that of a confined space where workers may be exposed to incident RF from nearby cell-sites, RF equipment or television and radio broadcasting towers.

A confined space has the potential of being hazardous since its structural dimensions are sometimes of the order of magnitude similar to the wavelength of RF in the SAR(specific absorption rate) region of the electromagnetic spectrum, and may propagate with little energy loss in this space which acts as a waveguide for this wavelength. This RF energy is able to reflect off of the walls of the space setting up points of maximum intensity where constructive interference occurs between reflected and incident rays. These maximum intensity points may exceed the exposure limits for people as set by International Standards. Some confined spaces include: rectangular tanks, man-holes, pipes, air-condition ducts, vessel radio rooms, aircraft cockpits, engineering operating rooms, ships, tanks, cargo containers and silos.

Electromagnetic wave propagation at higher frequencies such as in the SAR (30- 1000 MHz) region is a special concern to authorities involved in setting RF and microwave exposure safety guidelines. Standards however set exposure limits for free space propagation but fall short in addressing limits for covert locations where the RF wave energy is confined within boundaries.

Waveguide technology has managed to constrain microwaves to remain within set boundaries, with fixed frequencies that force the waves to behave in a manner different to if they were moving in free space. This technology has offered the ability to transport more energy for communication purposes other than transmission lines. The size of a waveguide may be to the order of a few centimetres and can guide RF of wavelengths of the order of centimetres also

but what if spaces of larger dimensions are capable of being waveguides and can guide waves of larger wavelengths such as those that correspond to frequencies between 30MHz and 1000MHz?

RF ray model tracing techniques and waveguide theory will be used to construct an algorithm that predicts the intensities and positions of constructive interference zones or hot zones when RF rays between 30-1000 MHz are transmitted through confined spaces. The model will be tested using a point source for RF propagation inside an empty rectangular space constructed with highly reflective walls and surface dimensions of 3m x 2m x 2m.

The findings of the research will contribute to the existing body of knowledge on RF safety in the workplace but will however be tailored to confined spaces where engineering, manufacturing and maintenance works are being carried out.

Use of COMSOL Multiphysics®

• The software will be used to trace the ray paths as well as the electric field intensities along 'a' and 'b', and the power densities as they leave a point source just outside the confined space and propagate along the guide in a 'zig-zag' manner. See fig 1.

• The ray tracing and field intensity/ power density will be done for 3* modes of propagation, namely the TE10, TE20 and TE30 modes and more if required, corresponding to a = $\lambda/2$, λ and $3\lambda/2$. See fig 2.

• The points of constructive interference where the electric field cross for simultaneous varying modes of propagation will be predicted using COMSOL Multiphysics®. This is done by superimposing the images of the three propagation modes on each other and identifying the intersection points. These points will then be analysed to determine which constitute constructive interference, i.e. where the path difference between ray are a multiple of λg, the guide wavelength.

• This procedure will be done for guides (confined spaces) which are closed at both ends, closed at one end and open at both ends. See Drawings.

• Inputs to model and COMSOL: m and n which are the number of half wavelength variations in 'a' and 'b', dimensions of 'a' and 'b', frequencies, speed of light, permittivity and permeability of air inside guide, reflectivity of inner walls of guide, wall material conductivity, length of guide- 'l', propagation equation,

• Calculations obtained from COMSOL: guide wavelength- λg, cut off wavelength and cut-off frequency - λc and fc, angles of incidence and reflection from walls, attenuation coefficient, position of hot zones based on the ray tracing superimposing stated earlier and intensities at these points based on the propagation equation developed for the model,

• Graphs- plot graphs of power density and field intensities versus position, E position of hot zone and S versus angle of incidence

Discussion

The radiation coming from the antenna in fig 3 may have a wavelength of the order of magnitude of the width and height of the cargo container which may create a waveguide in the container.
Table 1: Cargo container dimensions

The table shows cargo container dimensions with height and width almost the same. This may be safe as far as RF propagation is concerned but is not stipulated as a requirement for this hazard so manufacturers are free to shape containers into any dimensions and may therefore unknowingly design a potential waveguide.

RF therefore may not pose a threat in free space once we are in compliance with the exposure limits but man has built high buildings containing confined spaces such as a/c ducts where men will have to work. RF will be incident on these structures and all contained in them as they propagate from their sources.

Results

The model is expected to:
1. Predict and trace the path of the rays inside the guide for varying frequencies of the same guide
2. Superimpose the ray paths for each frequency and show the constructive interference points
3. 1 and 2 above must be completed for guide open at both ends, closed at one end and closed at both ends
4. Predict the intensities of the hot spots
5. Place positions of hot spots on a field map with field coordinates- to be designed
6. Plot graphs of hot zone characteristics along the guide using polar coordinates
7. Predict positions and intensities for frequencies not used in the scope of this work
8. Plot field patterns along guide (confined space)

Conclusion

This model arises out of the belief that a more rigorous treatment of RF propagation in confined spaces is needed to provide data and analysis techniques to international standards bodies on worker exposure and safety, so that more accurate exposure guidelines may be set. This arises from the public outcry of their experiences from stated adverse biological effects. In this regard, the research must continue for us to have sufficient information to manage this radiation if indeed the dangers claimed are found to be credible.

Reference

1) A Guide to Radio Frequency Hazards With Electric Detonators: N.C. Department of Labor Occupational Safety and Health Division 1101 Mail Service Center Raleigh, NC 27699-1101, Cherie Berry, Commissioner of Labor

2) Chatterjee, R. 1968. Elements of Microwave Engineering. Ellis Horwood series in electrical and electronic engineering. John Wiley and Sons, New York.

3) Cleary J.G and G. Wyvill. 'Analysis of an algorithm for fast ray tracing using uniform space subdivision' Vis. Comput., vol 4, pp65-83, 1998.

4) Durgin G, N. Patwari and T.S. Rappaport, "Improved 3D ray launching method for wireless propagation prediction" Electron Lett., vol. 33, no.16, pp 1412-1413, 1997.

5) Fortune S.F. D.M Gay, B.W.Kerninghan, O/Landron, R.A. Valenzuela and M.H Wright 'Wise design of indoor wireless systems; Practical computation and optimization," IEEE Comput. Sci. Eng.Mag., pp.58-68, Spring 1995.

6) HO P, and T.S.Rapport, 1993. Wireless Channel Prediction in a Modern Office Building Using and Image Based Ray Tracing Model, Proc. IEEE Globecom Conf, IEEE Press, 1003, pp 1247 – 1251.

7) Honcharenko W. 1992. Mechanisma Governing UHF Propagation on Single Floors in Modern Office Buildings, IEEE Trans. Vehicular Tech, Vol 41, No 4, 4 Nov. 1992, pp 496-504.

8) Horikoshi J 1.2 GHz Band Wave Propagation Measurements in Concrete Buildings for Indoor Communications, IEEE Transactions on Vehicular Technology, Vol. VT -35, No4. November 1986.

9) Mathews, P and I Stephenson, 1968. Microwave Components, Chapman and Hall Ltd, 11 New Fetter Lane, London EC. Ch 1, pg 3-27.

10) Mathews, P and I Stephenson, 1968. Microwave Components, Chapman and Hall Ltd, 11 New Fetter Lane, London EC4. Pg 25.

11) Molkdar D. 1991. Review of Radio Propagation Into and within Buildings, IEEE Proceedings-H, vol. 138, No 1, February 1991.

12) Okumura E, E. Ohmori, Kawano T, Fukuda K, 'Field strength variability in UHF land mobile service', Rev. Elect. Comm.Lab., vol.16, no 9-10, pp.825-873, Sept- Oct. 1968.

13) Porrat D and D.C Cox. UHF Propagation in Indoor Hallways, 2003

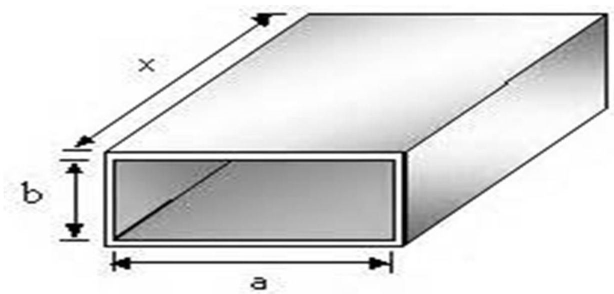
14) Rappaport T.S. Wireless Communications: Principle and Practice. Englewood Cliffs, NJ: Prentice Hall, 1996.

15) Seybold, John S. 2005. Introduction to RF Propagation.pg11. John Wiley and Sons, Inc., Hoboken, New Jersey,

16) Whitaker, Jerry. 2002. The RF Transmission Systems Handbook. CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431. Pg 15-13.

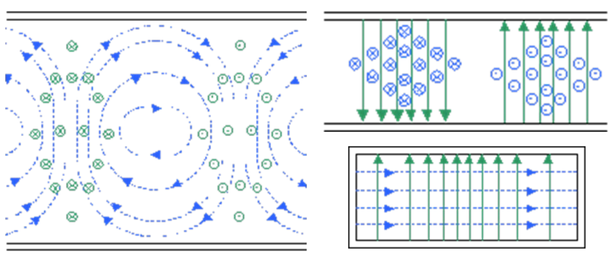
17) Zhang Z, Z Yun and M.F Iskander, "Ray tracing method for propagation models in wireless communication systems, " Electron Lett., vol. 36, no 5, pp 464-465, March 2000.

Figures used in the abstract



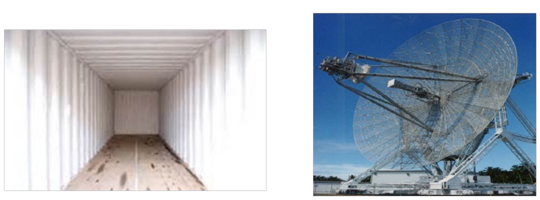
Source: http://www.bing.com/images/search?q=waveguides

Figure 1: Picture of waveguide.



http://www.rfcafe.com/references/electrical/waveguide.htm

Figure 2: Examples of the field configuration within a guide which is to be simulated for a live confined workspace.



http://www.bing.com/images/search?q=inside+dimensions+of+cargo+containers&qs=n&form=QBIR&pq=inside+dimensions+of+cargo+containers&sc=0-27&sp=-1&sk=#a : Source:http://en.wikipedia.org/wiki/File:Radar_antenna.jpg

Figure 3: Antenna in close proximity to cargo confined space.

Desig-nation	Length			Height			Width			Maximum gross weight	
	mm	ft	in	mm	ft	in	mm	ft	in	kg	lb
1A	12,192	40		2,438	8		2,438	8		30,480	67,200
1AA	12,192	40		2,591	8	6	2,438	8		30,480	67,200
1B	9,125	29	11¼	2,438	8		2,438	8		25,400	56,000
1BB	9,125	29	11¼	2,591	8	6	2,438	8		25,400	56,000
1C	6,058	19	11¼	2,438	8		2,438	8		20,320	44,800
1CC	6,058	19	11¼	2,591	8	6	2,438	8		20,320	44,800
1D	2,991	9	9¾	2,438	8		2,438	8		10,160	22,400
1E	1,968	6	5½	2,438	8		2,438	8		7,110	15,700
1F	1,460	4	9½	2,438	8		2,438	8		5,080	11,200

Figure 4: Table showing cargo container dimensions.