

Fuzzification of Electromagnetic Interference Patterns Onboard Commercial Airlines Due to Wireless Technology

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Abstract

The use of portable wireless technology has increased dramatically over the past few years. Over the years however, numerous reports have cited portable electronic devices (PEDs) as a possible cause of electromagnetic interference (EMI) to aircraft navigation and communication radio systems. PEDs may act as transmitters and their signals may be detected by the various radio receiver antennas installed on the aircraft. Measurement of the radiated field coupling between passenger cabin locations and aircraft communication and navigation receivers, via their antennas is defined herein as interference path loss (IPL) [1]. Personnel from NASA Langley Research Center, Eagles Wings Inc., and United Airlines performed extensive IPL measurements on several Boeing 737 airplanes. In previous work, the IPL data collected was graphically plotted and presented using MATLAB. This paper provides an introductory result of modeling EMI patterns using Fuzzy Logic, using the graphical analysis of IPL data summarized in [1]. The application of fuzzy logic seeks to provide a means of estimating IPL at various locations within an airplane passenger cabin using simple modeling parameters. Fuzzy logic methods may provide a means to assess IPL characteristics of aircraft that have not been subject to expensive measurement or modeling processes and may also be useful for estimating the merit of aircraft design changes intended to minimize the potential for EMI.

1. Introduction

In the spring of 2002, engineers from NASA Langley Research Center, United Airlines, and Eagles Wings Inc. teamed to collect extensive IPL data on several out-of-service Boeing 737-200 and 747-400 airplanes. The following four systems were considered: Instrument landing system Glideslope (GS) located in the nose of the aircraft, Traffic Alert and Collision Avoidance System (TCAS) located on top of the second window of the aircraft, VHF Omnidirectional system located on top of the emergency exit near window 16, and finally the instrument landing system Localizer (LOC) located on the tip of the tail of the aircraft. Details of IPL measurements can be found in [1] and [2]. IPL measurements were taken on and between each seat location of the aircraft across the 32 rows in both horizontal and vertical polarizations; therefore, a total of eight measurements were taken on each row (labeled W, A, AB, B, BC, C, CI, I in the graphs herein) where 'W' represents the window location and 'I' represents aisle. The IPL data measured was then plotted in a 3-D representation in [1] to view and understand the locations of the greatest interference in relation to the aircraft antenna system of concern. Some of the resulting MATLAB graphs from [1] are included in this paper for comparison purposes.

2. Fuzzy Logic and Assumptions Used for Modeling

Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambitious, imprecise, noisy or missing input information. The logic extends Boolean logic to handle the expression of vague concepts. To express imprecision in a quantitative fashion, it introduces a set membership function that maps elements to real values between zero and one (inclusive); the value indicated the "degree" to which an element belongs to a set. A membership value of zero indicates that the element is entirely outside the set, whereas a one indicates that the element lies entirely inside a given set. Any value between the two extremes indicate a degree of partial membership to the set. [3]

The four-step fuzzy reasoning procedures employed by applications includes: Fuzzification, which establishes the fact base of the fuzzy system. First, it identifies the input and output of the system and then identifies the appropriate if-then rules and uses raw data to derive a membership function. At this point, one is ready to apply the fuzzy logic to the system. As inputs are received by the system, inference, the second step, evaluates all if-then rules and determines their truth values. If a given input does not precisely

correspond to an if-then rule, then partial matching of the input data is used to interpolate an answer. Several methods of answer interpolation exist. Then composition combines all fuzzy conclusions obtained by inference into a single conclusion. Different fuzzy rules might have different conclusions, so it is necessary to consider all rules. The final step of defuzzification converts the fuzzy value obtained from composition into a “crisp” value; this process is often complex since the resulting fuzzy set might not translate directly into a crisp value. Defuzzification is necessary, since controllers of physical systems require discrete signals.

Using the rules above, a Fuzzy system was designed and implemented to model the Electromagnetic interference patterns due to PEDs onboard Boeing 737-200. Before modeling the system however, a few major assumptions had to be made. Past measurements have revealed that electromagnetic wave propagation from the aircraft passenger cabin to aircraft antennas is primarily influenced by the presence and location of window and door apertures in the (typically) aluminum fuselage. The specific details of this propagation are not possible to measure without corrupting the propagation phenomena, and are extremely difficult to model. Figure 1(a) shows the propagation problem mentioned above. A simple fuzzy logic model allows the passenger cabin propagation phenomena to be modeled by a rectangular box, with antennas located directly in top of the window locations. As seen in Figure 1(b), the waves are now assumed to have a straight propagation from antenna to the window, and then straight inward propagation from the window to the seat. This simple assumption helped keep the model in rectangular coordinates, instead of polar coordinates.

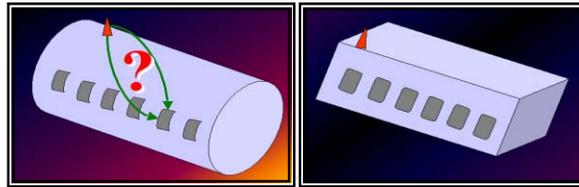


Figure 1: (a) Wave Propagation Uncertainty in a Real System,
(b) Assumed Fuselage Shape and Antenna location for Modeling

Another problem before modeling was the actual dimensions of the airplane were unknown. Since the entire model is based on the distance as the major factor, the author wanted to use the actual dimensions of a Boeing 737 to model the EMI patterns. Since the necessary dimensions were not available in time for this analysis, estimated “seat units” were used, where one unit represented one seat length. For the modeling performed in this paper, the height of the plane is estimated to be 5 seat units. Finally, since the results from the Localizer antenna were not as predicted, the Localizer Antenna was not modeled in this paper. In future, the reflection phenomenon and the detail that the Localizer antenna is located very high on the tip of the tail of the aircraft may be added.

3. EMI Rules for Fuzzy Modeling

After observing the graphical patterns on B-737 in [1], three rules are derived. Three factors that affect the EMI patterns include the seat’s distance from the door, from the windows as well as from the aircraft’s antenna. Probabilities between 0 to 1 were assigned to each seat based on the distance between the seats and the parameters (door, window or antenna). From the graphical plots, visual conclusions were drawn, such as “if the distance from the door to the seat is greater than 5 units, little to no coupling existed.” With such visual understanding of the graphical plots, the following three rules were created:

I. Seat Distance from Window:

From the graphical plots in [1], it was concluded that as the distance from window increased, coupling decreased. From the visual analysis of the graphs in [1], the following graph was obtained for modeling purposes with the equivalent set of equations:

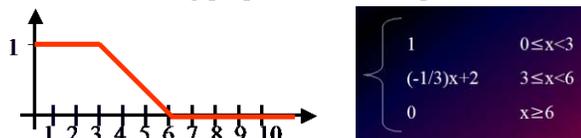


Figure 2: Probability of Coupling (y) vs. Seat Distance (x). Equations based on Rule 1

II. Seat Distance from Door:

The locations of the doors have a very important role in the EMI patterns in the graphical plots. The electromagnetic waves propagate and “leak” more freely from the doors than from the fuselage or small windows of the aircraft. The distance from door to seat equals to the slope between the seat and the door, this can be represented by the equation below, where every variable represents distance:

$$\Delta Y/\Delta X = |\text{door-seat_row}/\text{seat_to_window}|$$

From the equation, the following ranges can be derived: $\Delta Y/\Delta X = (1 \rightarrow 31)/(1 \rightarrow 31) = (1 \rightarrow 31)$

The range of the numerator is from 1 to 31 from the 32 possible rows of the aircraft, the denominator has a range between 1 to 31 as well. The division of the numerator with the denominator can also range from 1 to 31. From the graphical plots, the probability of a seat to have high coupling was a 1 when the seat distance was only one units away from the door. As the distance increased, the probability of high coupling decreased, leading to a zero probability of coupling after a distance of 4 units away from the door.

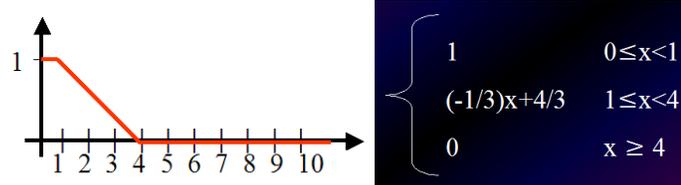


Figure 3: Probability of Coupling (y) vs. Seat Distance (x). Equations based on Rule 2

III. Seat Distance from Antenna:

The location of the antenna was the most important factor in determining the coupling intensities throughout the aircraft. As observed from the graphical plots, as the distance from the antenna increased, the coupling decreased. Calculating the distance from the antenna to the seats inside was a little more complex than before as first, the distance from the antenna to window needed to be calculated, then added to the distance from window to seat. The coupling range can be represented by the following equation, where the variables represent distance:

$$\Delta Y/\Delta X + S2W = |\text{antenna-seat_row}/\text{height} + \text{seat_to_window}|$$

According to the above equation, the following coupling ranges can be derived:

$$\Delta Y/\Delta X + S2W = (1 \rightarrow 31)/5 + (1 \rightarrow 8) = (1/5 \rightarrow 6) + (1 \rightarrow 8) = (1/5 \rightarrow 14)$$

The distance from antenna was estimated such that if the distance was less than 4 seat units, the coupling should be maximum, while if the distance was greater than 9 seat units zero coupling would exist.

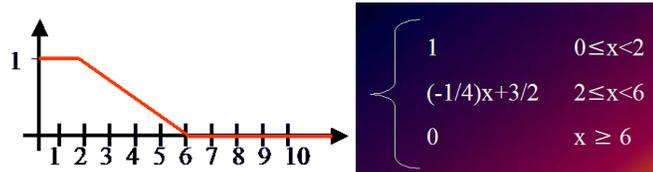


Figure 4: Probability of Coupling (y) vs. Seat Distance (x). Equations based on Rule 3

4. Modeling Results and Conclusion

A MATLAB script was written to make the modeling dynamic as well as plotting the results similar to the graphs for actual IPL measurements. The user was able to define the length of the aircraft in terms of the number of rows, the number and location of doors, the location of the antenna as well as the height of the plane. The airplane was modeled as an 8 by 32 matrix; 8 representing the possible seat locations in a row, from window to aisle. The 32 represented the possible number of rows of the aircraft, from the front of the fuselage, to the tail. Once the locations of the doors and antenna were inputted, the software applied all three rules to each of the elements of the 8x32 matrix. Then the three resulting 8x32 matrices were merged together into a fourth 8x32 matrix using addition. The results from Fuzzy Modeling are shown in Figure 5a for a TCAS system. Figure 5b shows the graphical results in MATLAB from the

actual IPL measurements on a TCAS system. Similarly, Figures 6a and 6b show a close comparison of graphs derived from Fuzzy modeling vs. actual IPL plot on a VHF system. The results from modeling are similar to the graphical results from the actual IPL data. These preliminary results appear promising. The next step will be to improve the model further with actual airplane measurements. The model will also be further improved to add the reflective properties as well as the effects of different polarizations, i.e. horizontal and vertical polarizations.

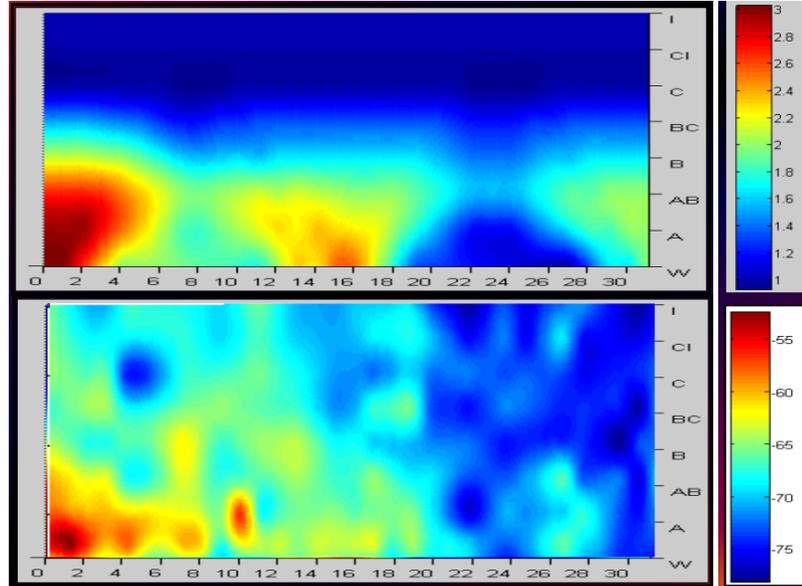


Figure 6: (top) Results from Modeling with input antenna located at Window 2, and doors located at 1, 16 and 32 respectively; (bottom) Graphical representation of actual IPL measurements for a TCAS system

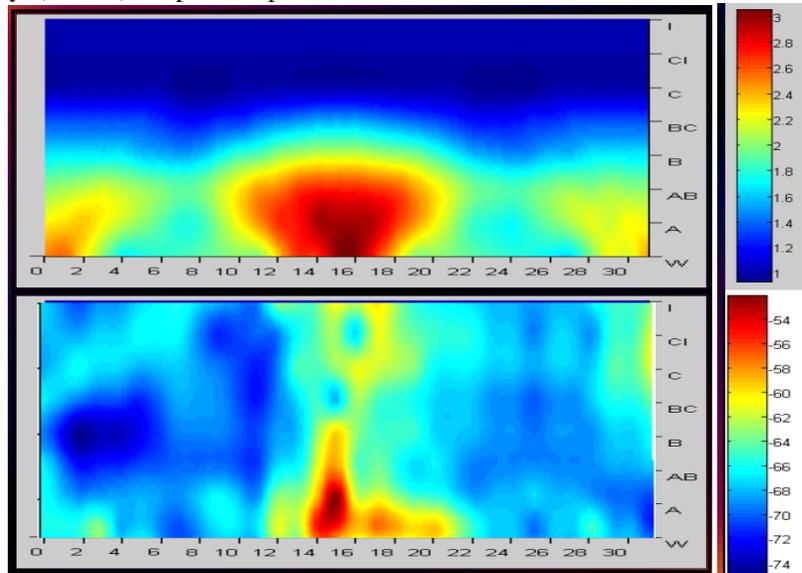


Figure 6: (top) Results from Modeling with input antenna located at Window 16, and doors located at 1, 16 and 32 respectively; (bottom) Graphical representation of actual IPL measurements for a VHF system

5. References

- [1] Jafri, M., J. Ely, L. Vahala, "Graphical and Statistical Analysis of Airplane Passenger Cabin RF Coupling Paths to Avionics." Digital Avionics and Systems Conference, 2003.
- [2] Fuller, Gerald. "B737-200 Path Loss Tests: Victorville, California." Mariposa, CA, March 2002, Task 1 report under NASA Contract L-16099.
- [3] Zadeh, L and R. Yager. "Fuzzy Sets, Neural Networks, and Soft Computing." VNR Publishing, 1994.