Path Loss from a Transmitter Inside an Aircraft Cabin to an Exterior Fuselage-Mounted Antenna

K.W. Hurst & S.W. Ellingson

Dept. of Electrical & Computer Engineering
Virginia Polytechnic Institute & State University
ellingson@vt.edu

2008 IEEE Int'l Antenna & Propagation Sym.

Introduction

The increasing use of mobile electronic devices by passengers and equipment on large aircraft may increase the likelihood of interference with the aircraft's electronic systems.

Thus, the ``interference path loss'' (IPL) from a transmitting device inside the cabin, to the antenna terminals of a "victim system" (such as GPS), is of interest.

Full-wave and other deterministic techniques are impractical and undesirable for this purpose due to the large electrical dimensions of the aircraft, as well as the variability of the cabin configuration.

We describe here an approximate approach that is not limited by computational burden and can provide additional useful insight into the problem.

Summary of the Method

Power transmit by device in cabin

↓

Microwave cavity theory to estimate power escape through widows

Replace windows with magnetic current moments radiating same power

UTD to estimate power transfer from current to antenna

↓

IPL lower-bounded by sum of phase-aligned per-window contributions

Interior: "Power Balance Theory" (PBT)

Allows one to zero in on dominant loss mechanisms:

$$\frac{1}{Q} = \frac{1}{Q_1} + \frac{1}{Q_2} + \frac{1}{Q_3} + \frac{1}{Q_4}$$

Q_1: Associated with wall conductivity

Q_2: Associated with absorption by objects in chamber

Q_3: Associated with escape through wall apertures

Q_4: Associated with escape into antenna eff. apertures

$$L_w = \frac{P_{d3}}{P_T} = \frac{P_{d3}}{P_d} \approx \frac{Q_2}{Q_2 + Q_3}$$

$$Q_1 = \frac{3V}{2\mu_r S\delta} \qquad Q_3 = \frac{4\pi V}{\lambda < \sigma_t >}$$

$$Q_2 = \frac{2\pi V}{\lambda < \sigma_a >} \qquad Q_4 = \frac{16\pi^2 V}{N\lambda^3}$$

- Adapted from D.A. Hill *et al*. (1994), *IEEE Trans. on Electromagnetic Compatibility*, 36, 169.
- **Key idea:** Model cabin as a lossy cavity. If sufficiently "reverberant", then power escape through windows depends only on "bulk" media and geometrical values, and is insensitive to the specific materials, positions, and orientations.

Required Parameters for PBT:

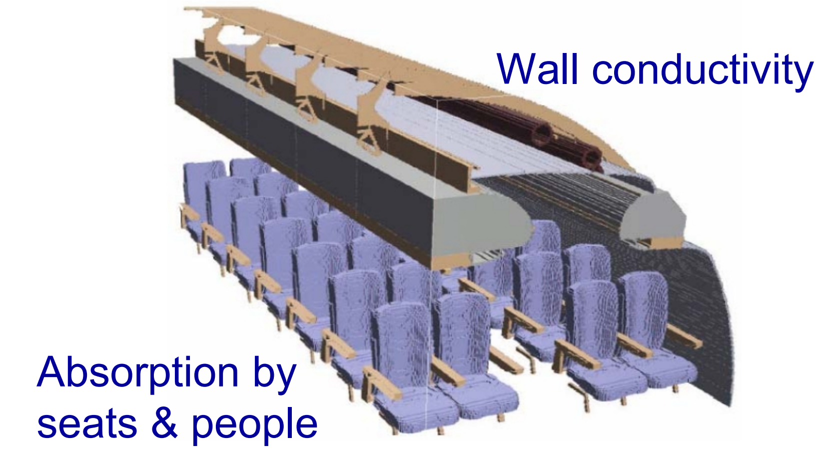
V = volume of compartment

S = surface area of compartment

$<\sigma_a>$ = absorption loss cross-section

$<\sigma_t>$ = transmission loss cross-section

Number & size (but not shape) of windows



PBT Applied to Aircraft Cabins: GPS L1

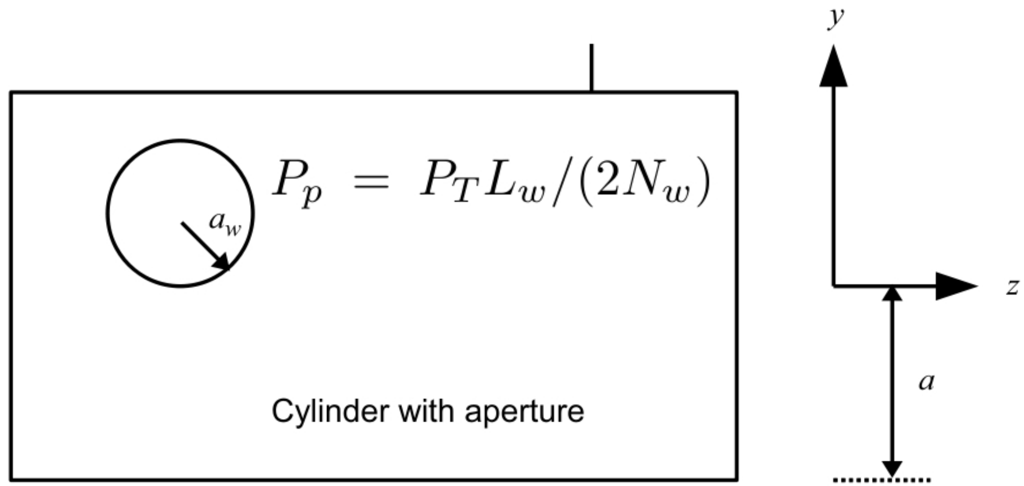
Aircraft	Passenger Load	L_w [dB]	Total Q	Loss in People	Loss in Seats
B727-200	Full	−16.2	101	88.8%	8.9%
	50%	−13.7	181	79.8%	16.0%
	Empty	−6.7	893	0.0%	78.7%
B737-200	Full	−16.9	87	89.0%	2.1%
	50%	−14.3	158	80.0%	16.0%
	Empty	−7.3	798	0.0%	81.2%
B747-200	Full	−17.9	90	89.5%	8.9%
	50%	−15.4	162	80.9%	16.2%
	Empty	−8.2	851	0.0%	84.8%
B767-300	Full	−18.5	124	89.6%	9.0%
	50%	−16.0	225	81.2%	16.2%
	Empty	−8.7	1197	0.0%	86.5%
B777-200	Full	−18.4	185	89.6%	9.0%
	50%	−15.8	336	81.2%	16.2%
	Empty	−8.6	1780	0.0%	86.1%
A330-300	Full	−18.1	159	89.5%	9.0%
	50%	−15.5	288	81.0%	16.2%
	Empty	−8.3	1516	0.0%	85.3%

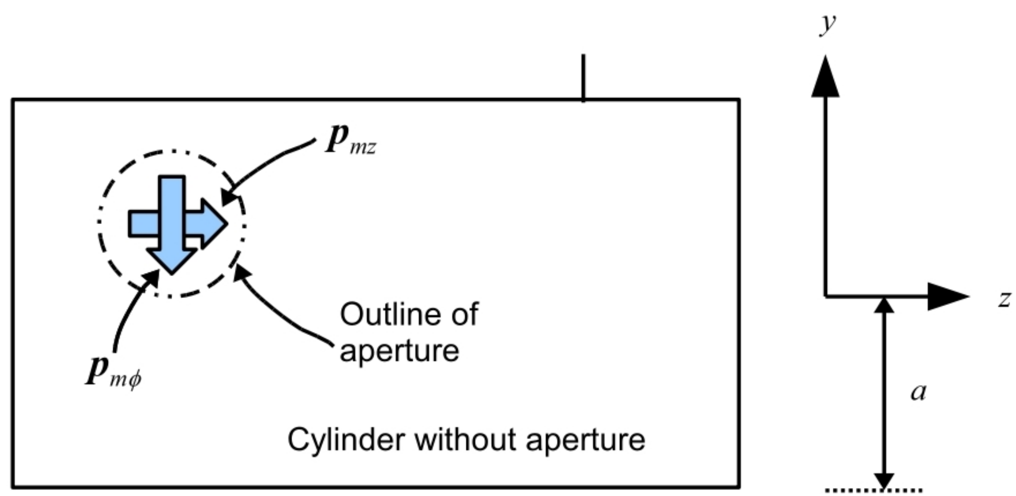
- L_w is the ratio of power escape through windows to total power radiated by device
- Also shown is percentage of total power dissipated into people and seats
- Note passenger loading has a large effect on amount of power escaping through windows

GPS L1 = 1575.42 MHz
(GPS is a key system of interest in IPL studies)

Interior-to-Exterior Coupling

- Assume roughly equal power leaves each window (supported by measurement studies)
- Replace each window with equivalent magnetic current moments radiating the same amount of power
- Fuselage modeled as perfectly-conducting right-circular cylinder

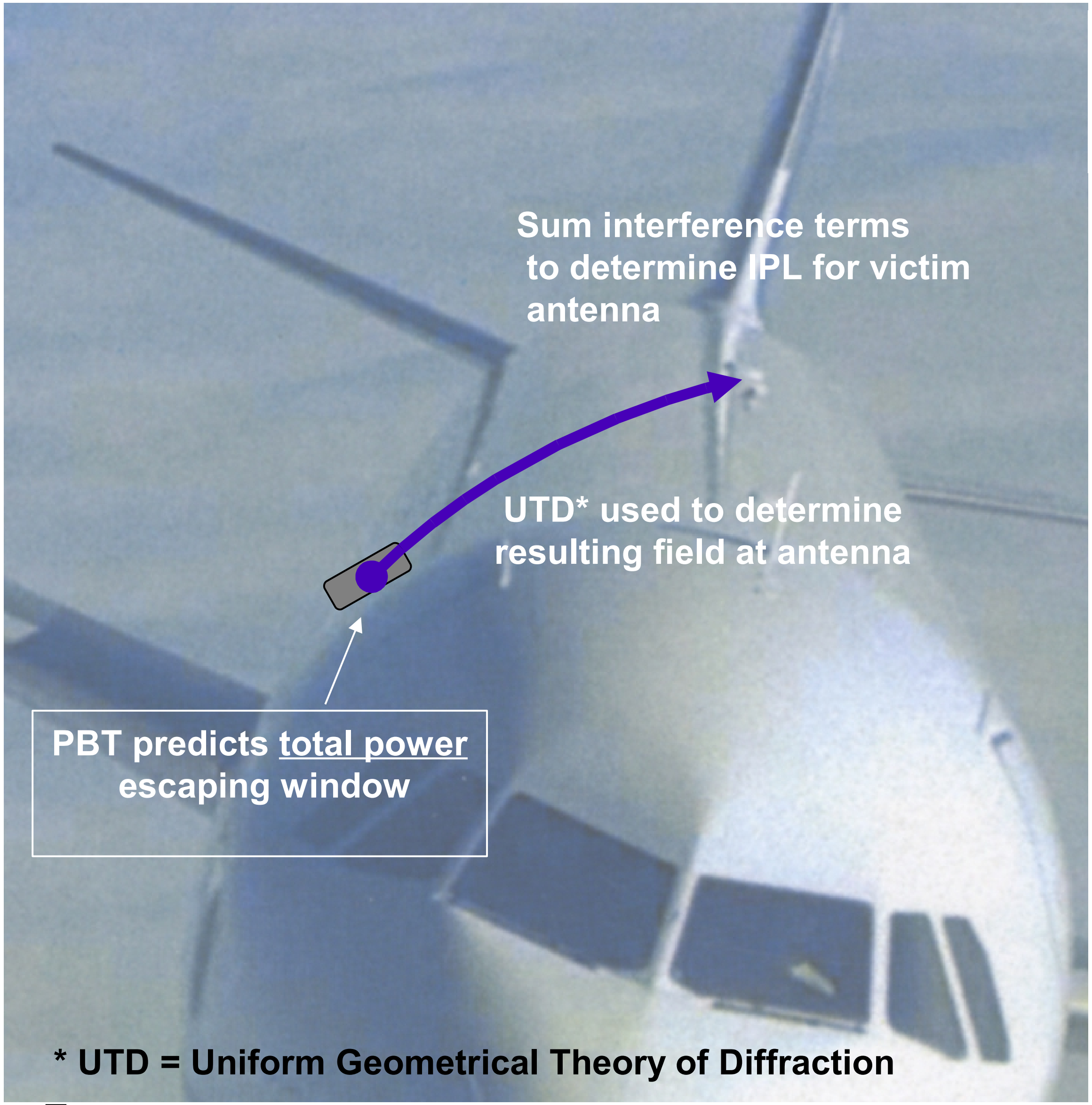




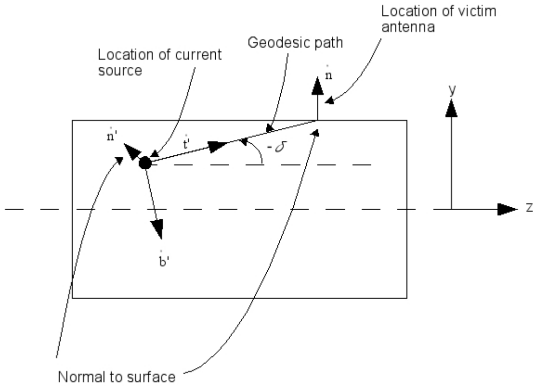
$$\mathbf{p}_{m\phi} = \hat{\phi}\sqrt{\frac{12\pi\eta P_p}{k^2}}\ , \text{ and}$$

$$\mathbf{p}_{mz} = \hat{\mathbf{z}}\sqrt{\frac{12\pi\eta P_p}{k^2}}$$

Exterior: UTD Surface Diffraction

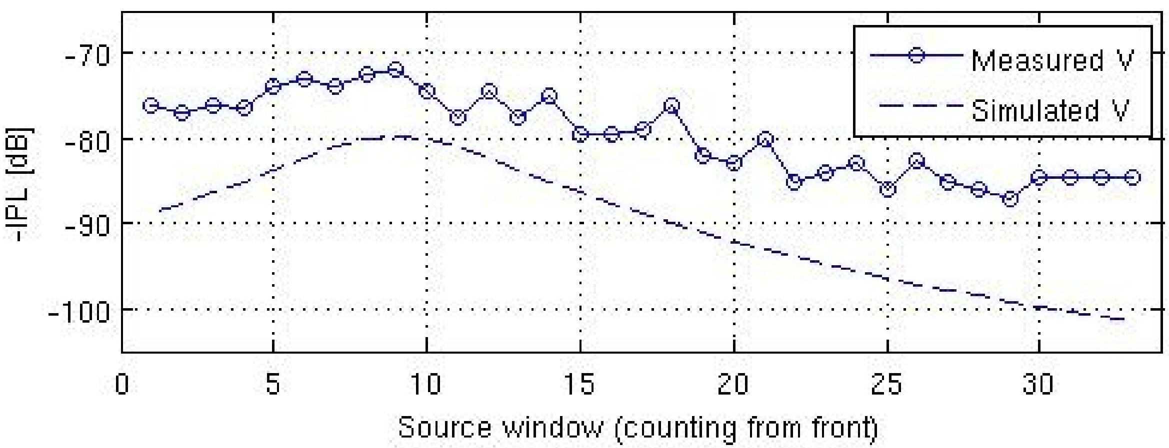


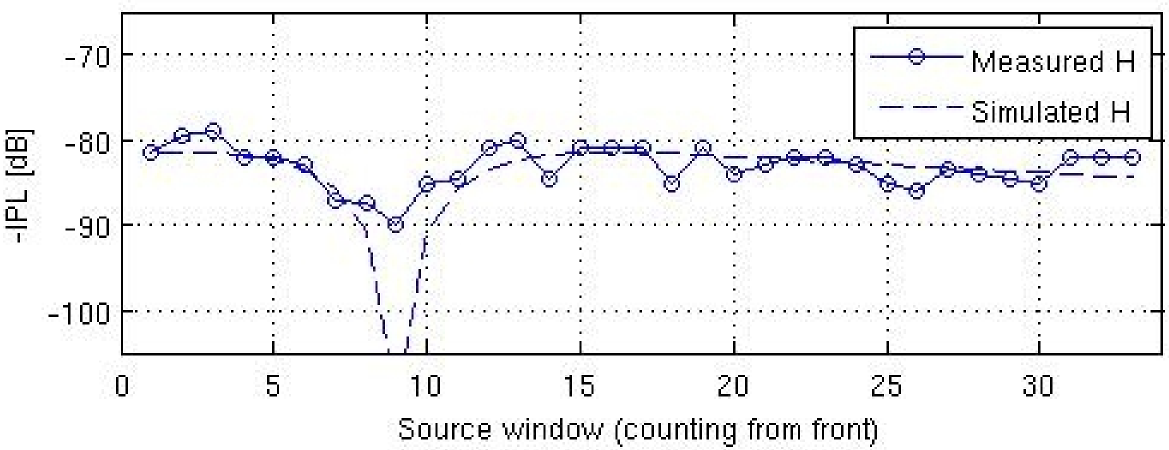
$$\mathbf{E}_p^r = -\frac{jk}{4\pi}\mathbf{p}_m \cdot \left[2\left(\hat{\mathbf{b}}'\hat{\mathbf{n}}\left\{\left(1-\frac{j}{kt}\right)V(\xi)+T_0^2\frac{j}{kt}\left[U(\xi)-V(\xi)\right]\right\} + \hat{\mathbf{t}}'\hat{\mathbf{n}}\left\{T_0\frac{j}{kt}\left[U(\xi)-V(\xi)\right]\right\}\right)\right]\frac{e^{-jkt}}{t}$$



P.H. Pathak & Wang (1981), *IEEE Trans. Ant. & Prop.*, AP-29, 911.

<u>Single</u> Window-to-Antenna IPL Comparison





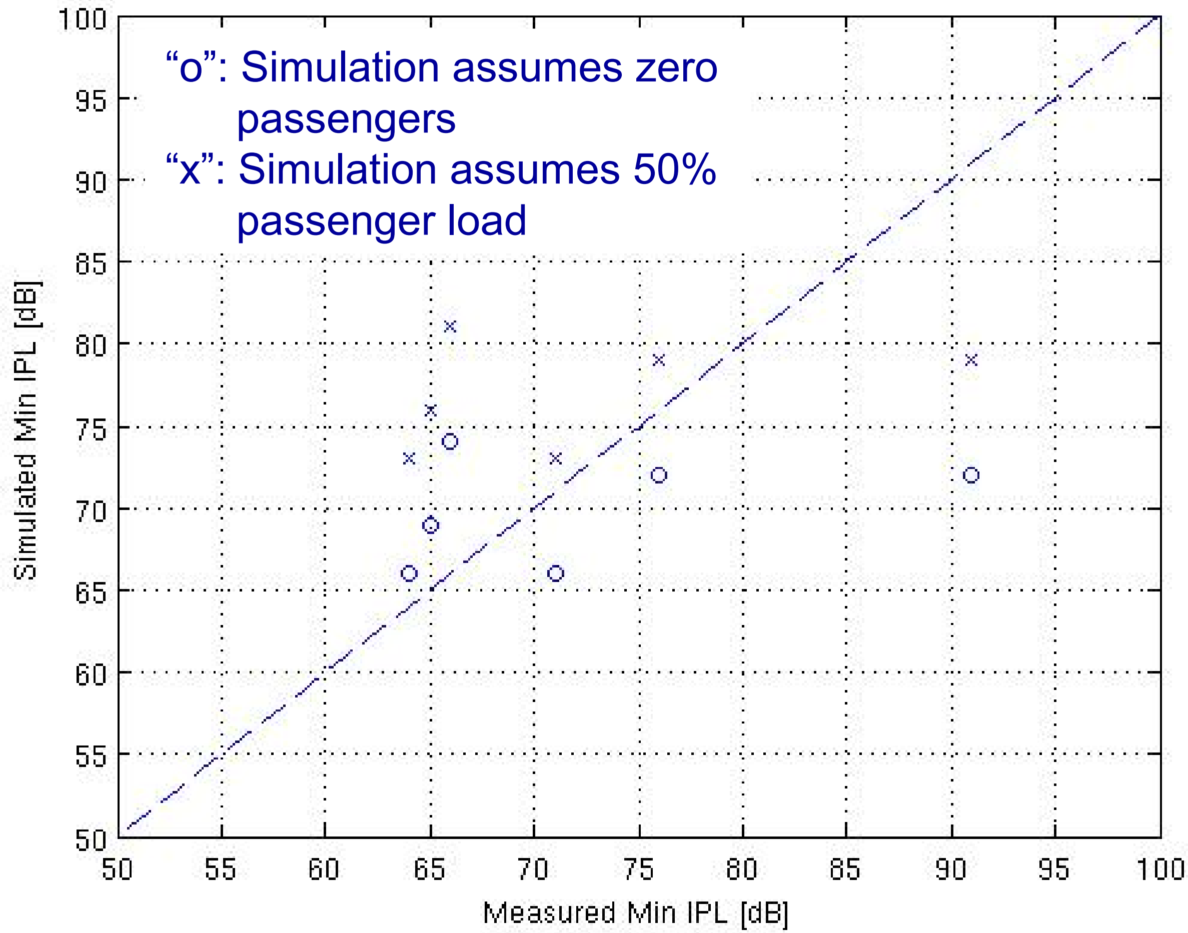
GPS L1 = 1575.42 MHz
(GPS is a key system of interest in IPL studies)

<u>Measurement data:</u>
Jafri, Ely, & Vahala (2005), *Digital Avionics Systems Conf.*, 1, B.5-1.

<u>Simulation:</u>
UTD creeping wave assuming magnetic current moment equivalent to dipole placed in window

Discrepency in V-pol results is unexplained, but turns out to be irrelevant when all windows are combined, as result is most accurate when IPL is minimum.

Cabin-to-Antenna IPL Comparison



Aircraft	Pasngr Load	Sim. Min. [dB]	Mean [dB]	Meas. Min. [dB]	Ref.
B727-200	Full	75	96		
	50%	73	94		
	Empty	66	87	71	[29], [10]
B737-200	Full	76	96		
	50%	73	93		
	Empty	66	86	64	[2]
B747-200	Full	79	103		
	50%	76	101		
	Empty	69	93	65	[2]
B767-300	Full	81	103		
	50%	79	101		
	Empty	72	93	91	[30]
B777-200	Full	84	106		
	50%	81	103		
	Empty	74	96	66	[30]
A330-300	Full	82	105		
	50%	79	102		
	Empty	72	95	76	[31]

Simulation includes all windows; min IPL calculated assuming phase-aligned addition of window terms.

GPS L1 = 1575.42 MHz
(GPS is a key system of interest in IPL studies)

Measurement data compiled from many sources (see journal paper).

Frequency Dependence of IPL

Using B737 dimensions for an antenna located a fixed location (= position of the GPS antenna in the previous examples):

			0% load		100% load		
f	ka	ka_w	L_w	IPL	L_w	IPL	System
118 MHz	4.6	0.3	−63.4 dB	71 dB	−73.8 dB	81 dB	VOR/VHF Voice
330 MHz	13.0	1.0	−45.5 dB	65 dB	−55.4 dB	75 dB	Glide Slope
962 MHz	37.9	2.8	−7.3 dB	40 dB	−16.9 dB	50 dB	DME
1227 MHz	48.3	3.6	−7.3 dB	44 dB	−16.9 dB	53 dB	GPS L2
1575 MHz	62.0	4.6	−7.3 dB	47 dB	−16.9 dB	57 dB	GPS L1
5060 MHz	199.2	14.8	−7.3 dB	66 dB	−16.9 dB	76 dB	MLS

a = radius of fuselage

a_w = radius of windows

Note frequency trends:

IPL increases at low frequencies because windows become electrically small

IPL increases at high frequencies because creeping wave path loss increases

IPL is minimum (i.e., worst case) around 1 GHz.

Summary

- **This approach yields results consistent with measured results and provides additional physical insight that would be difficult to obtain through measurements or full-wave methods**

- **This approach is reasonable when the aircraft cabin and fuselage are electrically large. At VHF and below, other coupling mechanisms – e.g., coupling through wiring harnesses – dominate IPL**

- **Easily extended to deal with antennas at other locations on aircraft by including additional UTD diffraction terms**

- **Additional details: K.W. Hurst & S.W. Ellingson (2008), *IEEE Trans. Electromagnetic Compatibility*, in press (preprint available: http://www.ece.vt.edu/swe/)**

Virginia Tech