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GTD ANALYSIS OF RADIO WAVE PENETRATION THROUGH WINDOWS FOR ESTIMATION OF IN-DOOR SERVICE AVAILABILITY IN LMSS-P

Shinichi NOMOTO
KDD R&D Laboratories
2-1-15, Ohara, Kamifukuoka, Saitama 356, Japan

1. Introduction.

There are a number of ongoing projects to provide global telephony and/or data services by means of personal land mobile-satellite systems (LMSS-P), especially LEO/MEO systems. The nominal link budgets imply service provision to the users with a hand-held terminal under a line-of-sight condition, i.e. out-door environments. However, in-door service provisions would be required to some extent and the availability could be a discriminative feature of those systems from users' point of view. In contrast with the case of out-door environment, there are few propagation studies regarding in-door satellite radio reception [1]. The paper gives theoretical prediction model on radio wave penetration through windows based on GTD approach. The service availability can then be estimated.

2. GTD model.

A program has been coded which is based on UGTD (Uniform Geometrical Theory of Diffraction) with corner diffraction corrections [2]. The model is simply obtained by approximating the window(s) by rectangular opening(s) on a thin, conducting sheet. Reflected paths via side walls or floor/ceiling (multi-path) are ignored; only singly diffracted paths via window frames are taken into account. Also, importantly, the model has no pane; discussion on attenuation loss due to glass is outside the scope of the paper. Therefore, the results shown here should be considered representing the upper bound (optimistic) predictions in terms of link performances.

3. Comparison with measured data.

Figure 1 shows the geometry of a window for which measurement data are available. In the measurement, an airplane was used as a sham LEO satellite. The windows consists of six openings divided by thin grids. The most relevant sample which includes relatively clear line-of-sight condition is compared with the GTD result in Fig. 2. During the run, the airplane transmitting a 1.82-GHz signal was flying so as to keep almost a constant elevation angle of 25.5°(±1.5°) viewed from the receiver in the room. By comparison;

(i) The measurement data has fast fading components due to multi-path which is ignored in the GTD model.

(ii) The slow varying signal levels of the measurement agrees well with the GTD model. (Thus, the glass attenuation of the window is negligible in this particular case.)

Fig. 2 clearly demonstrates the validity of the model. It is found out that geometrical intuitive perception is considered sufficient to understand the signal strength in first order approximation at this frequency range.

4. S-band Radio Wave Penetration through "Model Window."

Because in-door performances primarily depends on the relative geometry of the line-of-sight path to the windows, we here use a nominal window, "Model Window," for quantitative discussions. The size of the Model Window is 1.0 m in width and 1.5 m in height. The receiver locates at 0.6 m below the top frame of the window and at 0.4 (and 0.6) m from the left (and the right) side frame.

Figures 4 (a) and (b) show the signal strength variation, at 2 GHz, in terms of receiver distance from the window and the satellite elevation angle, respectively. The azimuth angle of the line-of-sight is assumed to be equal to that of the normal direction of the window. (The window is exactly facing the satellite in terms of azimuth angle.) Suppose that the system link budget allows up to about 5 dB loss for building penetration, in order to provide the in-door services down to about 1 m from windows, we need a low elevation (<20°) satellite towards the window facing direction. (Moreover, the glass must be transparent.) At an elevation angle of 40° or above, the user must remain as close to the window (< 0.5 m) as possible.

5. In-Door Signal Strength of LEO/MEO Systems.

Using the program, the statistics of signal level are investigated for an example LMSS-P employing 10 MEO (~10,400 km altitude) satellites in 2 orbital planes (Walker's notation of 10/2/0) inclined 45° with respect to the Equatorial plane. The result for a user, 0.5 meter inside the room from the Model Window, at 20°N latitude is plotted in Fig. 5. The four curves correspond to the directions normal to the window (north/east/south/west). The 50 percentile values are greater than -5 dB except for the north facing window, which has about -9 dB.

6. Conclusions.

Radio wave penetration into buildings through windows has been studied by applying GTD. The effectiveness has been verified by a comparison with measured data. Although the model ignores multi-path fading, etc., it gives decent accuracy to estimate the in-door service availability of LMSS-P principally designed for line-of-sight conditions, enabling us to compare those of various LEO/MEO's.

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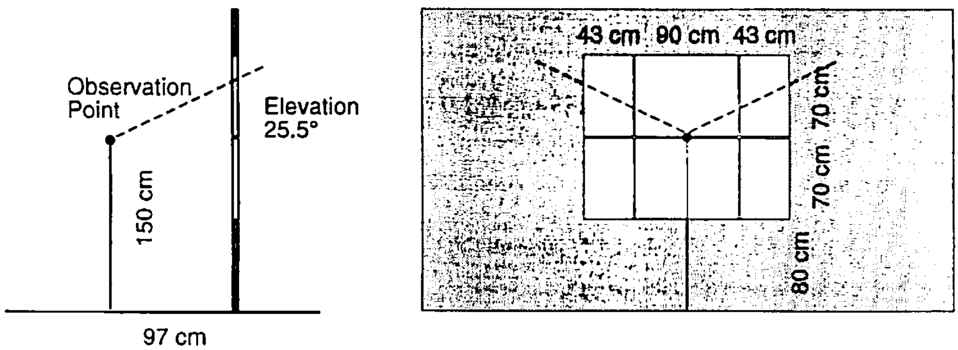
References:

[1] W. J. Vogel and G. W. Torrence: "Propagation Measurements for Satellite Radio Reception Inside Buildings," *IEEE Trans. Antennas Propagat.*, vol. 41, no. 7, pp. 954 -961, July 1993.

[2] F. A. Sikta, W. D. Burnside, T. T. Chu, and L. Peters, Jr.: "First-Order Equivalent Current and Corner Diffraction from Flat Plate Structures," *IEEE Trans. Antennas Propagat.*, vol. 31, no. 4, pp. 584-589, July 1983.



(a) Side View. (b) Front View.

Fig. 1. Geometry of the Hotel Room.

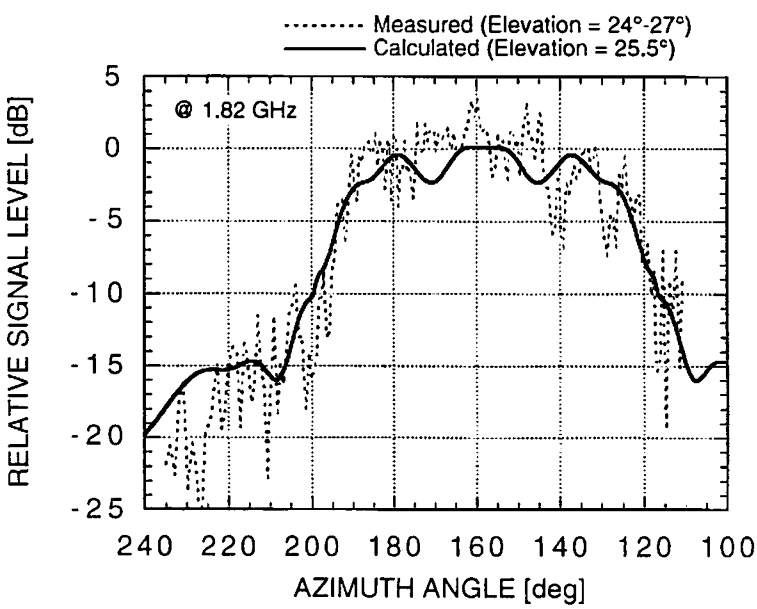
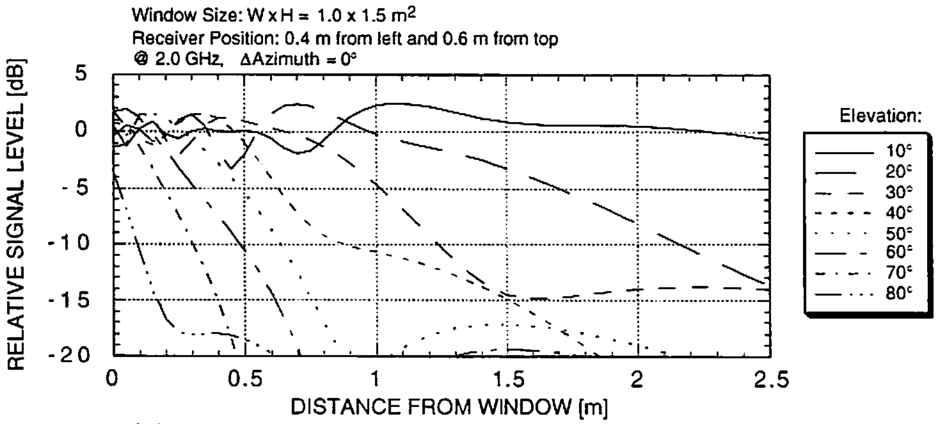
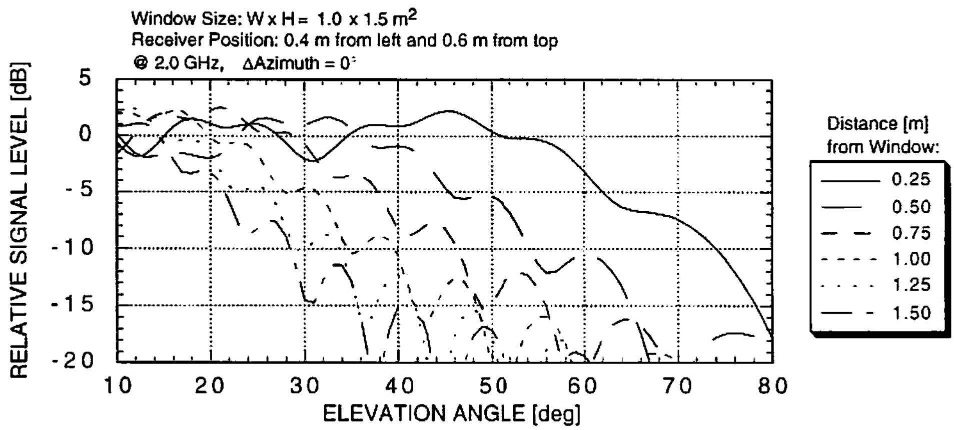


Fig. 2. Signal Level Variation over Azimuth Angles.

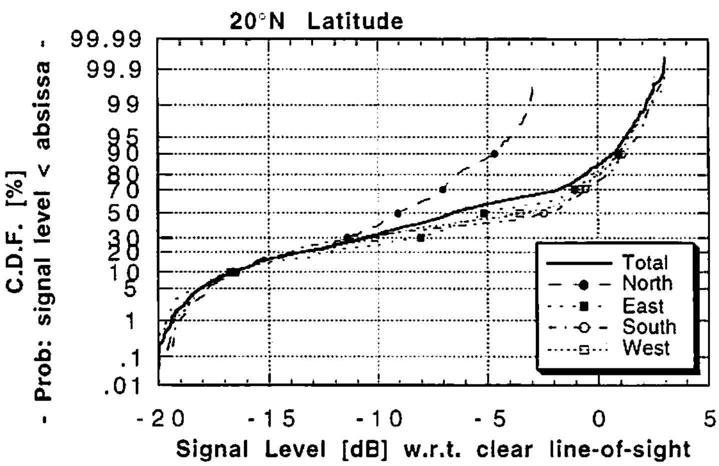


(a). - as a function of distance from the window -



(b). - as a function of elevation angle -

Fig. 3. Building Penetration through the Nominal Window.



Distance from the Window = 0.5m.

Fig. 4. Signal Level Statistics for 10/2/0 MEO Satellite Systems.