Penetration Loss of Doors and Windows inside Residences using ISDB-T Digital Terrestrial Television Signal at 677 MHz

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***Abstract*— This paper presents the results of indoor propagation measurements conducted at 16 residential sites at 677 MHz using live digital television transmission of National Broadcasting Network (NBN). This study is part of the extensive measurement campaign done last March to May 2011, in partnership with NBN, a government TV network. The main purpose of this study is to validate the digital TV performance of the Japanese TV standard, Integrated Services Digital Broadcast-Terrestrial (ISDB-T).**

Sixteen residences located in an urban area within 7 kilometers of NBN were chosen falling under Classes A, B, C and D categories of houses in the Philippines. Using a commercially available indoor antenna placed on top of a tripod at a height of 1.5 meters, power received in dBm is measured using a spectrum analyzer. Data is captured in a storage device and reception is visually monitored using a set top box and a TV set.

Measurement points are large openings of the house like doors and windows and data is captured every cluster measurements of 9 points on each spot. An antenna is placed directly in front of the doors and windows to establish RF reference level outdoor. Indoor signal strength is measured and compared with the outdoor reference level. The drop in signal level establishes the effects of materials to the transmitted signal and thereby helps identify the reason for signal degradation. The difference between outdoor and indoor signal levels also helps evaluate the penetration loss of different materials like wooden doors, glass windows, jalousie windows, window frames, concrete walls, GI sheets and metals. These are typical residential local materials. Average Penetration Loss (APL) for each house/building category using the difference between the measured outdoor signal level and the indoor signal level values were computed and compared with similar studies found in the literature.

***Index Terms*— Average Penetration Loss, Digital Terrestrial Television, indoor, ISDB-T, outdoor, UHF**

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I. Introduction

The adoption of and eventual switch to digital television will open up more opportunities for both industry players as well as the television viewers. Digital broadcasters can provide more digital channels in the same space for Standard Definition TV (SDTV), High-Definition Television service for (HDTV) and other non-television services such as multimedia or interactivity. All these features can be well appreciated if the intended signal is received via terrestrial path inside the house using a typical indoor antenna. A subscription to cable or satellite network providers for the 2nd and 3rd TV sets with set top box can pull up the household bills.

Knowledge on signal degradation enables RF designers to determine the required field strength for a reliable coverage in a specific area. Results of the study can help in system planning by making it possible to adjust the appropriate transmitter parameters.

The aim of the study is to determine the APL inside residences using locally available materials found in classes A, B, C and D house categories in the Philippines. Several papers found in the literature have also evaluated and computed indoor penetration loss for buildings [1-5] and houses [6-9] . Measurements were done at different operating frequencies from VHF-UHF up to microwave region and for different applications like DTV, High Altitude Platforms (HAP), Universal Mobile Telecommunication Systems (UMTS), ISM and Satellite to Indoor Communication Networks. Several wall materials have also been investigated at [10, 11] and the average penetration loss of concrete wall, bricks and wood were reported including standard deviations.

I. MEASUREMENT PROCEDURE

NBN is one of the pioneers in Digital Television. It is located at Visayas Avenue, Quezon City transmitting a 1 KW power and operating at UHF Channel 48 (677 MHz). It has a system gain of 10.77 dB using a horizontally polarized panel antenna at a height of 550 ft. Table I below lists the ISDB-T Transmitter parameters used in the conduct of this study.

Table I
Transmitter Parameters

Parameter	Value
Mode 3	8K
Modulation	64 QAM HD, QPSK, 1 seg
Guard Interval	1/8
Convolutional Encoding	¾ HD, 1 seg
UHF Channel	48
Frequency	674-680 MHz (677.142 MHz)
Bit rate	16.8 Mbps - HD, 384Kbps

The instrumentation diagram shown in Fig. 1 was used to carry out the measurements needed. It consists of a commercially available indoor rabbit antenna amplified by AU40S MASPRO, connected to the ANRITSU spectrum analyzer where details of C/N, power received, field strength and delay profiles were captured and recorded in the data storage. Visual monitoring is achieved using analog TV with ISDB-T set top box to classify received signal as perfect, intermittent or failure.

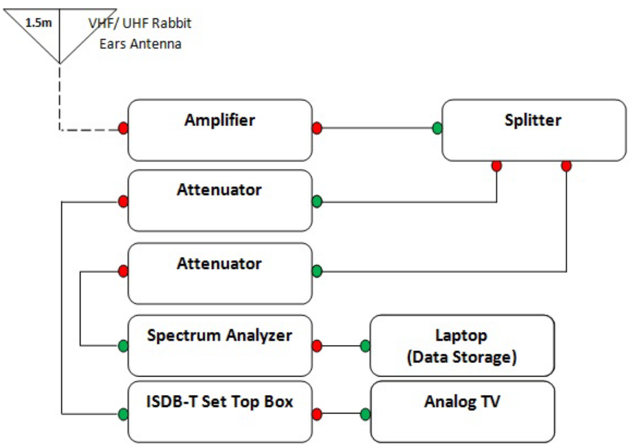

Fig 1. Measurement Instrumentation

Measurements were made at the façade and inside of sixteen (16) residences in Quezon City. Four (4) residences per dwelling classification were selected based on the type of construction materials used. Please refer to Table II.

Typical residential houses in the Philippines are constructed with non-uniform walls composed of doors and windows. Outdoor-to-indoor studies considered structural opening along the path under the assumption that outdoor to indoor paths are possible only through wall openings such as doors and windows [12] . The largest openings of the house that were used as measurement test points are doors and windows. Diverse sizes and materials were considered in different residential classes.

Table II.
Classification of Identified Houses According to Construction Materials

Class	Type	House / Building Materials	Typical Door and Window Size
A	Building, Single Detached, Duplex Townhouse	heavily reinforced concrete, glass doors and windows, metals	D_{wood}= 2.11m x 1.07m $D_{glass, sliding}$ = 2.44m x 1.98m W = 2.29m x 1.29m
B	Town house	reinforced concrete, wood, glass	D = 2.11m x 0.86m W = 1.47m x 1.19m
C	Apartment	slightly reinforced concrete, wood, glass	D = 1.96m x 0.9m W = 1.38m x 1.28m
D	Shanty	light non-reinforced materials	D = 1.83m x 0.75m W = 0.61m x 0.85m

Fig. 2 represents the measurement points outside and inside the selected residences. Nine cluster measurements of about 1 square meter from the wall were performed. The antenna is positioned manually at 9 points in the front and back of doors and windows. Please refer to Figs. 3a and 3b for sample actual measurements. With the help of a GPS, receiver antenna was positioned at maximum reception at every test point. Spectrum analyzer was set to 677 MHz. Data was recorded and transferred to a storage device. Indoor measurements were performed with closed doors and windows and only ground floor openings were considered in the entire study.

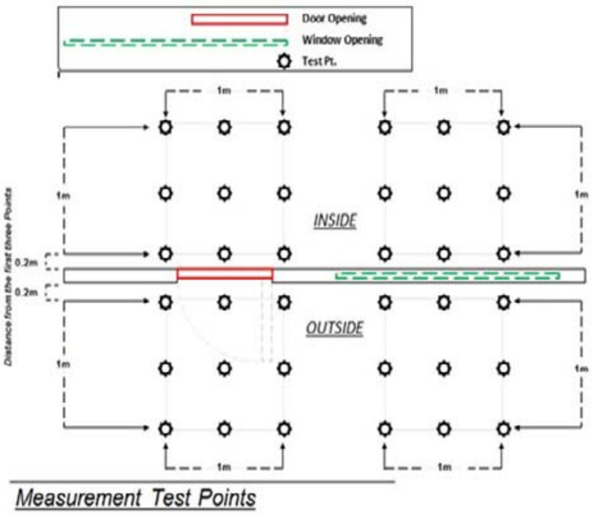

Fig 2. Measurement points for all doors and windows

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(a) (b)

Fig 3. Sample measurements at doors (a) outside (b) inside

II. MEASUREMENT RESULTS

Thirty Six (36) measurements inside and outside of the identified 16 residences were made for a total of 576 collected signal power levels. Figure 4a represents the actual constellation of received outdoor signal recorded from the spectrum analyzer. This is an example of a perfect signal with a C/N ratio of 30.8 dB. Figure 4b indicates a received power of -47.7 dBm and field strength of 93.7µV/m. The distance of this residence from NBN is about 1.3 Kms at an elevation of 33.54 m with outside temperature at 32° C. A perfect signal was achieved owing to its close distance from the transmitter.

(a) (b)

Fig 4. Spectrum analyzer display for one outdoor measurement of (a) constellation (b) field strength and power received

Table III summarizes the penetration loss computed from the difference between outdoor and indoor power received levels for the 4 residential categories. The average penetration loss for each large openings of the house i.e. doors and windows, was computed using Equation 1. Detailed description of the identified residences can be found in Table IV.

$$\textbf{APL(dB)} = \textbf{Mean Pr}_{out}\textbf{ (dBm)} - \textbf{Mean Pr}_{in}\textbf{ (dBm)} \qquad (1)$$

Table III
Penetration Loss Summary of Four Residential Classifications

Class	(Outside) Mean Signal Level (dBm)	(Inside) Mean Signal Level dBm	Average Penetratio n Loss (dB)	Signal Condit ion
A (overall)	**-66.37**	**-70.04**	**3.67**	**Inter-mittent to Fail**
door	-67.09	-71.44	4.35	
window	-65.39	-68.40	3.02	
B (overall)	**-47.18**	**-58.44**	**11.27**	**Perfect**
door	-45.54	-57.22	11.67	
window	-49.83	-60.16	10.33	
C (overall)	**-53.49**	**-62.84**	**9.34**	**Perfect**
door	-53.20	-67.07	13.87	
window	-53.92	-60.21	6.30	
D (overall)	**-51.52**	**-57.55**	**6.02**	**Perfect**
door	-52.07	-56.81	4.74	
window	-51.04	-58.44	7.40	

Table IV
Residential Description and APL

Class	Type of House and Construction Material	Typical Size	APL (dB)	σ (dB)
A	**Overall**		**3.67**	**-2.52**
door	Building, Single Detached, Duplex Townhouse with oversized wooden door and glass sliding doors	D = 2.11m x 1.07m Thickness = 0.04m Ds= 2.44m x 1.98m (Sliding Door)	4.35	-1.64
window	oversized glass window	W1 = 2.29m x 1.29m	3.02	-5.12
B	**Overall**		**11.27**	**6.83**
door	Town houses with screened wooden door	D = 2.11m x 0.86m Thickness Door = 0.04m Screen = 0.03m	11.67	7.23
window	glass window with aluminum screen	W = 1.47m x 1.19m	10.33	4.18
C	**Overall**		**9.34**	**11.02**
door	2-3 storey apartments with screened wooden door, oversized steel framed door with aluminum screen	D = 1.96m x 0.9m Thickness Door = 0.04m Screen = 0.03m	13.87	7.11
window	screened wooden-framed glass window, jalousie window	W = 1.38m x 1.28m	6.30	12.49
D	**Overall**		**6.02**	**6.89**
door	Shanties with G.I. Sheet wooden framed door , thin wooden door (lawanit)	D1 = 1.83m x 0.75m	6.79	7.73
window	GI sheet, jalousie and wooden window	W1 = 0.61m x 0.85m	7.40	6.90

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A. Class A

Class A measurements were done at various locations in Quezon City up to a distance of 7.5 Kms. This resulted to intermittent to failed reception due to its distance from NBN. Diverse residential types of the same class were used for the purpose of this study like a 4 storey building residential, a single detached house and a duplex town house. All residences have different door and window structures and materials. Oversized wooden doors with thickness of 0.04 m resulted to average penetration losses of 2.8 dB, which is in good agreement with published reports of 1.4-2.9 dB at 2.4 GHz [13]. For oversized glass sliding doors, penetration loss of 4.83 dB for coated glass was measured. This resulted to an average penetration loss of 4.35 dB for all doors in Class A dwellings.

For windows, oversized glass windows were encountered at one single detached residence and the 4 storey residence including windows at side walls. An APL of 3.02 dB was measured. It was noticed that Class A houses have larger opening apertures and radiated walls than Class B, C and D. The doors and windows occupy a large part of the wall thereby allowing stronger signal inside. This resulted to a lower overall APL of 3.67 dB. This observation agreed well with the works of Plets et.al. [3], where penetration losses were found to be affected by the number of radiated walls.

B. Class B

Class B measurements were performed in one compound of a 5 door townhouse located at Bagong Pagasa Quezon City. This place is about 1.2 km from NBN and elevated at about 51.8 m. There are 5 identical houses but only four were considered in the measurements. The largest openings at the façade of the town house are one door and one window located at the ground floor. 144 measurements were collected and processed resulting to 11.67 dB APL for all doors with a standard deviation σ= 7.23 dB; 10.33 dB APL for all windows and σ= 4.18. This leads to an overall APL for both openings as 11.27 dB and σ= 6.83. All the identified houses have large wooden doors of around 0.04 m thickness and doubled with an aluminum screen door of 0.03 m thickness.

Windows are made of glass with metal frame and aluminum screen. Installing aluminum screen doors are common in tropical countries like Philippines as safety insect protection during summer. This is why no literature was found on the APL of wooden doors with aluminum screen guards. Likewise, since these are row houses, no side wall for signal illumination is possible but only through the facade.

Class C

Class C measurements were done in one apartment of different house structures and heights. Located at Bagong Pagasa Quezon City, the place is about 1.2 km from NBN and elevated at about 33.54 m. There are 4 different houses, two of which are identical; one is a 3 storey apartment with one large opening and 1 front house facing the major road with 2 large openings. 144 measurements were also collected and processed resulting to 13.87 dB APL for all doors with a standard deviation σ= 7.11 dB; 6.3 dB APL for all windows and σ= 12.49. This leads to an overall APL for both openings as 9.34 dB and σ= 11.02. Note that 3 of the identified houses have wooden doors of around 0.04 m thickness and doubled with an aluminum screen door of 0.03 m thickness. Another door is composed of oversized steel framed door with aluminum screen. This is why an increase in 2 dB of APL for doors of Class C was noticeable as compared to Class B.

Windows for Class C is also variable. Some are made of glass with wooden frame and aluminum screen but one has a jalousie window. A drop of 4.03 dB in APL for windows was observed when a wooden frame in windows was used instead of metal. An overall decrease in the APL of 1.93 dB from Class B to Class C was measured.

C. Class D

Class D measurements were done in squatter's area in Agham Road Quezon City. This place is less than one kilometer from NBN and elevated at about 40.85 m. There are 4 different houses identified, all with one storey level, two of which are identical. One is a variety store with one large opening and 1 below ground level house. All of them are facing the major road. 144 measurements were also collected and processed resulting to 6.79 dB APL for all doors with a standard deviation σ= 7.73 dB; 7.55 dB APL for all windows and σ= 6.9. This leads to an overall APL for both openings as 6.02 dB and σ= 6.89. A large deviation for doors was noticeable due to one house using a GI sheet for door instead of wood. This resulted to a large difference in measured penetration loss for wooden doors of 2.46 dB and GI sheet door which is 11.51 dB which leads to an average of 6.79 dB.

Windows for Class D is also variable especially in sizes. Some are made of jalousie windows (coated), GI sheet (for the variety store) and wood. This resulted to penetration losses of 8.62 dB, 3.10 dB and 1.82 dB respectively. A large deviation is noted due to different materials used. A decrease in the APL of 3.32 dB from Class C to Class D is measured.

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Fig. 5 shows the Cumulative Distribution Function (CDF) for penetration loss of all the measurement data in the 4 residential classes. The four classes fit well with the log normal curve.

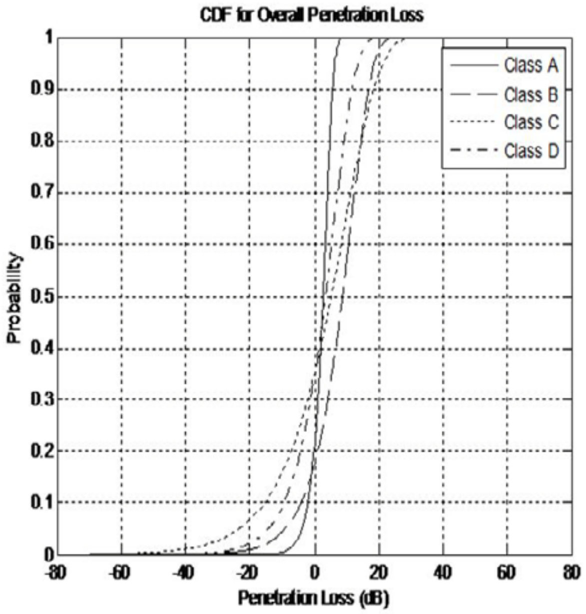

Fig. 5. Cumulative distribution plot of Class A-D

III. CONCLUSION

This paper presents the results of penetration loss measurements at 677 Mhz of residential houses classified as Class A, B, C and D. With doors and windows closed, detailed measurements were performed at the ground floor of each 16 identified residences with a fixed receiver height of 1.5 m. Effects of the number of doors and windows, their sizes and construction materials for each class were investigated and reported. The APL for classes A, B, C and D are Class 3.67 dB; 11.27 dB; 9.34 dB and 6.02 dB, respectively.

Class A, located at larger spaces, inside subdivisions and non commercial area obtained the lowest APL due to the presence of side walls and larger openings or entries of signal at home other than the front doors and windows. Since Classes B, C are row houses most commonly called town houses for Class B and apartments for Class C, radiated walls are missing. Larger APL values were obtained in Class B owing to thicker walls and metal reinforcements. For Class D, light materials used to serve as doors and windows can also deteriorate signal quality particularly GI sheets. APL loss decreases from heavy to light materials. A successful fit to log normal was demonstrated.

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