Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Penetration Loss Measurement at 300 GHz for Building Entry Loss Estimation]
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Abstract: [we describe the penetration loss measurement at 300 GHz for building entry loss estimation. Penetration losses of several building materials are measured, and its coefficients are extracted. By using these measured data, the building entry losses of the buildings can be estimated.]

Purpose: [Information of IEEE 802.15 IG THz]

Penetration Loss Measurement at 300 GHz for Building Entry Loss Estimation

Hirokazu Sawada, Kentaro Ishizu, Fumihide Kojima, Keizo Inagaki, Hiroyo Ogawa, Katsumi Fujii, Akifumi Kasamatsu, and Iwao Hosako

Penetration Loss Measurement at 300 GHz for Building Entry Loss Estimation

- Building Entry loss is presumed as an additional loss to free-space propagation loss. It causes by elements such as wall materials, doors, and windows, on the path of the building entry.

- ITU-R Recommendations P.BEL (Building Entry Loss) has been established on March 2017 as a new recommendation for the interference assessment, including MMW bands such as 24.25-86 GHz (IMT-MMW bands relating to WRC-19 A.I.-1.13.)

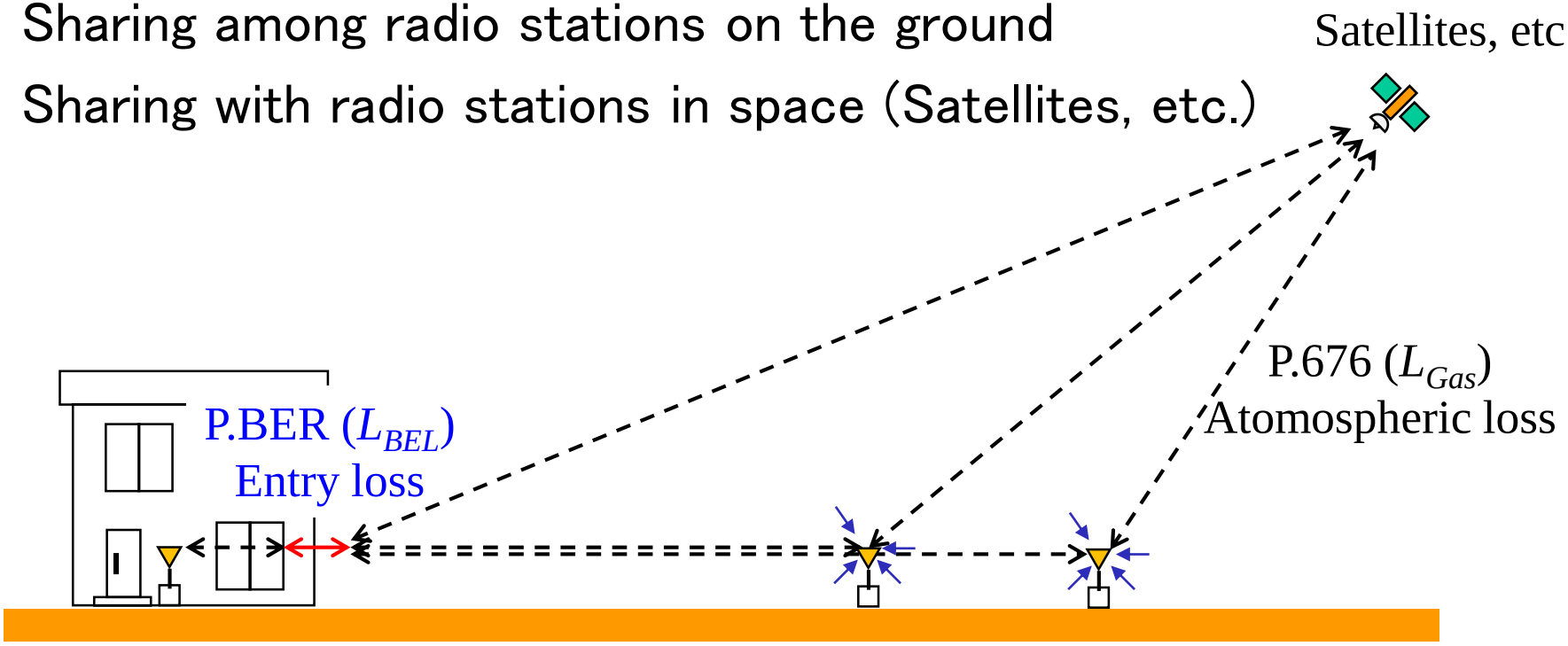
- The use of the P.BEL is being considered even in the THz bands (275-450 GHz) where the WRC-19 AI 1.15 is targeting for identification.

- The purpose of this measurement is to consider the frequency extension of the P.BEL to the 300 GHz bands by estimating the entry loss.

ITU-R Recommendations for sharing study

For interference study, each recommendation is referenced on the basis of P.452

- Sharing among radio stations on the ground
- Sharing with radio stations in space (Satellites, etc.)

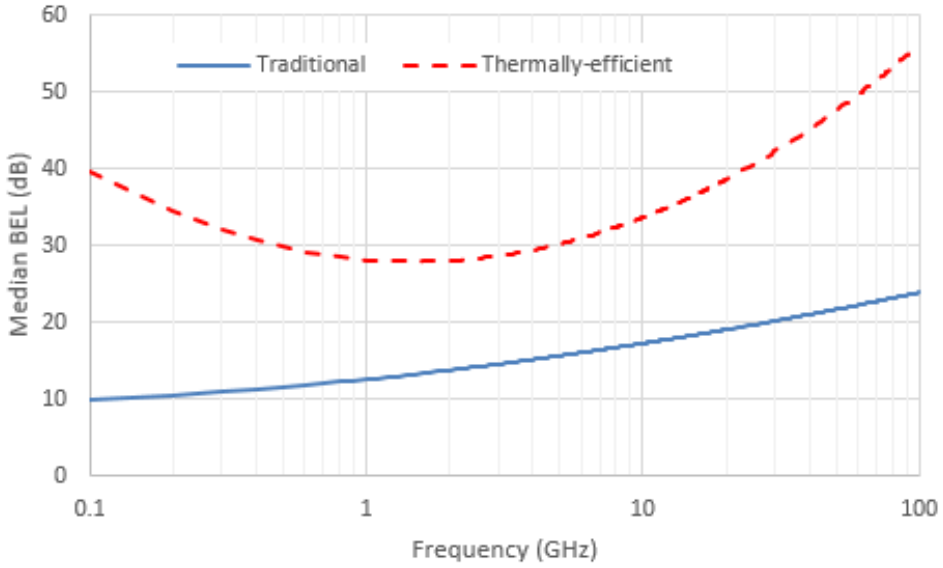


P. BEL estimation formula

- Up to100 GHz, the entry loss can estimate.
- The estimation formula becomes different by the presence of thermal insulation materials contained in the wall.
- At the SG3 meeting on March 2017, various building loss data have input. And the loss estimation formula have been developed depending on the condition such as “Traditional” or “Thermally-efficient”

FIGURE 1

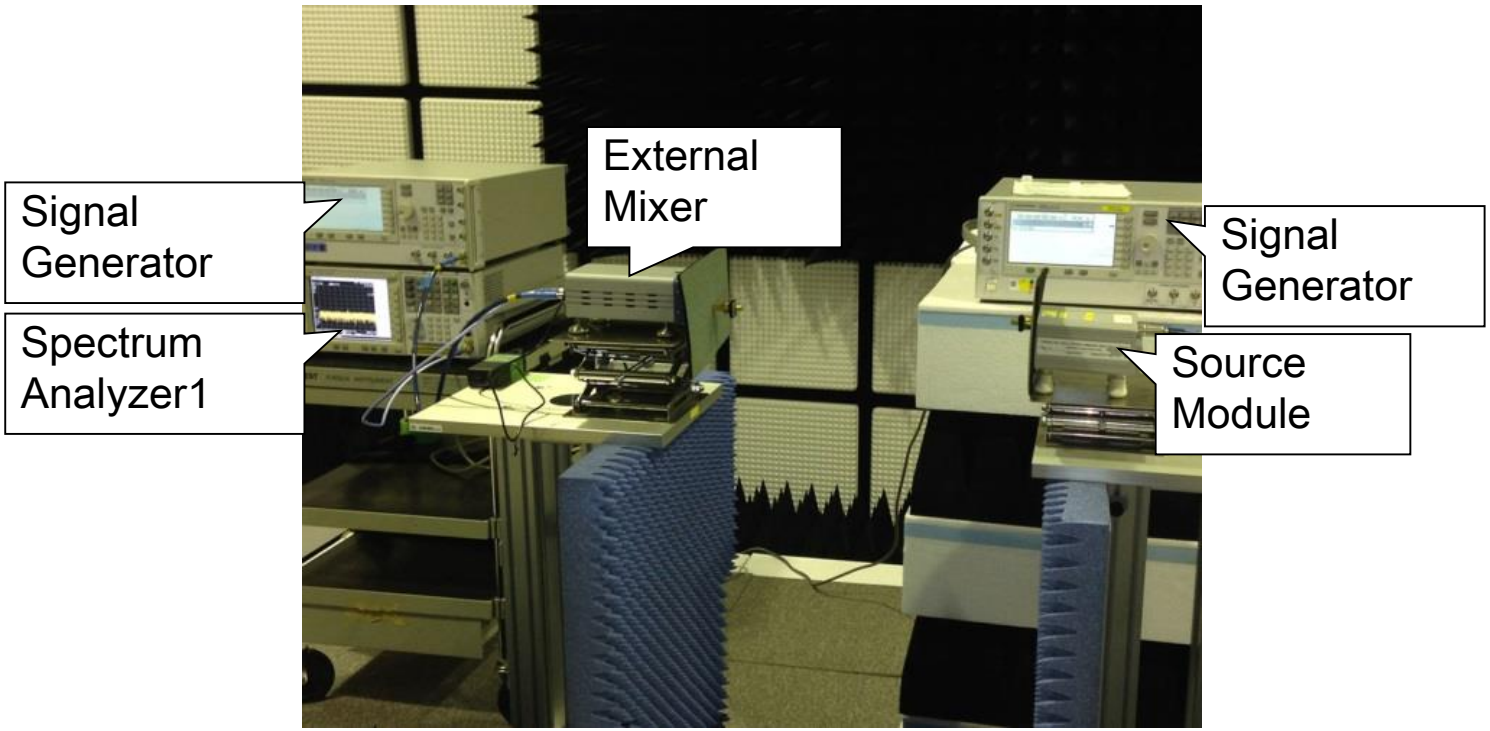
Median building entry loss predicted at horizontal incidence



When there is thermal insulation materials,
The reason for the larger change on the curve is that the size of the Fresnelsone and the window are related.

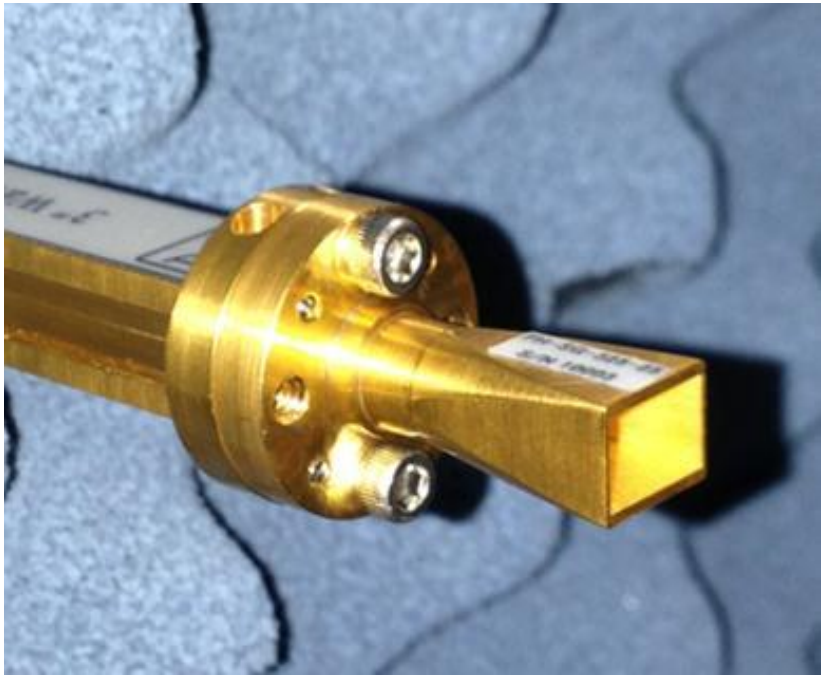
Measurement System

- Non-modulated continuous waves in the 300 GHz bands are used for the propagation loss measurements
- An additional loss of building entry loss is estimated from the difference between free space loss and the loss when something is exists on the same path.

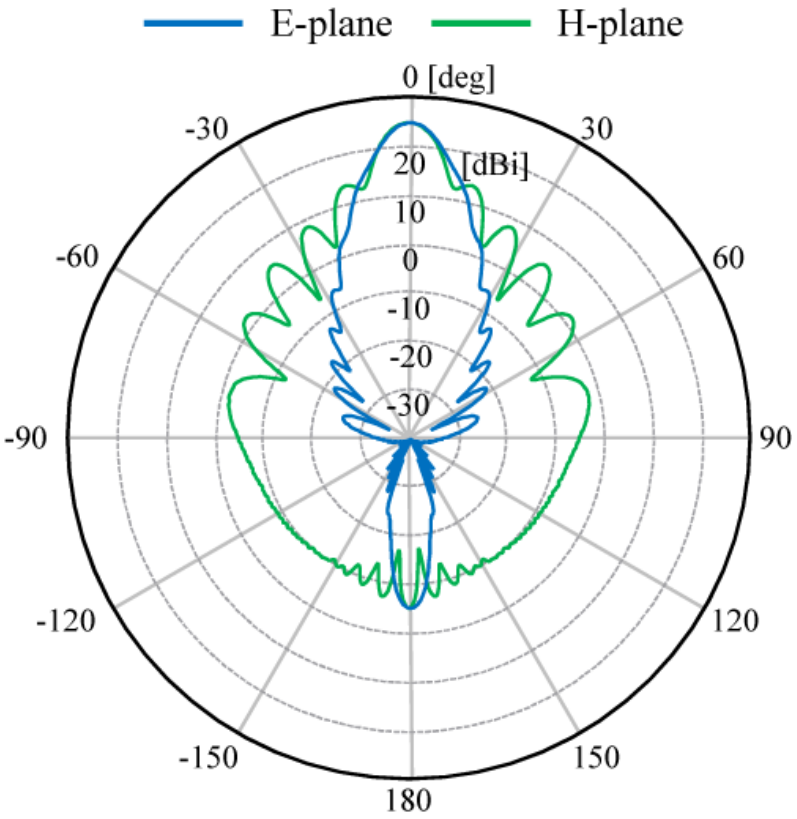


Antenna for the measurement

- A set of square horn antenna (Tx & Rx) was used with vertical polarization.
- Gain:25 dBi, Half angle:10 degree



Square Horn Antenna



Directional(300 GHz)

Measurement Results: BEL (1/3)

- Glass door (the thickness of 5mm): Open / Close
- Metal Blind: Open, Close [0 (Horizontal), 45 (Slant), 90 (Vertical) degree]

Opened Glass Door

BEL = 0 dB

Closed Glass Door

BEL = 18.6 dB

Closed Glass Door With Blind (Horizontal angle)

BEL = 20.5 dB

Closed Glass Door With Blind (45 ° slant angle)

BEL = 28.4 dB

Closed Glass Door With Blind (Vertical angle)

BEL = 36.3 dB

Measurement Results: BEL (1/3, cont.)

- Glass wall (with 10 mm thickness)
- Receiving power with the same distance is used as the base of the measurement.

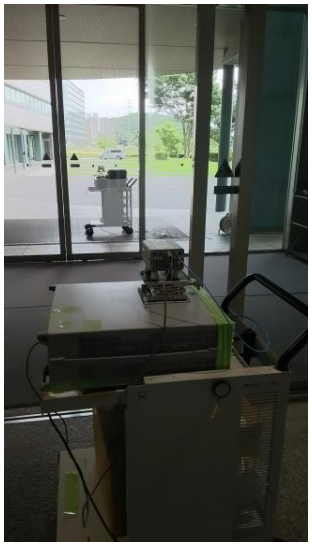
Building Material	BEL (dB)
Glass Wall (10 mm thickness)	30.5
Glass Wall (10 mm thickness) with Blind (0^O horizontal angle)	34.5
Glass Wall (10 mm thickness) with Blind (45^O Slant angle)	37.4
Glass Wall (10 mm thickness) with Blind (90^O vertical angle)	38.2

Measurement Results: BEL (2/3)

- Double Glass automatic door (with 10 mm thickness)

Opened Glass Automatic Doors

BEL = 0 dB



Closed Outer Glass Automatic Door

BEL = 27.1 dB

Closed Inner Glass Automatic Door

BEL = 27 dB

Closed All Glass Automatic Doors

BEL = 54.1 dB

Measurement Results: BEL (3/3)

- Glass window (with 5mm thickness) + Screen door + Shutter

Glass Window: OP
Screen Window: OP
Shutter: OP

BEL = 0 dB

Glass Window: OP
Screen Window: CL
Shutter: OP

BEL = 1.9 dB

Glass Window: CL
Screen Window: OP
Shutter: OP

BEL = 18.5 dB

Glass Window: CL
Screen Window: CL
Shutter: OP

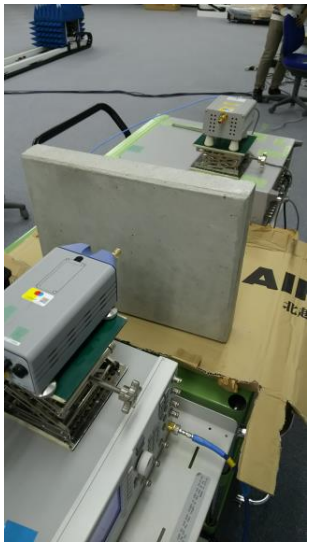
BEL = 20.5 dB

Glass Window: -
Screen Window: -
Shutter: CL

BEL = Na

Problems of BEL measurement

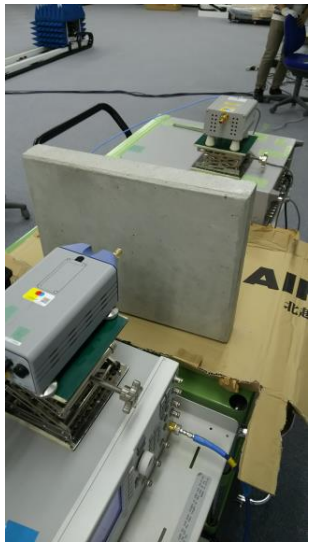
- In the outer wall (without glass-made window / door /wall) of the building or wooden house, the BEL becomes too large, and the receiving power becomes smaller than the noise power of the system.
- From the measurement result above, transmission loss can be estimated by the addition of each loss.
- The estimation of exterior wall losses is investigated by measuring the building materials individually.



[Example of wall loss measurement of wooden house]
Received Power becomes below the noise level.

Measure the thin building materials for the estimation of BEL.

Transmission loss of building materials



Concrete

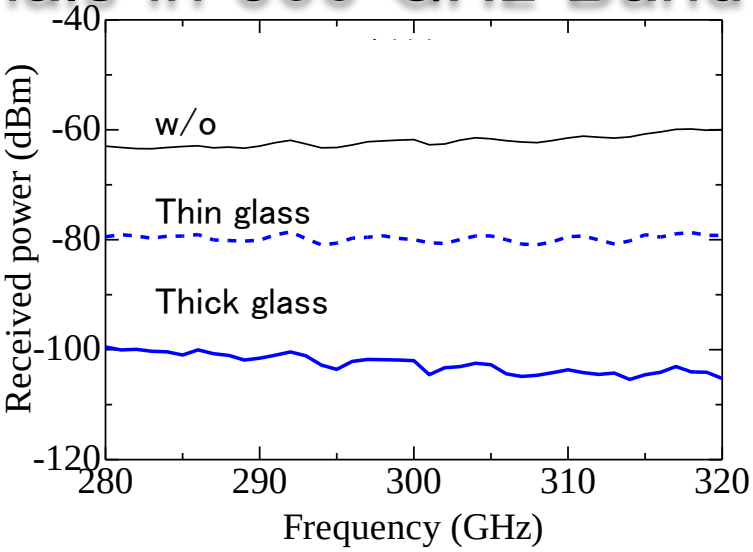
Glass

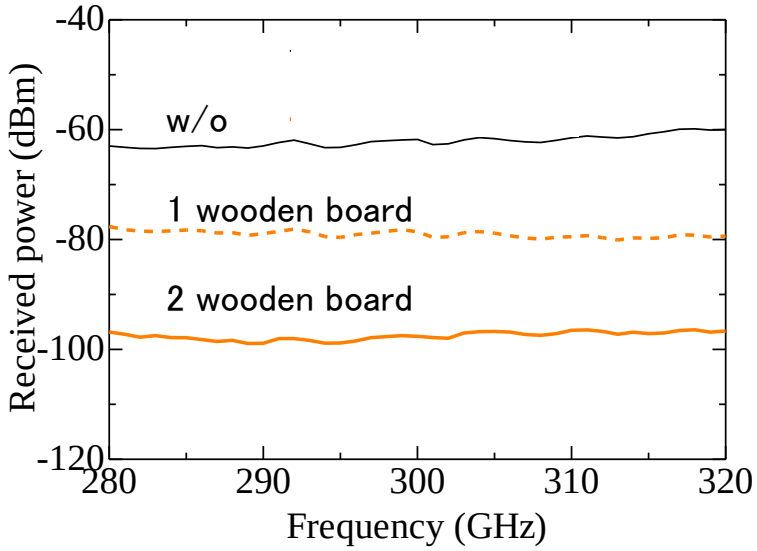
Wood, plaster board, Plastic

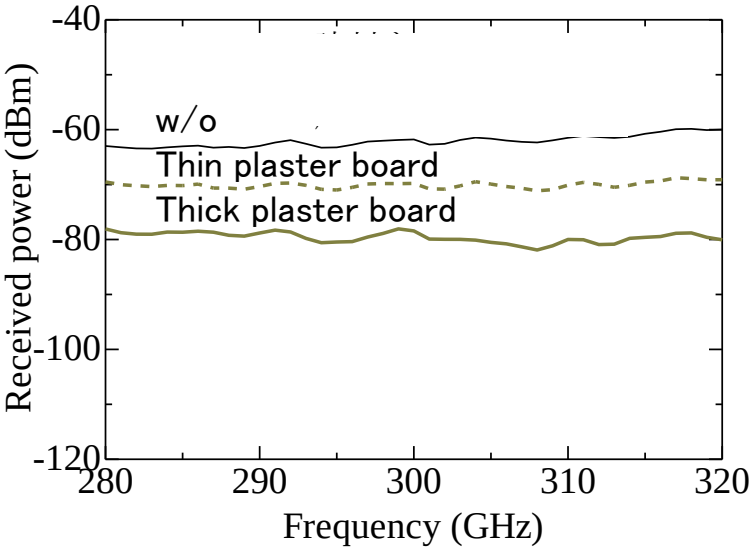
Building Material	Thickness (mm)	Loss (dB)
Concrete	60	53
Plaster Board	21.9	23
Plaster Board	12.4	14
Plaster Board	9.5	7
Glass	12	39
Glass	16.5	57
Wood	17.6	41
Wood	8.8	21
Plastic	3	8
Styrofoam	5	1
Vinyl	0.2	0.3
Cloth	2.4	4
Cardboard	3.2	5
Paper	0.1	1

Transmission of Materials in 300 GHz Band

- Transmission loss measurement from 280 to 320 GHz
- Changes within the band is few dB.

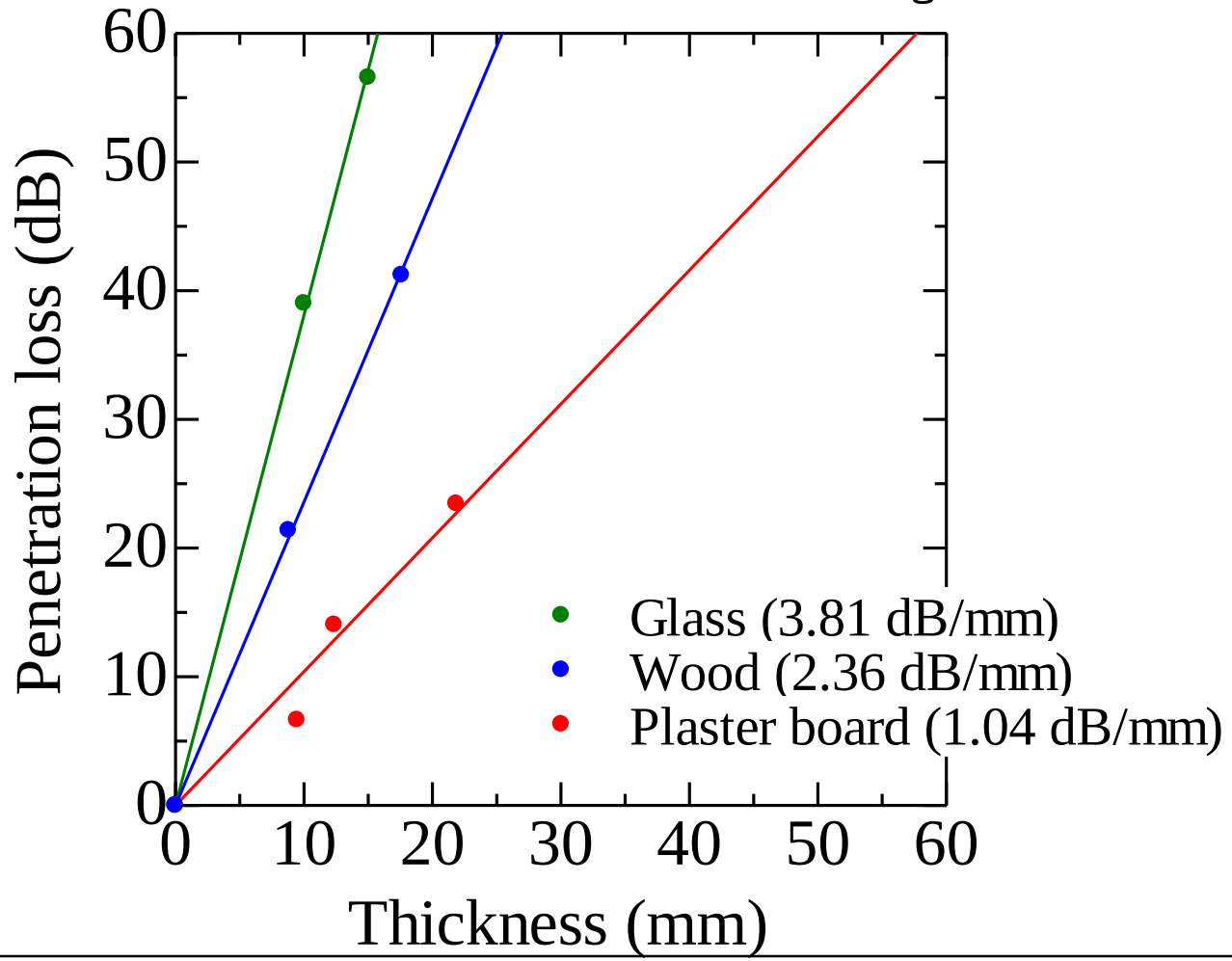






Transmission loss factor of building materials

- The transmission loss coefficient is extracted because the transmission loss is linear to the thickness of the building material.



Loss measurement by fixture（1/2）

- Measurement of transmission loss by fixtures inside of buildings
- Measuring interior walls and doors in wooden houses

Inside wall of the wooden house
(Thickness is 100 mm)
Loss = 38.3 dB

Wooden door of the Wooden house
（Thickness is 38 mm）
Loss = 12 dB

Loss measurement by fixture（2/2）

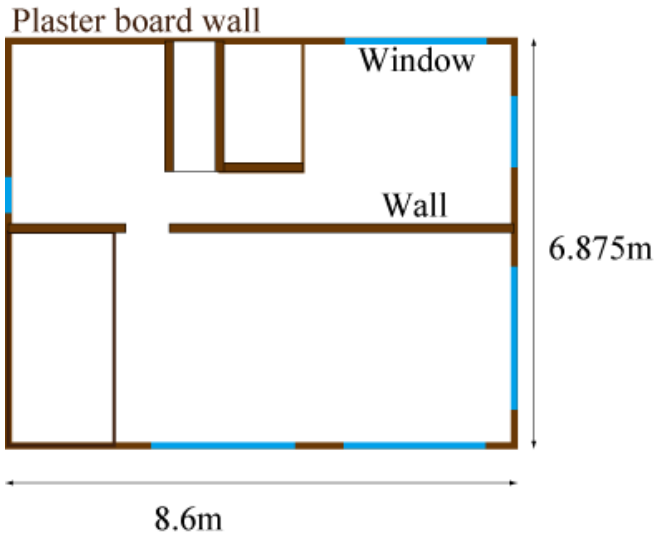
Door
(Thickness is 41 mm)
Loss = 47.7 dB

Partition
(Thickness is 60 mm)
Loss = 22.7 dB

Inside Glass Door
(5 mm thickness)
Loss = 46.5 dB

Structure of wooden houses

- The outer wall is a doubled plaster board structure.
- There is thermal insulation materials (TIM) in the outer wall, but the loss of TIM is unclear, so the building without TIM is presumed to the BEL

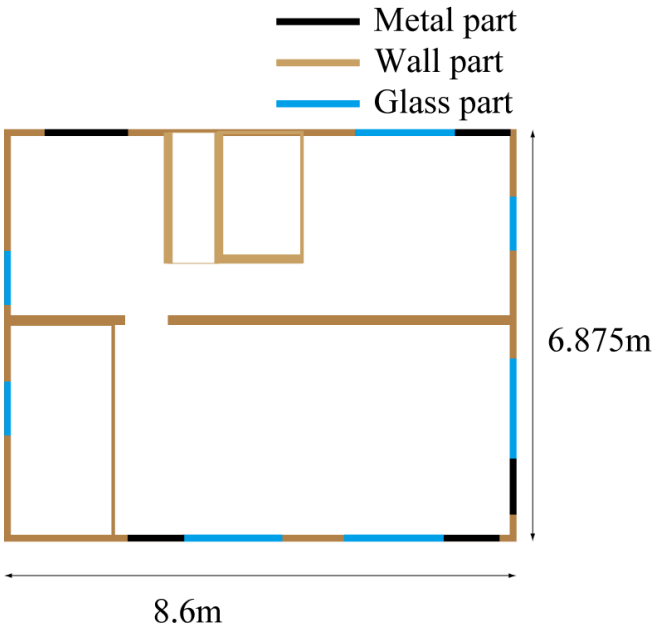


Outdoor wall structure (Outside side wall is waterproof)

120mm ⟷ 2 Plaster Boards (10mm + 10mm thickness)
With Air gap

Estimation of the BEL in case of wooden houses

- Calculate the loss by multiplying wall thickness with loss of building material
- Estimate the median and average value of the BEL by the composition ratio of the exterior wall calculating from the structure drawings



Material ratio of the outer walls

Plaster Board Wall:63%(83%)

Glass windows:13%(17%)

Metal Walls (shutters, doors):24%

※( ): incase without the metal wall

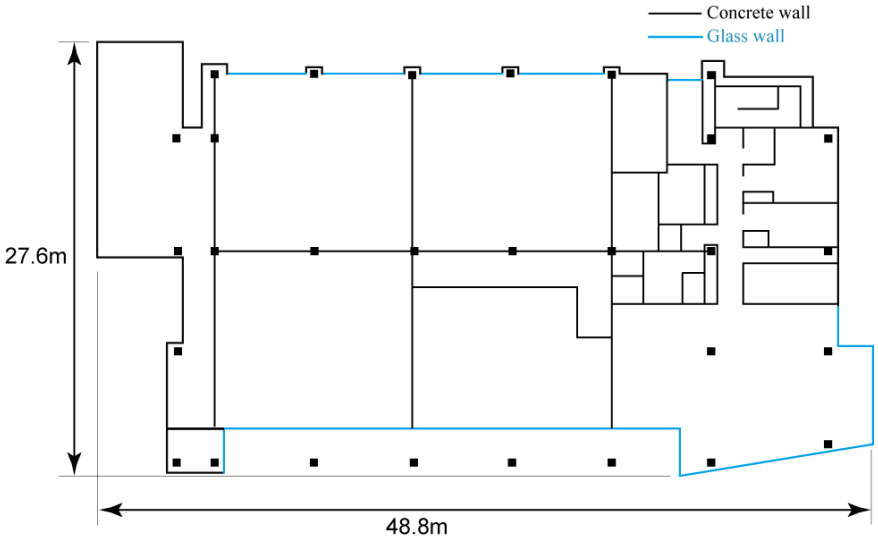
Median: 20.8 dB

Average (excluding metal walls):

20.8 * 0.83 + 18.5 * 0.17 = 20.5 dB

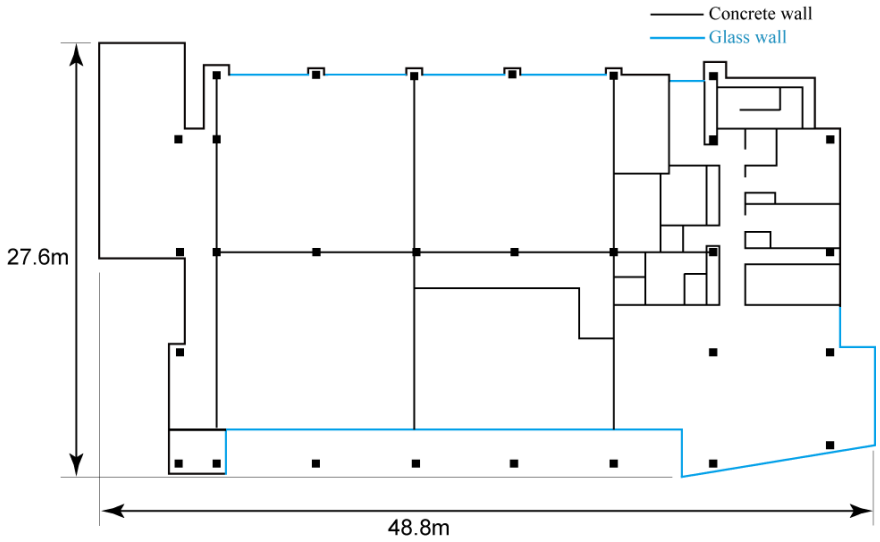
Structure of a light-weight steel frame building

- At the ground floor, there are many glass walls (with small losses) and many doors. The other exterior walls are made of concrete and the thickness varies depending on the location.The thickness of the concrete is around170 mm.



Estimation of BEL in light-weight steel frame Bld.

- Calculate the loss by multiplying wall thickness with loss of building material
- Estimate the median and average value of the BEL by the composition ratio of the exterior wall calculating from the structure drawings

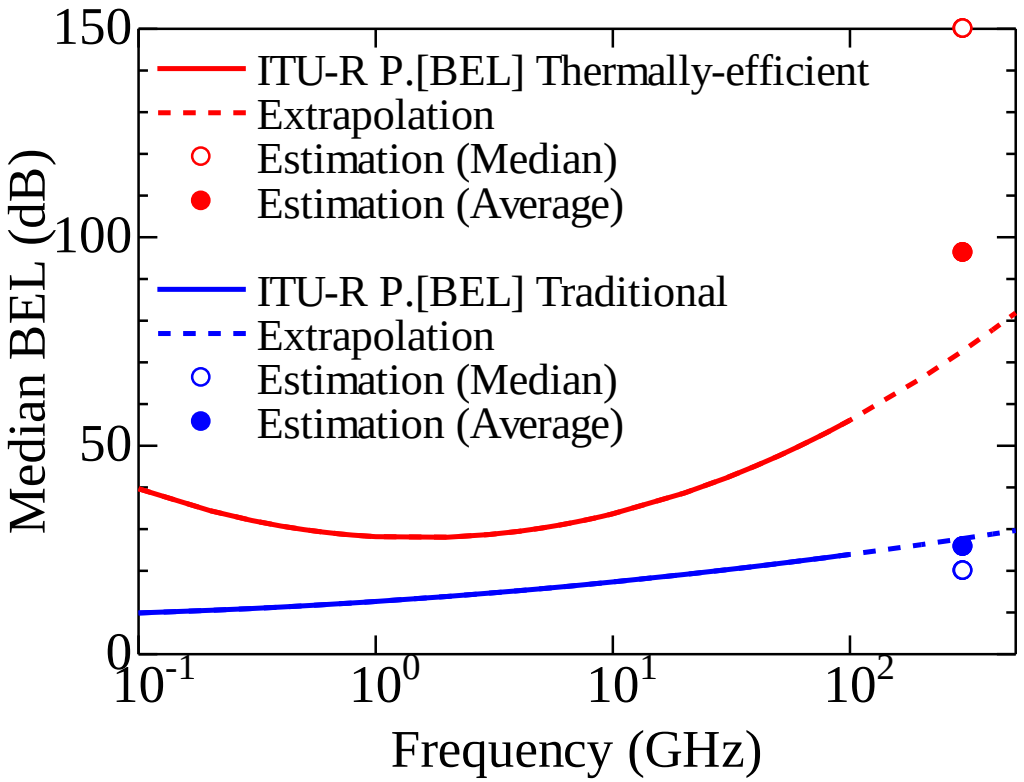


Material ratio of the outer walls
Glass windows: 44%
Concrete Wall: 56%

Median: 53 * 170/60 = 150 dB
Average:
38 * 0.44 + 53 * 170/60 * 0.56 = 100.8 dB

Comparison with the P. BEL

- In case of wooden houses, our results well matches to the P.BEL Traditional.
- In case of light-weight steel frame building, our results show 70 dB larger in median and 20 dB larger in average than those values of P.BEL Thermally-efficient.
- In the interference power evaluation, an extrapolated P. BEL formula up to 300GHz is possible to use as a reference value. Because it increases the safety margin.



Summary

- Measurement of transmission loss of building materials and fixtures in 300 GHz band.
- Estimation of transmission loss curve for the various thickness of building materials
- Estimation of BEL in case of wooden houses and lightweight steel frame buildings
- Comparison between the extrapolated P. BEL (up to 300 GHz) and the value of the estimated curve.
- Consideration of the availability of the extrapolated P. BEL for the interference power evaluation.

REF: ITU-R P-recommendations for sharing of the IMT2020

Recommendations provided to TG5/1 for sharing study with other business

Name	Overview	Apply for		
		vs. Space	vs. Aviation	vs. Ground
P.1144	Guide to How to apply a propagation model	X	X	X
P. [BEL]	Building Enrty Loss	X	X	X
P. [Clutter]	Clutter Loss	X	X	X
P.619	Ground-Interference assessment between space systems	X		
P.452	An estimation method of interference between ground systems			X
P.1411	Outdoor short distance propagation model			X
P.1238	Indoor propagation Model			X
P.2001	Long distance propagation model for ground			X
P.2041	Propagation between aircraft and space/ ground		X	
P.1409	Propagation model for HAPS		X	

REF: 300 GHz Band Indoor propagation loss model

- As a frequency extension in future, 300 GHz band propagation model has added to ITU-R Recommendations P.1238 (up to 100 GHz).
- The data center use case (which proposed for the use of 300 GHz band) has also been added to the environment.

Path loss coefficient *N*

Data Center Environment

Frequency (GHz)	Residential	Office	Commercial	Factory	Corridor	Data Centre
0.8	–	22.5[14]	–	–	–	–
0.9	–	33	20	–	–	–
1.25	–	32	22	–	–	–
1.9	28	30	22	–	–	–
2.1	–	25.5[4]	20	21.1	17[9]	–
2.2	–	20.7[14]	–	–	–	–
2.4	28	30	–	–	–	–
2.625	–	44[5]	–	33[6]	–	–
3.5	–	27	–	–	–	–
4	–	28	22	–	–	–
4.7	–	19.8[14]	–	–	–	–
5.2	30[2] 28[3]	31	–	–	–	–
5.8	–	24	–	–	–	–
26	–	19.5[14]	–	–	–	–
28	–	18.4[12] 29.9[12]	27.6[8] 17.9[12, 13] 24.8[12, 13]	–	–	–
37	–	15.6[14]	–	–	–	–
38	–	20.3[12] 29.6[12]	18.6[12, 13] 25.9[12, 13]	–	–	–
51-57	–	15[10]	–	–	13[10] 16.3[4, 10]	–
60	–	22[1]	17[1]	–	16[1] [7][9]	–
67-73	–	19[21]	–	–	16[11] 17.6[4, 11]	–
70		22[1]				
300	–	20[15]	–	–	19.5[9, 15]	20.2[15]

Propagation loss Model

$$L_{Total} = L(D_O) + N \log_{10} \frac{d}{d_o}$$

Added path loss factor for 300 GHz band

- Office environment
- Corridor Environment
- Data Center Environment