Project: IEEEP802.15 Working Group for Wireless Personal Area Network(WPAN)

Submission Title: [**Study of mm wave propagation modeling to realize WPANs**]

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Re: [**Millimeter wave propagation characteristics**]

Abstract: [60GHz-band Propagation characteristics are presented in this document]

Purpose: [Contribute to mm wave interest group for WPANs]

Study of mm wave propagation modelingⅢ to realize WPANs

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Study of mm wave propagation modeling to realize WPANs

60GHz-Band is expected to realize a very high rate transmission system. In this document, 60 to 70GHz propagation characteristics are presented for the promotion of new system proposals. Overview of propagation modeling was presented as Doc.: IEEE802. 15-03/0365 in Singapore meeting and Doc.: IEEE802. 15-03/0458 in Albuquerque. In this document,more detail information are presented.

Content

- **Complex permittivity of construction materials**
- **Correlation bandwidth**
- **Shadowing durations & attenuation**

This measurement results are a summary of the experimental works done in a collaboration research project for Millimeter-wave Ad-Hoc communication in YRP.

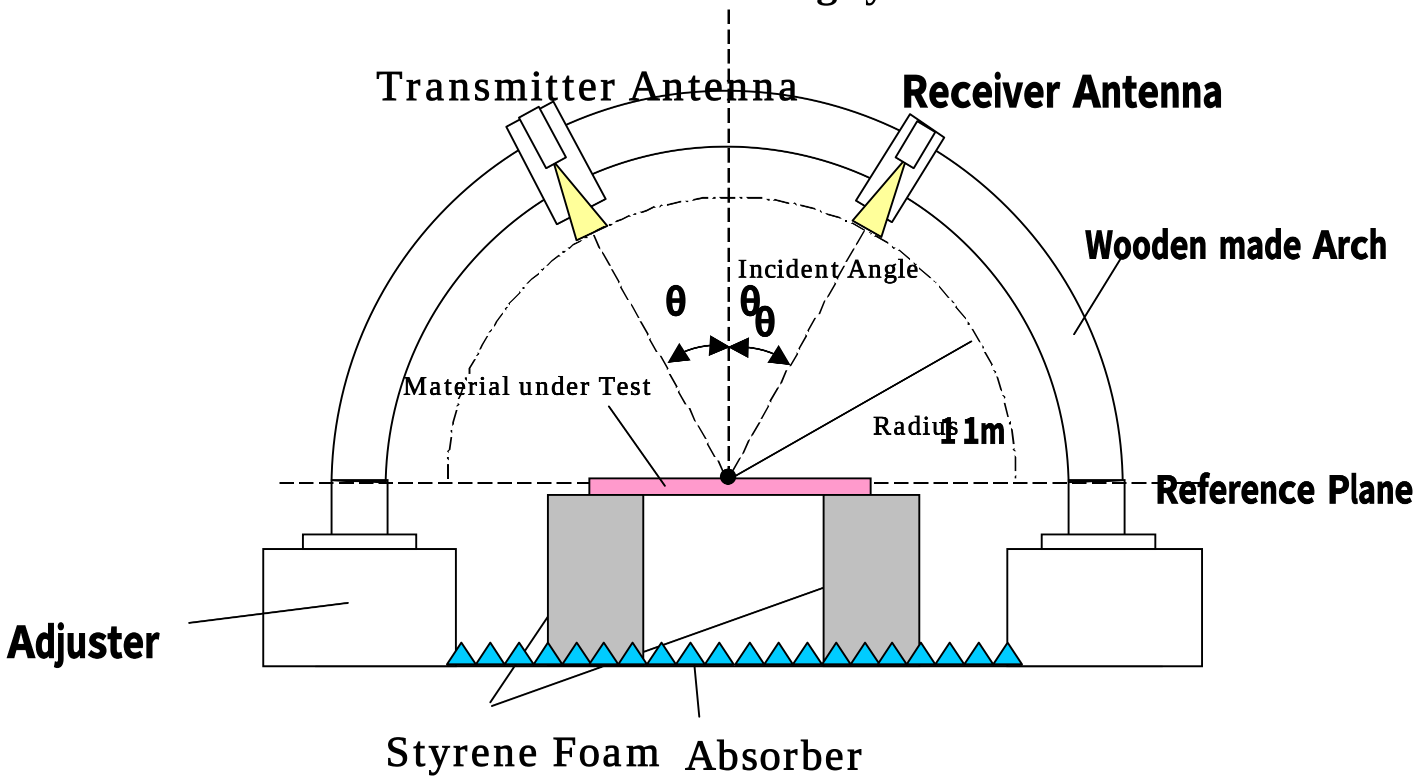
Complex permittivity of construction materials

To determine the value of complex permittivity, reflection characteristics was measured. For several materials, measurement of transparency coefficient was done to calculate more accurate complex permittivity. In this contribution, Experimental results and calculation results are presented.

Complex permittivity of construction materials

To calculate the reflection and transmission characteristics from/through the building material, the complex permittivity of construction materials are indispensable.

Reflection coefficient measuring system



Measuring parameter & Characteristic of horn antenna

Measuring parameter	Specification/Condition
Distance	1m
Polarization	Linear TE/TM
Incident angle	5º to 80º every 5º
Frequency	62GHz／70GHz
Measuring tool	Network analyzer, etc
Measuring reference	Al board (1.0m×1.0m×３.０㎜)

Antenna Frequency	Antenna Gain(dBi)	Beam width	
		E-Polarity	H-Polarity
62GHz	29.8	5.5º	６.０º
70GHz	30.7	４.９º	５.４º

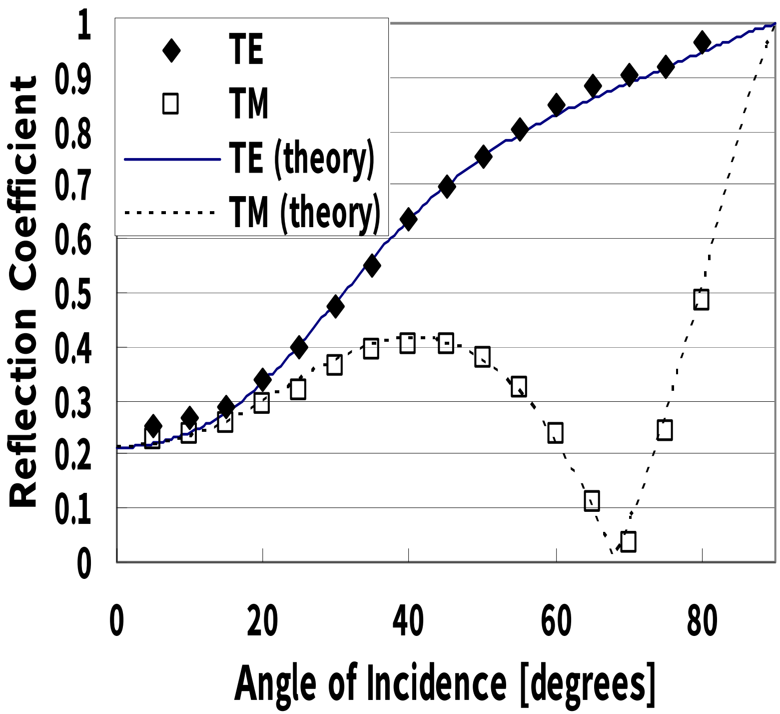
Construction materials and Size

Those materials and size are common for Reflection measurement and Transparency measurement

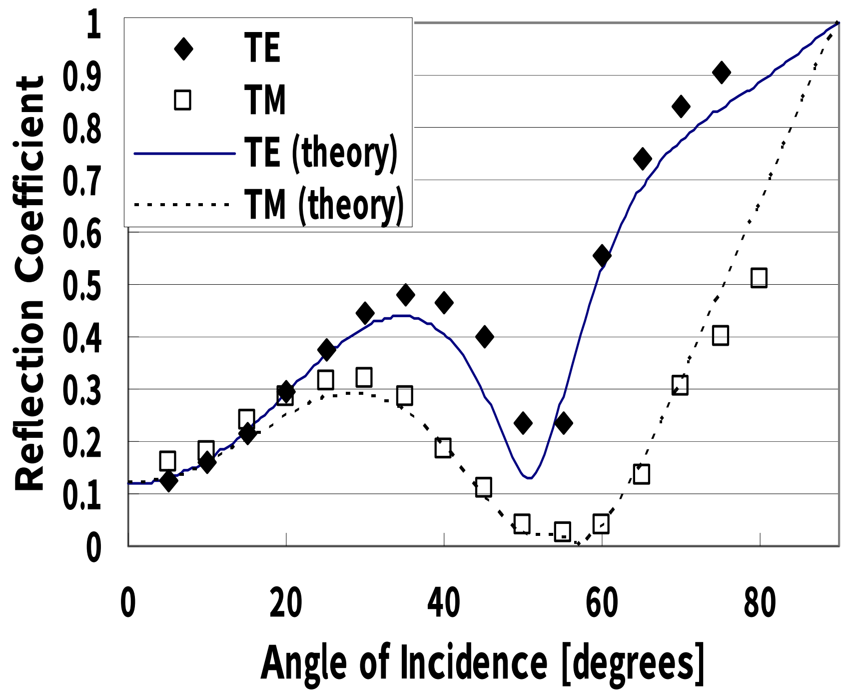
	Construction Material	Seize(length×width×thicknes)
A	Glass (Normal type)	1.0m×1.0m×6mm
B	Glass (Infrared absorption type)	1.0m×1.0m×6mm
C	Glass (Infrared reflection type)	1.0m×1.0m×6mm
D	Glass (with wire netting)	1.0m×1.0m×6.8mm
E	Plaster board (Wall)	1.8m×0.9m×12.5mm
F	Plaster board (Ceiling)	1.0m×1.0m×9.5mm
G	Marble（Bianco carrara)	1.0m×1.0m×19.6mm
H	Granite (Caledonia)	1.0m×1.0m×25.3mm
I	Granite (Zimbabwe black)	1.0m×1.0m×26.2mm
J	Lawn of grass (Dry)	0.5m×0.5m×30mm
K	Lawn of grass (Wet)	0.6m×0.6m×30mm

Number A to I are Materials for interior decoration

Reflection Coefficient of Glass & Plaster Board

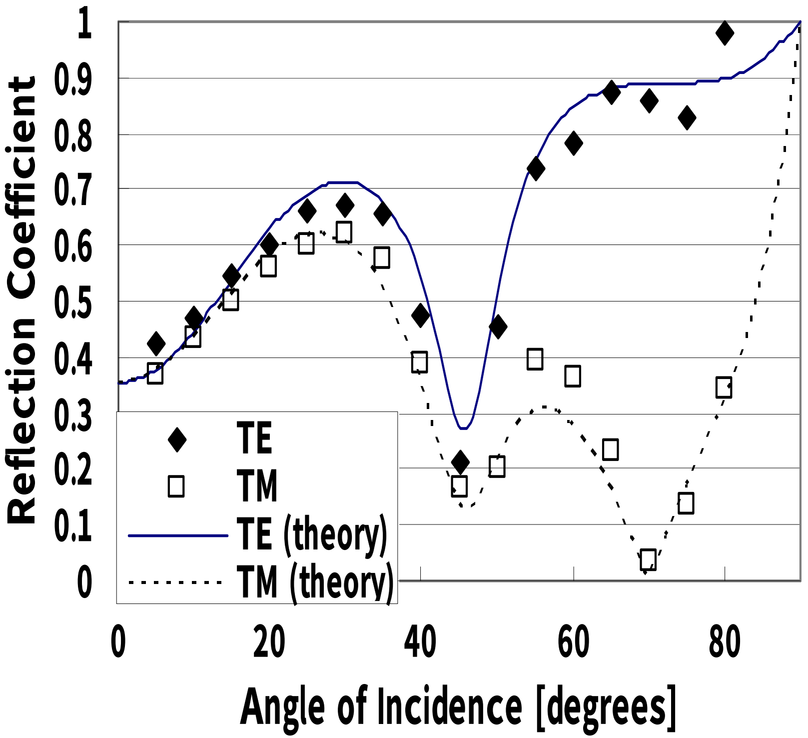


Glass (Normal)

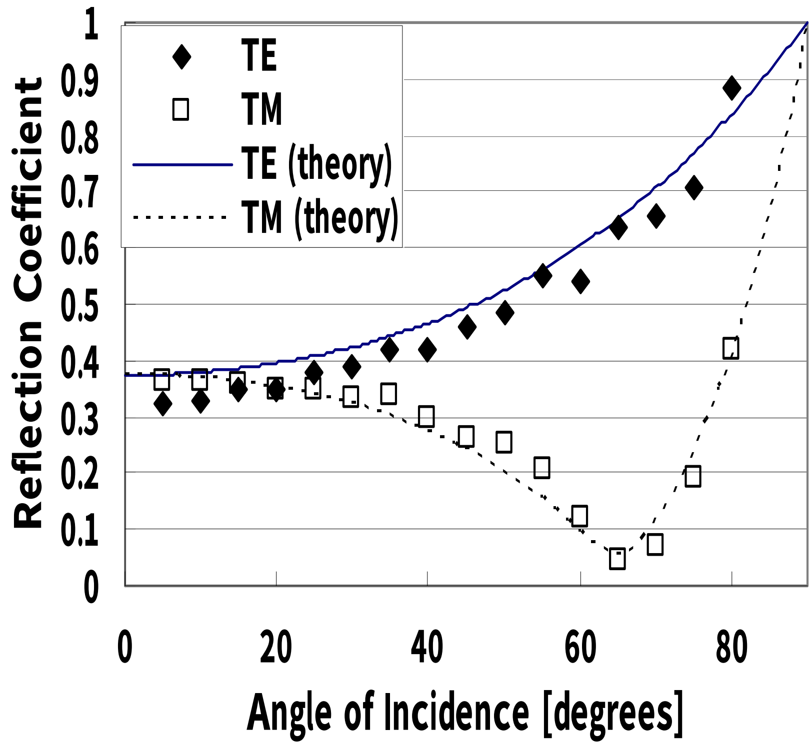


Plaster board (Ceiling material)

Reflection Coefficient of Marble Bianco carrara & Granite Caledonia

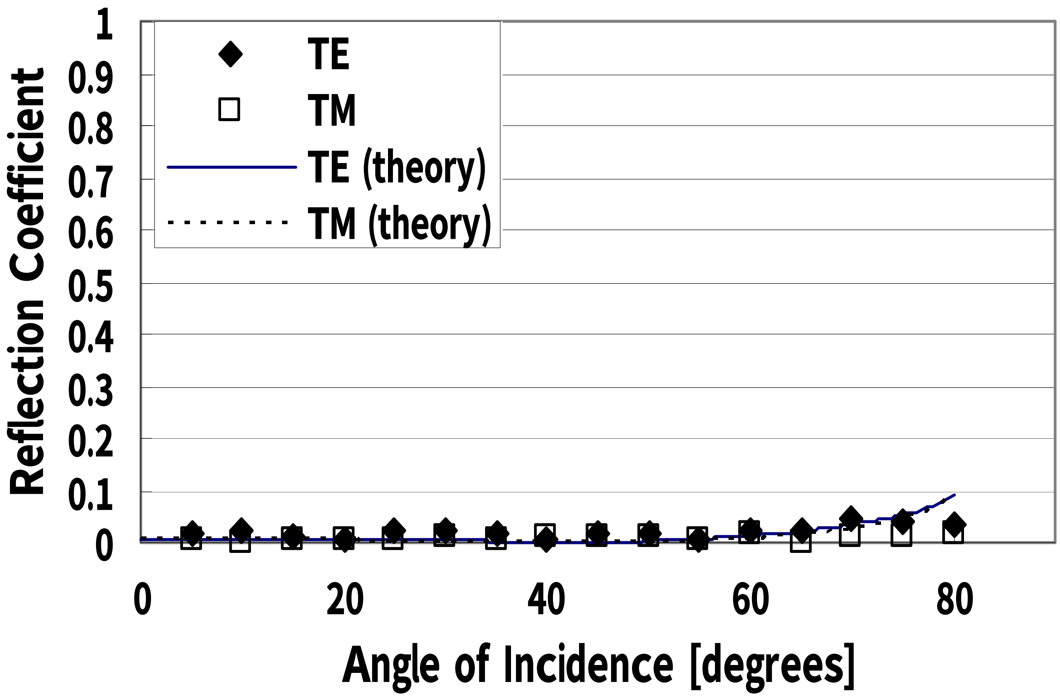


Marble Bianco carrara



Granite Caledonia

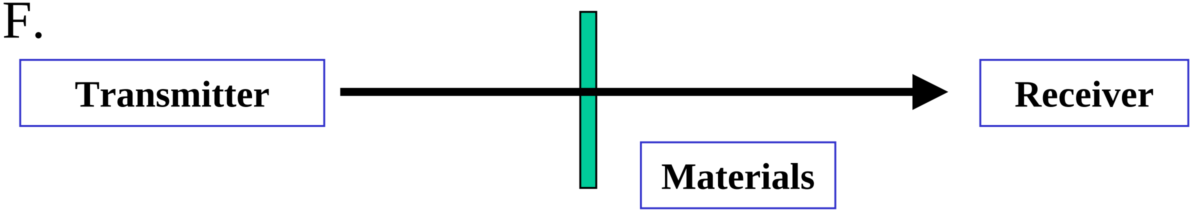
Reflection Coefficient of Wet lawn (Effective value)



Measured values and estimated result for wet lawn (70GHz)

Transparency Coefficient

On the condition of antennas aligned in vertical and 2m distance, Transparency was measured as comparison with free space loss. Materials are A to F.



	Material	Coefficient	
		62GHz	70GHz
A	Glass (Normal type)	0.674	0.674
B	Glass (Infrared absorption type)	0.609	0.666
C	Glass (Infrared reflection type)	0.647	0.678
D	Glass (with wire netting)	0.647	0.591
E	Plaster board (Wall)	0.848	0.810
F	Plaster board (Ceiling)	0.861	0.828

Complex permittivity

A-F: Actual value calculated by Reflection coefficient and Transparency coefficient

G-K: Effective value calculated by only Reflection coefficient

	Construction Material	62GHz	70GHz
A	Glass (Normal type)	6.24-0.17i	6.16-0.13i
B	Glass (Infrared absorption type)	6.43-0.15i	6.45-0.16i
C	Glass (Infrared reflection type)	6.30-0.15i	6.14-1.67i
D	Glass (with wire netting)	6.08-1.27i	6.25-0.17i
E	Plaster board (Wall)	2.17-0.01i	2.66-0.02i
F	Plaster board (Ceiling)	2.48-0.03i	2.43-0.04i
G	Marble（Bianco carrara）	7.90-0.05i	7.40-0.04i
H	Granite (Caledonia)	4.85-1.42i	4.49-1.29i
I	Granite (Zimbabwe black)	6.75-0.52i	7.00-0.50i
J	Lawn of grass (Dry)	1.00-0.004i	1.00-0.006i
K	Lawn of grass (Wet)	1.00-0.004i	1.00-0.006i

Conclusion of Complex permittivity

There are three types of materials in measurement.

① Large influence by back-surface reflection such as Glass, Plaster board and Marble.

- **Results show the complicated trace**

② Small influence by back-surface reflection such as Granite

- **Results show very simple trace**

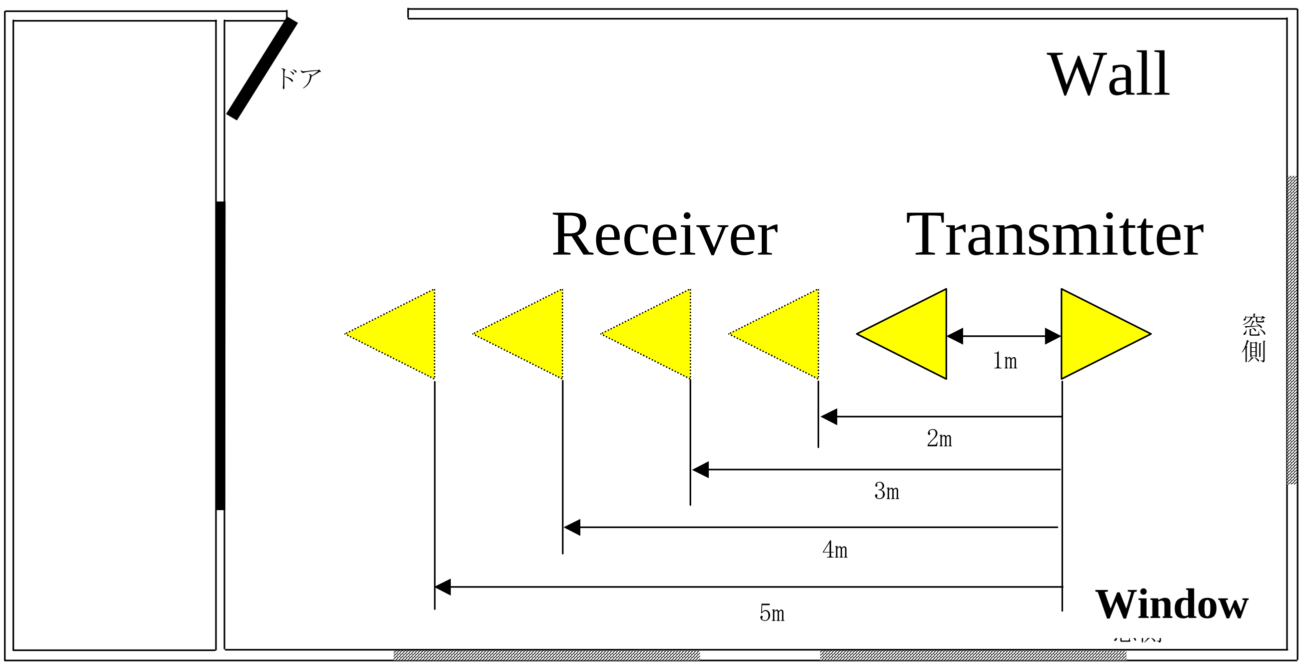
③ Small reflection from front surface such as lawn.

- **Results show similar traces for TE and TM mode**.

  Variation between wet and dry conditions is negligible.

Correlation bandwidth

Outline of test site for Correlation band width measurement



Definition of Correlation bandwidth

Correlation bandwidth is defined by Frequency correlation function

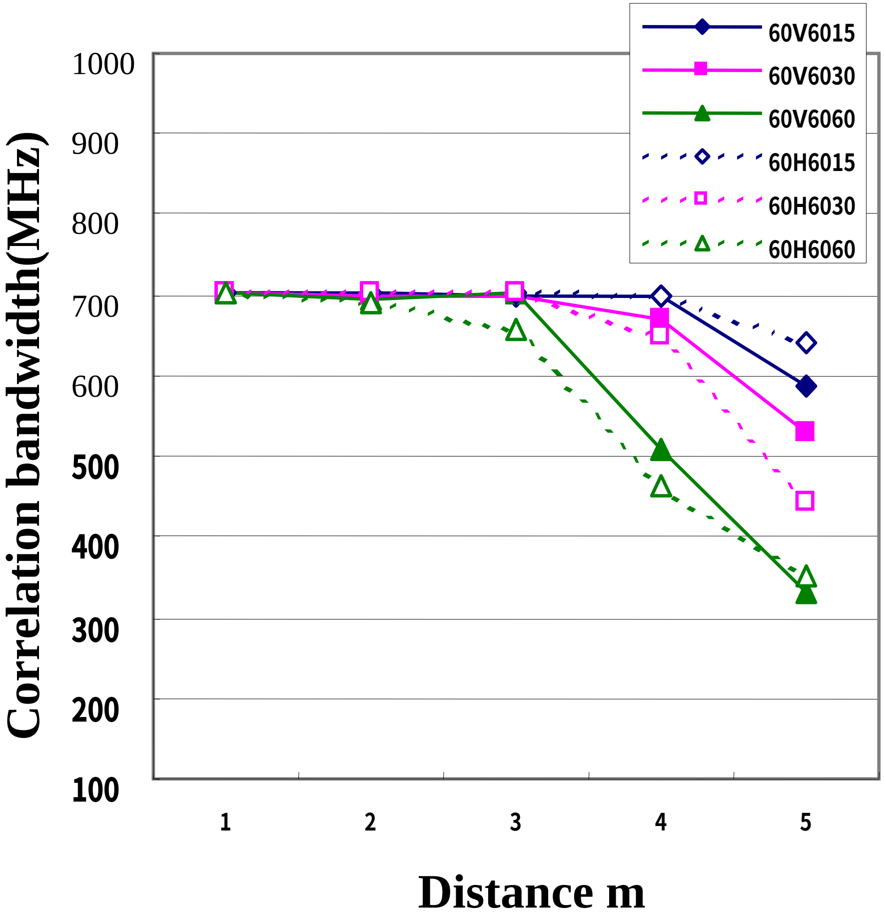
$$\rho(\Delta f) = \int_{-\infty}^{+\infty} p_h(\tau) \exp(-j2\pi\Delta f \tau) d\tau$$

$$0.5 = \left| \rho(\Delta B) \right|^2$$

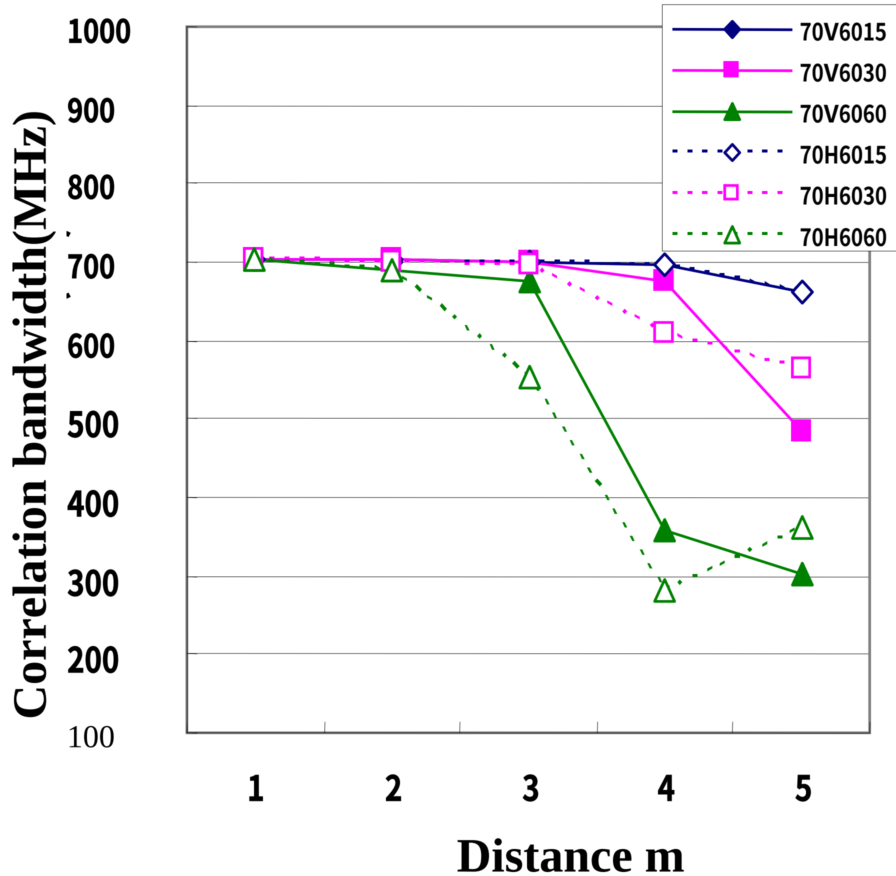
Table 1. Parameters for experiment.

Measurement equipment	HP8510C
Frequency	62.5GHz, 70GHz
Measured bandwidth	3 GHz
Transmission power	2 dBm
Antenna	Wave Guide Horn
Antenna Gain	22 dBi, 16 dBi, 10 dBi
3 dB beam width	15 deg, 30 deg, 60 deg
Polarization	V, H
Antenna Height	1 m

Distance - Correlation bandwidth characteristic

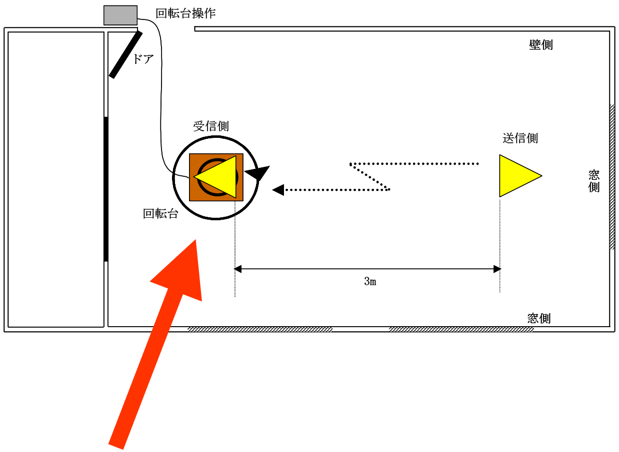


60GHz

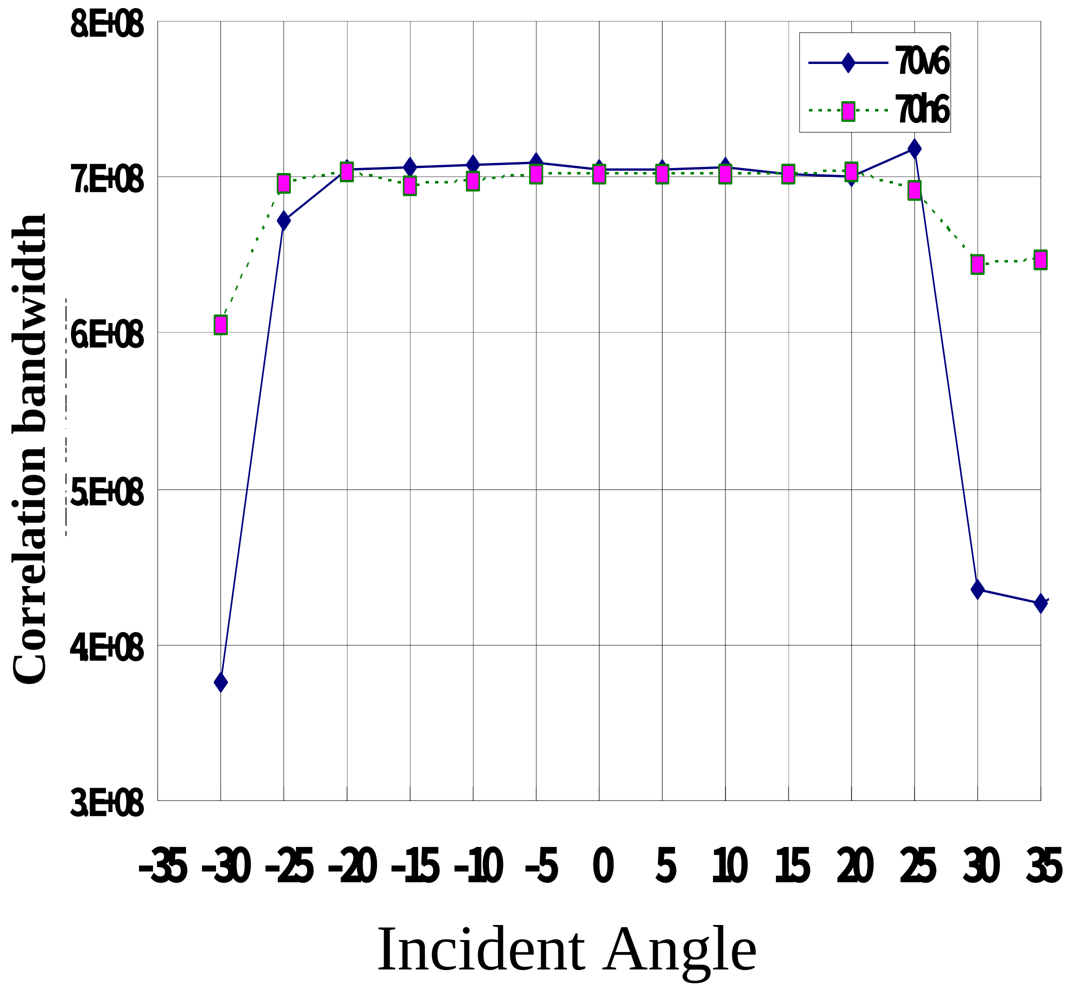


70GHz

Angle difference from Antenna axis - correlation bandwidth

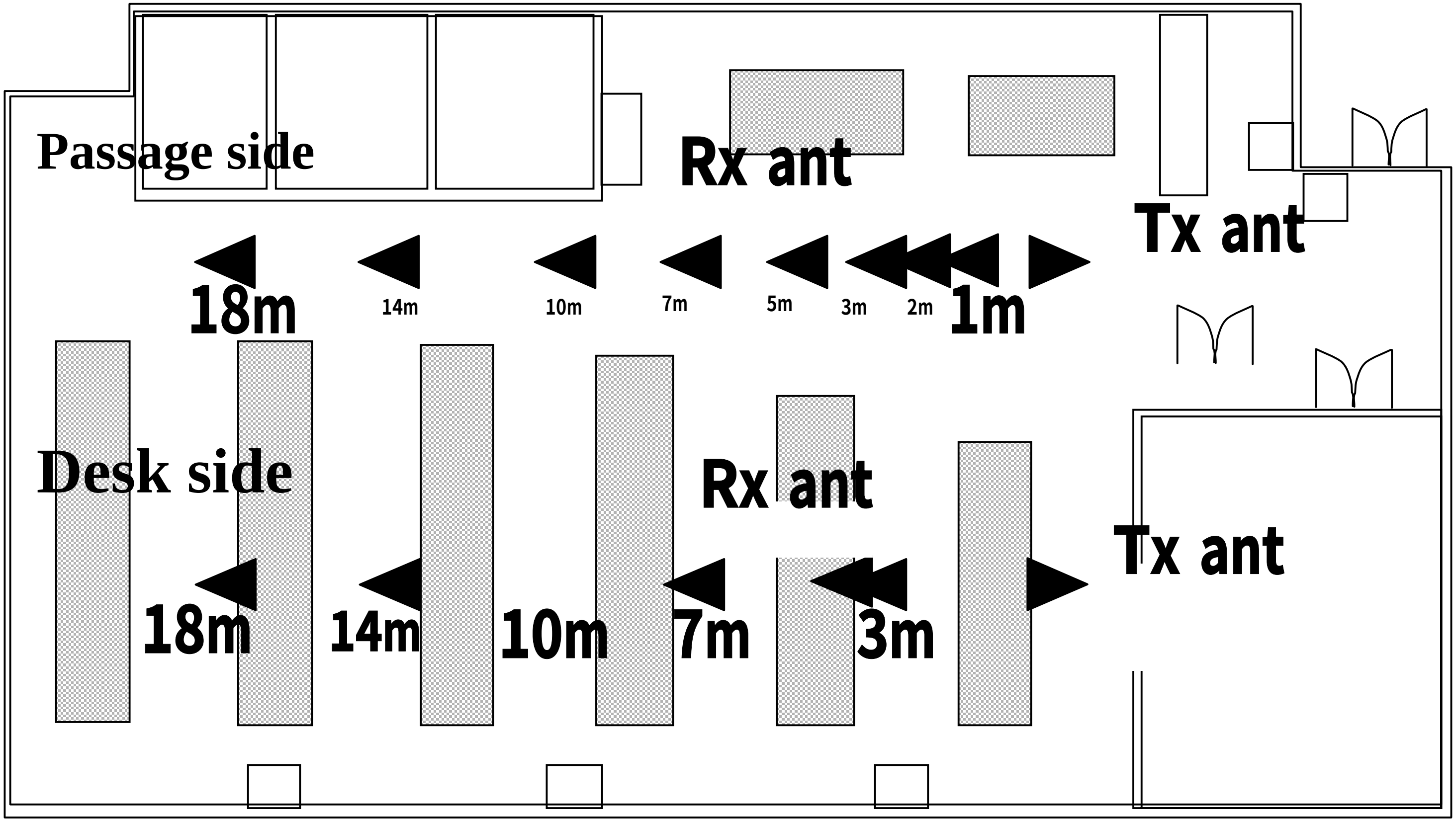


Turn Table

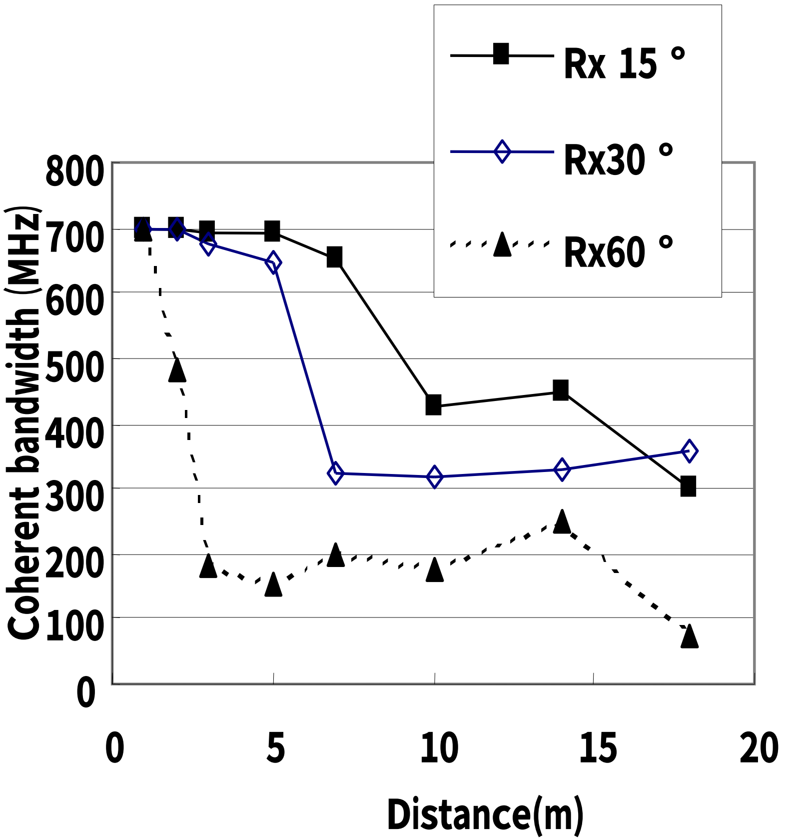


Correlation bandwidth in LOS／NLOS environment

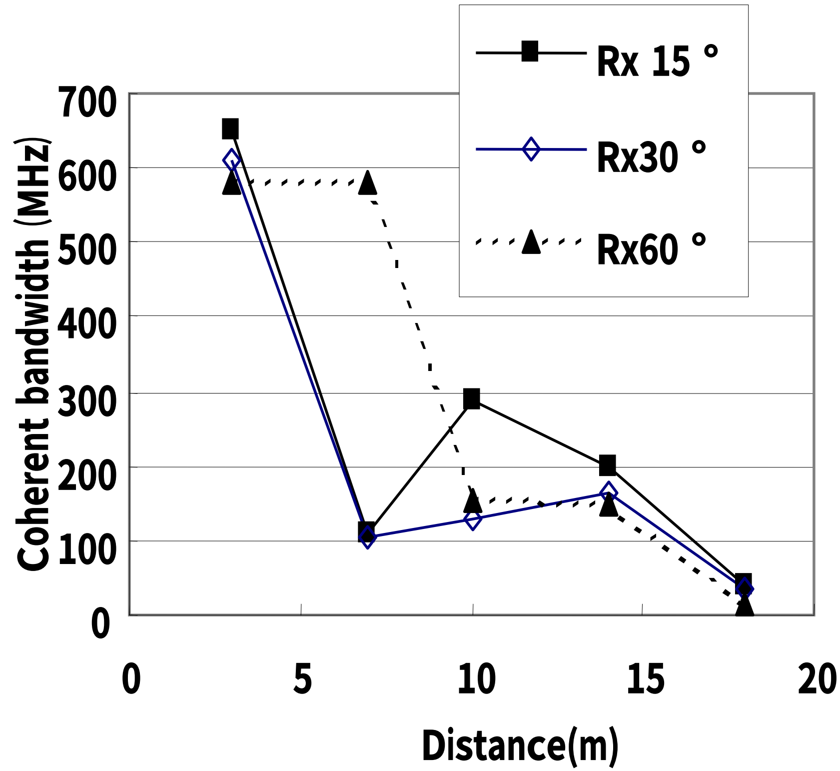
Outline of test site for correlation bandwidth



Correlation bandwidth results in LOS／NLOS environment

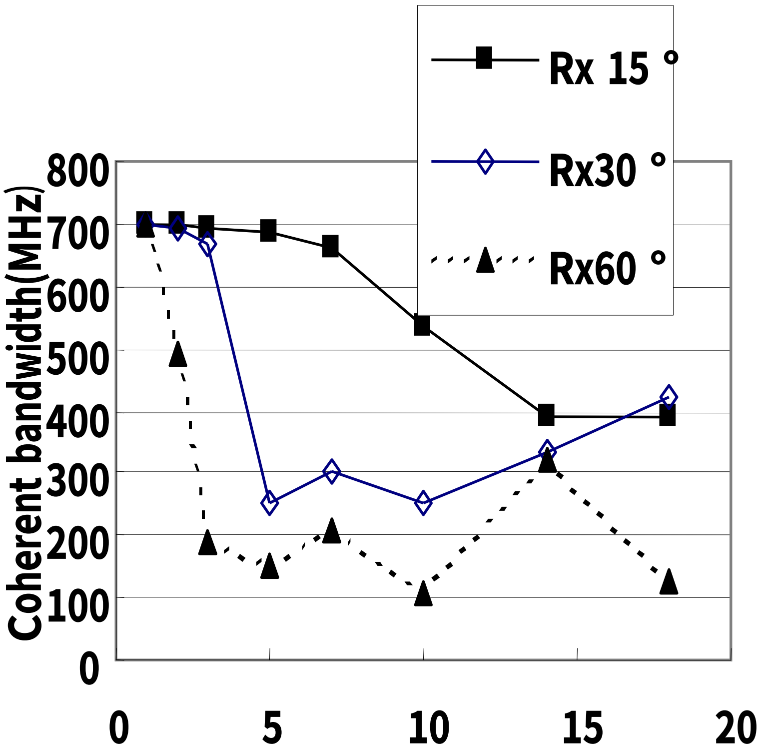


60G LOS



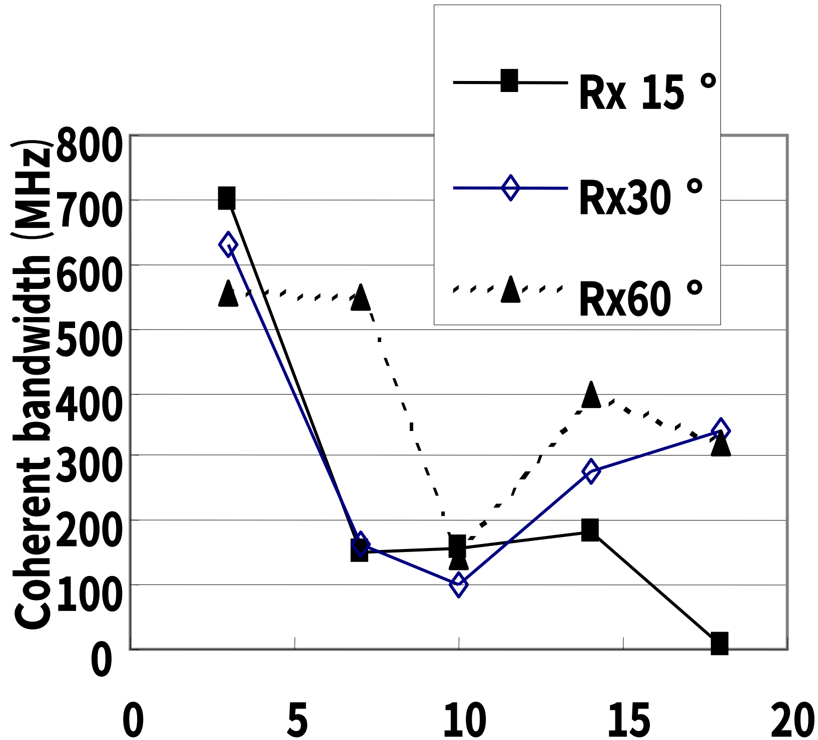
60G Non-LOS

- Continue -



Distance

70GHz LOS



Distance

70GHz Non LOS

Conclusion of Correlation bandwidth

Assuming the transmitter antenna beam width as 60 degrees and communication distance 3m, Correlation bandwidth by Antenna beam width can be obtained up to several 100MHz

60G	15°	30°	60°
3m	700MHz	700MHz	200MHz

70G	15°	30°	60°
3m	700MHz	680MHz	200MHz

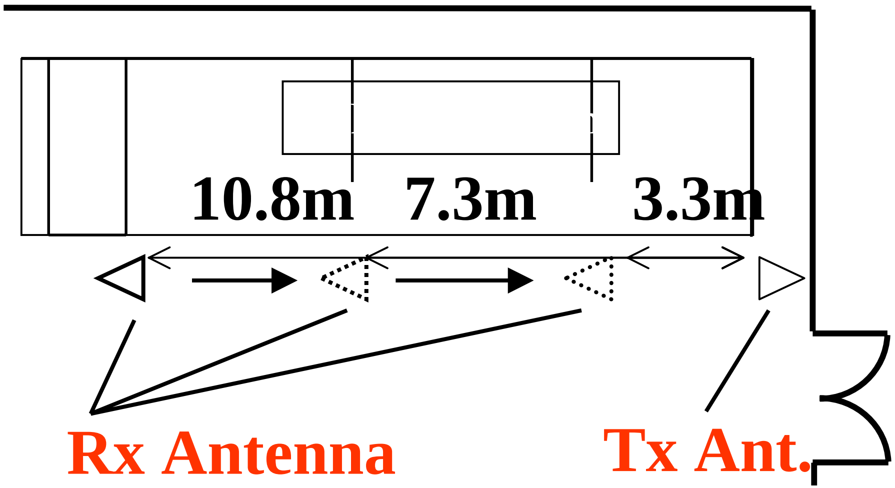
The value varied by Angle difference of antenna axis.

A Study on Shadowing Characteristics

Agenda of Shadowing Characteristics

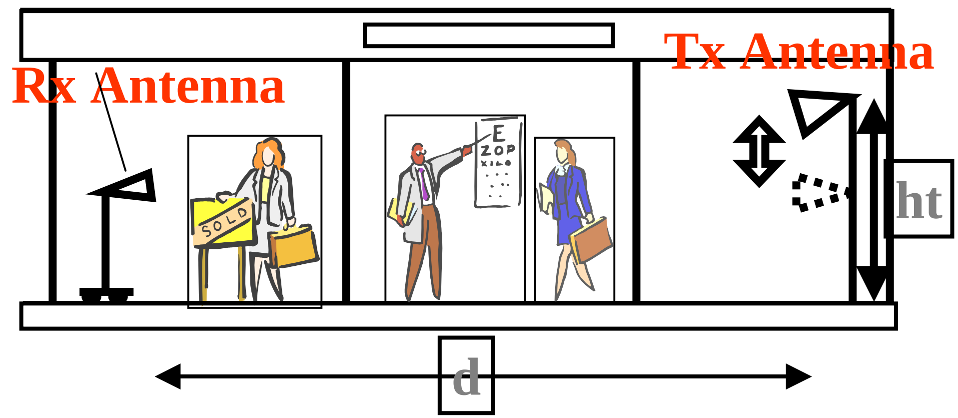
1. Characteristics of shadowing effect
    - Measurement procedure and scenery
    - Measurement results
2. Characteristics of human movement
    - Measurement outline
    - Investigation results
3. Proposal for estimation of shadowing duration
4. Conclusions

Measurement Procedure

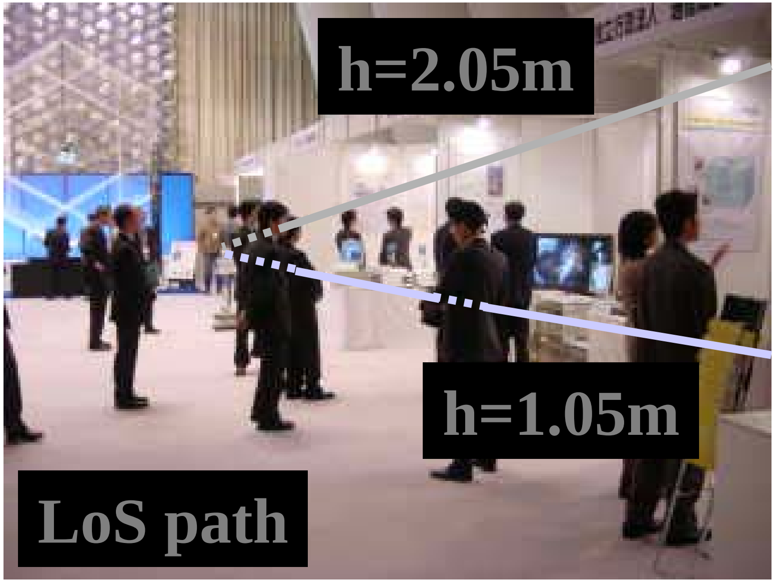


The width of hall :
22m x 13m
(Wooden inner walls)

Measurement layout
in the exhibition hall



Measurement Scenery



The exhibition hall scenery

h=2.05m

h=1.05m

Transmitting Antenna

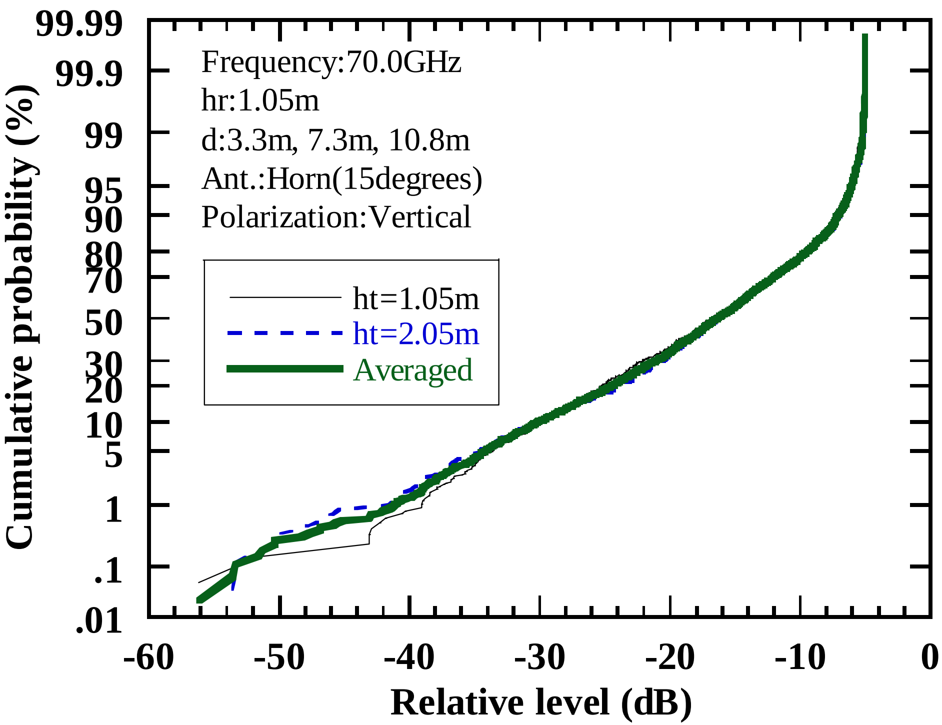
Measurement Parameter

Parameter for experiment

Frequency	70GHz	
Antenna Height	Tx	1.05m, 2.05m
	Rx	1.05m
Distance	3.3m, 7.3m, 10.8m	
Antenna	Wave Guide Horn	
Antenna Gain	22dBi	
3dB beam width	15degrees	
Polarization	Vertical	

Cumulative Probability Distributions of Relative Signal

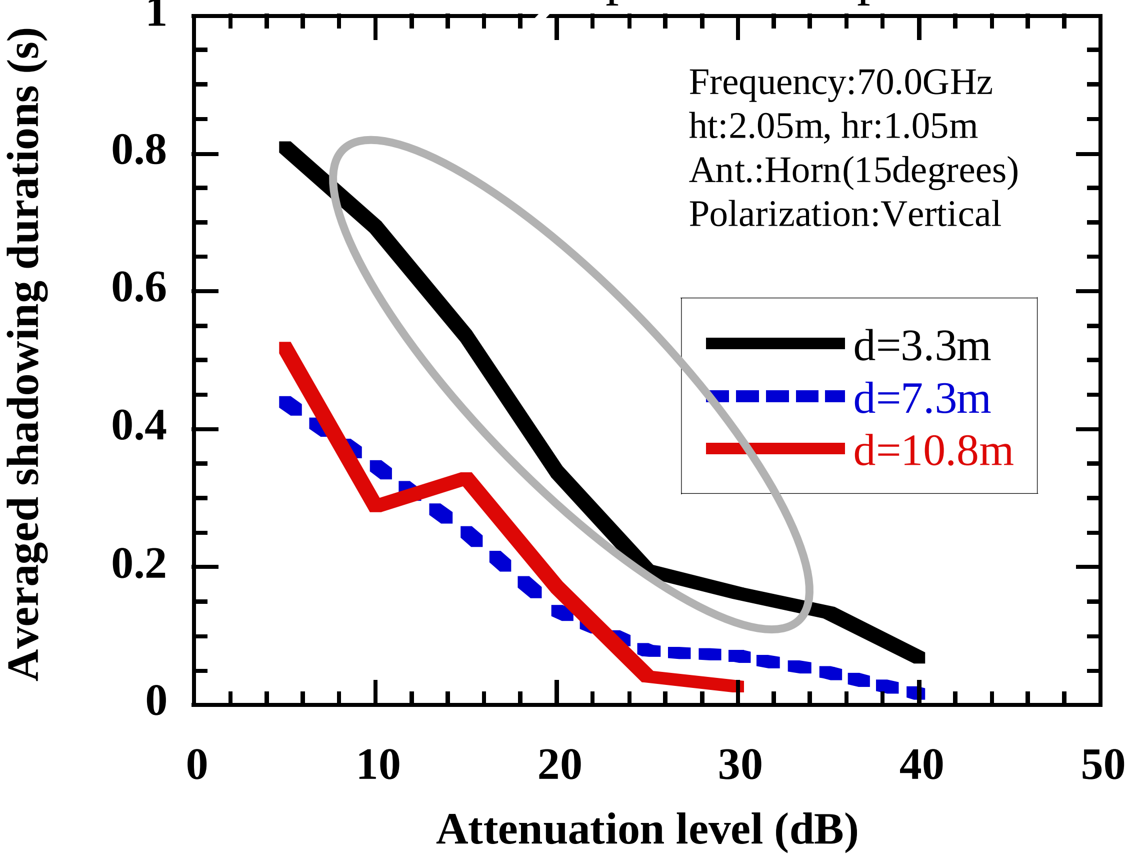
The averaged data of each propagation distance was described in this figure.



The result of cumulative probability distributions shows a strong consistency between the data of 1.05m and 2.05m.

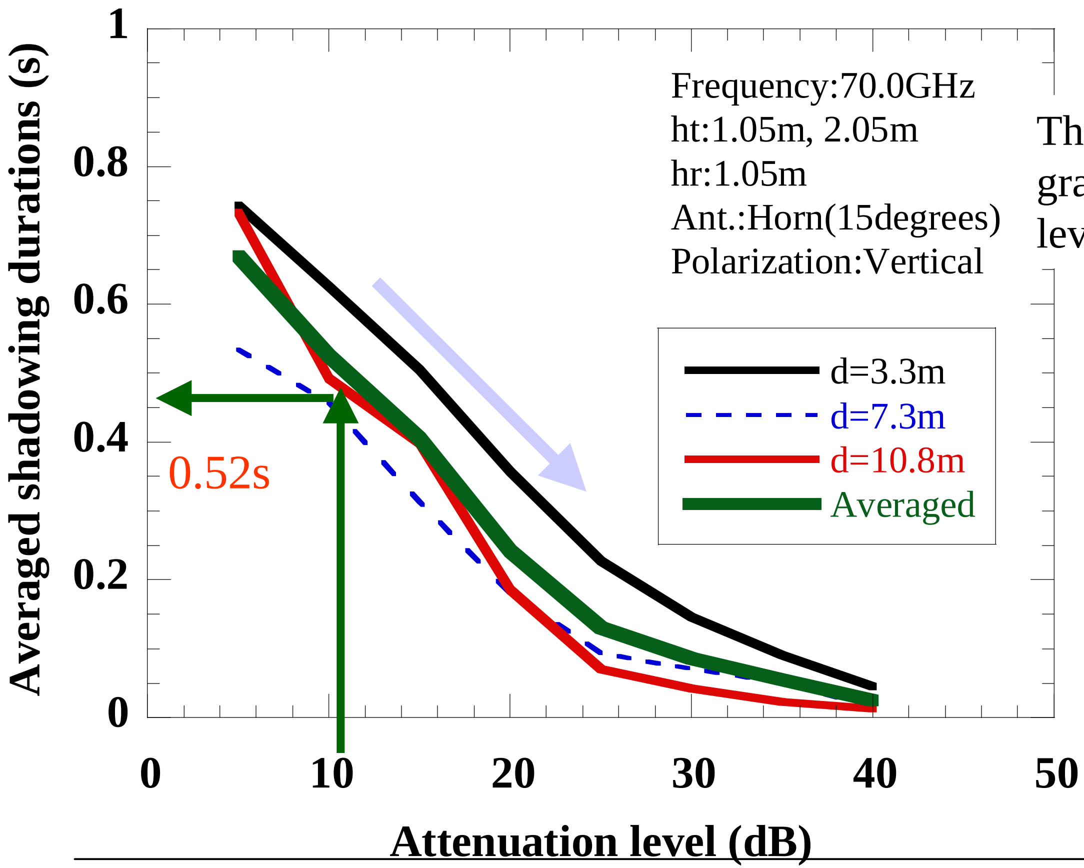
The Variation of Averaged Shadowing Durations

Shadowing duration becomes longer in 3.3m path in comparison with other paths.



The Variation of Averaged Shadowing Durations

All data was included when transmitting antenna height was set at 1m and 2m ,respectively.



The averaged shadowing duration decreased gradually with an increase in attenuation level.

Characteristics of Human Movement

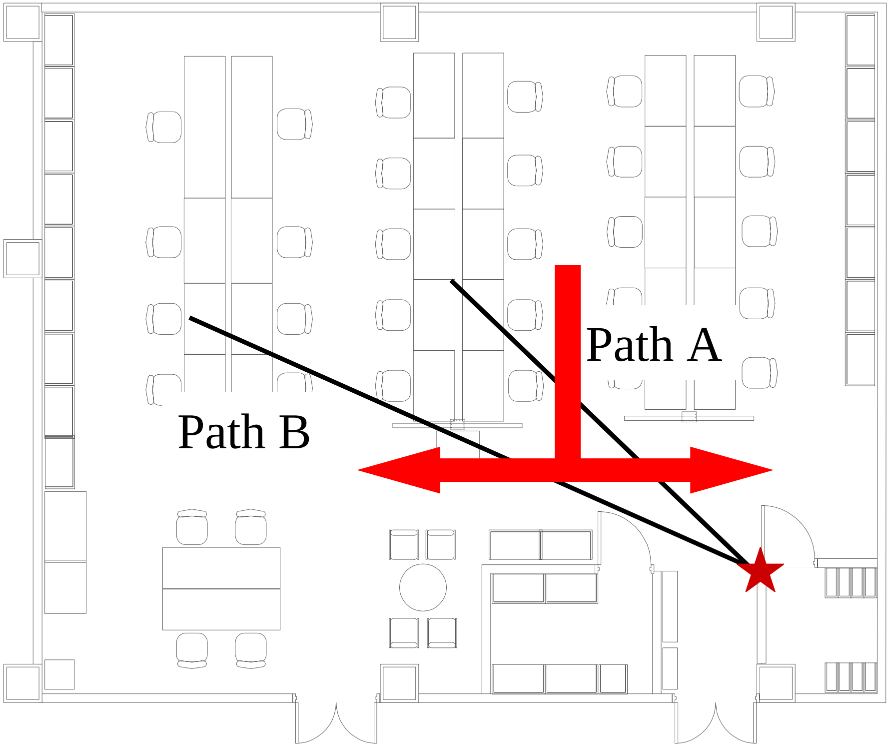
Outline of Investigation

- It is necessary to make clear not only the averaged shadowing duration but also the characteristics of human movement in the actual environment.
    - estimate the total amount of shadowing duration per hour

- We investigated characteristics of human movement in the two offices of different sizes .

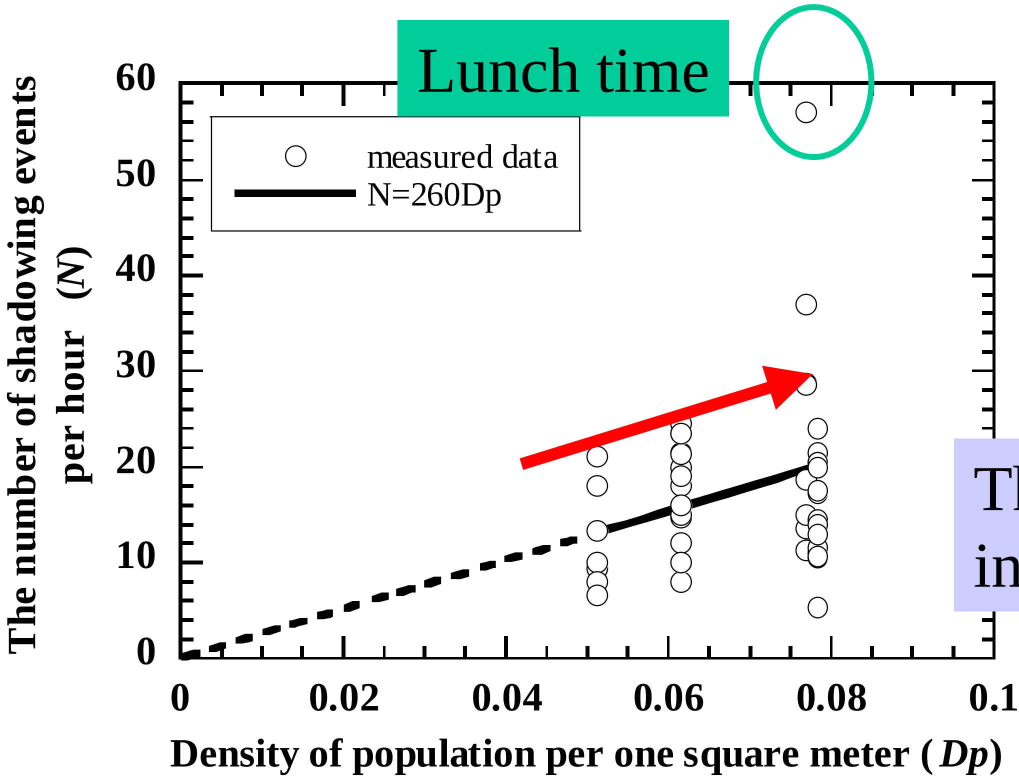
Measurement Procedure

-The width of office :
12m x 13m
-Observed time:
08:30～17:00
(2days , 2 offices)



A sample layout of the number of shadowing events

Characteristics of the Number of Shadowing Events Per Hour



Regression curve

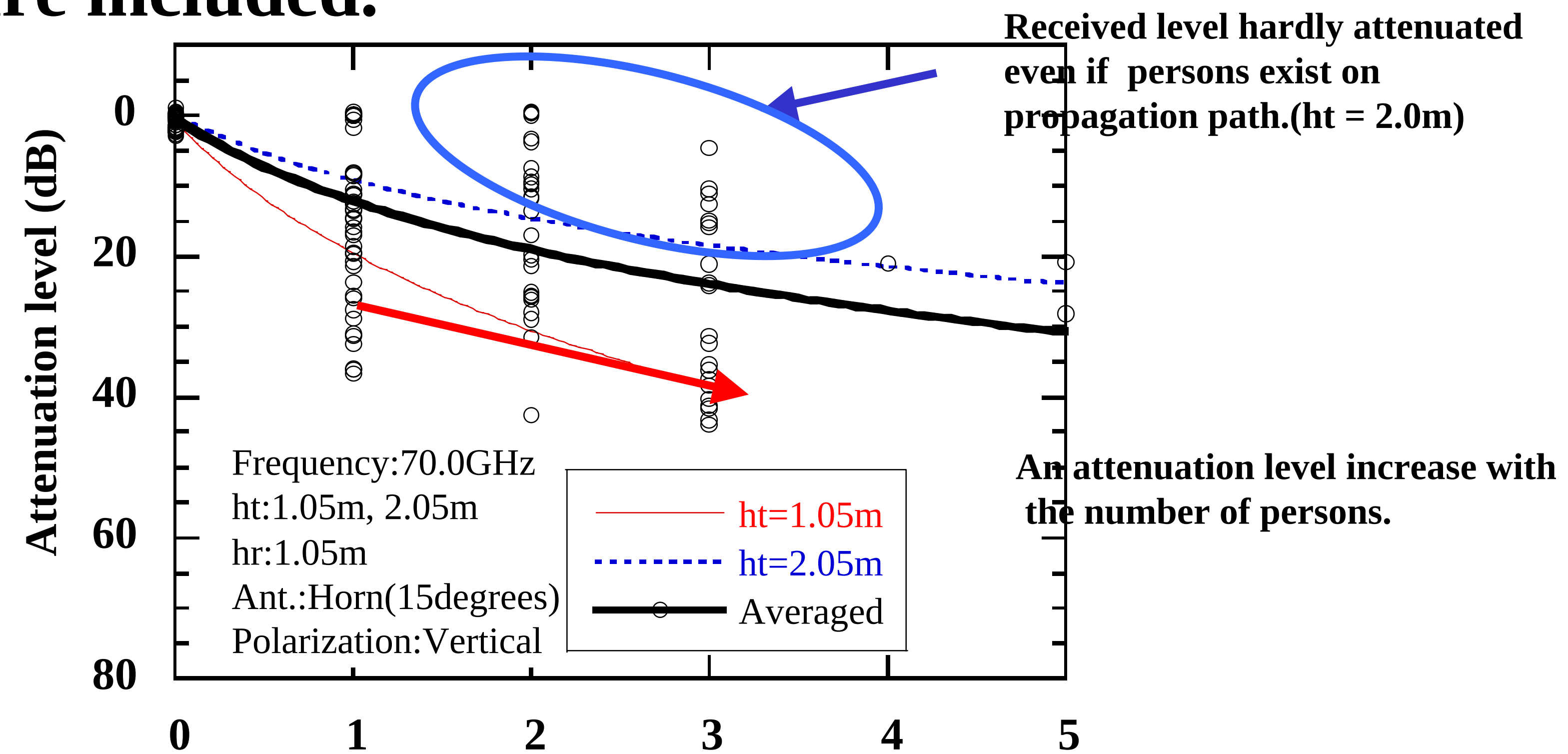
N=260Dp

0.05 ≤ Dp ≤ 0.0

The N increased gradually in proportion with Dp.

Relation Between Level Attenuation and the Number of Persons

All measured data at each distance and height are included.



Regression Curve

$$Loss_{shadowing} = 0.43 + 39.1\log(x+1)$$

$$0 \leqq x \leqq 5$$

$Loss_{shadowing}$：shadowing loss relative to the free space level

x : the number of persons in the LoS path

Proposal for Estimation of Total Amount of Shadowing Durations

-Tsd is expressed as follow

$$Tsd = Ts\_ave \times N$$

Tsd : total amount of shadowing duration per hour
Ts_ave : averaged shadowing duration
N : the number of shadowing event per hour

- Tsd can be estimated using relation of N and Dp, function of attenuation level.

$$Tsd = f(L_{ATT}) \times 260 \times Dp$$

Ts_ave : function of attenuation level (Slide30)
Dp : density of population (Slide34)

Conclusion

-Relation between attenuation level and averaged shadowing duration **were investigated.**

- Attenuation = 10dB :
  Shadowing duration is 0.52 s.
- Attenuation = 20dB :
  Shadowing duration is 0.25 s.

- Total amount of shadowing duration per hour
  - We proposed that it was estimated by using attenuation level and density of population.
  - Experimental formula was proposed.

Reference

[1]T.Suzuki, et al, “Millimeter-wave Ad-Hoc Wireless Access System-(9)RMS Delay Measurements In Indoor Radio Channels-“TSMMW2002,p-9(2002-03)

[2]N.Sakamoto, et al, “Indoor propagation Experiment at 60GHz and 70GHz-A study of propagation characteristic in an office environment-“ TECNICAL REPORT OF IEICE.RCS2002-3001,pp157-162(2003-03)

[3]N.Kuribayashi, et al, “Millimeter-wave Ad-Hoc Wireless Access SystemⅡ-(4)(4)Receiving Power Time Variation Characteristics in 70GHz Band Indoor Propagation–“ TSMMW2003,2-4,(2003-03)

[4]F.Ohkubo, et al, “Millimeter-wave Ad-Hoc Wireless Access SystemⅡ-(5)Statistical characteristic of shadowing loss due to human movement –“ TSMMW2003,2-5,(2003-03)

[5]N.Kuribayashi, et al, “Millimeter-wave Ad-Hoc Wireless Access System-(8)60GHz Band propagation Loss Characteristics Along the Surface of Wooden/Metallic Desk Planes-“ TSMMW2002,p-8(2002-03)

[6]T.Hirose, et al, “Millimeter-wave Ad-Hoc Wireless Access System-(7) Strict Solution of Fresnel Zone Radius and Visibility Estimation-“ TSMMW2002,p-8(2002-03)

Continue

[7]A.Akeyama, et al, “Propagation Characteristics in Indoor Environments” 2003 IEEE Topical Conference on Wireless Communication Technology (TCWCT2003)

[8] A. Kanazawa, D. Ushiki, and H. Ogawa, "Practical Propagation Measurements for Millimeter-wave Ad-hoc Wireless System", WPMC2003, vol.2, pp. 507-511, Oct. 2003.

[9] A. Kanazawa, N. Sakamoto, and H. Ogawa, "Propagation Measurements for Millimeter-wave Ad-hoc Wireless System in a train", WPMC2003, vol.2, pp. 512-516, Oct. 2003.

[10] F. Ohkubo, N. Ida, A. Akiyama, A. Kanazawa, H, Ogawa, “A Study on Shadowing Characteristics in Millimeter-wave Ad-hoc Wireless Access System” ClimDiff 2003 Fortaleza Brazil, Statistical and Fundamental Modeling of Radio wave Propagation in Wireless Systems Diff.22 1-7, Nov. 2003

[11] A. Kanazawa, H. Ogawa, K. Sakamoto, S. Tago, F. Ohkubo, M. Ida, A. Akeyama, N. Kuribayashi, and T. Hirose, "Measurement of Complex Permittivity of Construction Materials at 62 GHz and 70 GHz",IEICE, Vol.J87-B, No.3, To be published at Mar. 2004.