Superresolution Measurement of Non-specular Wave Scattering from Building Surface Roughness

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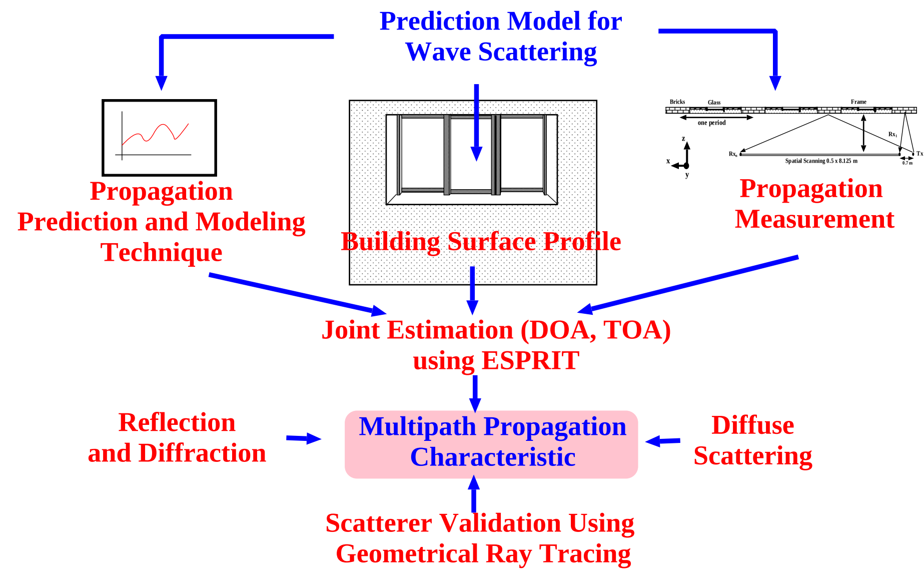
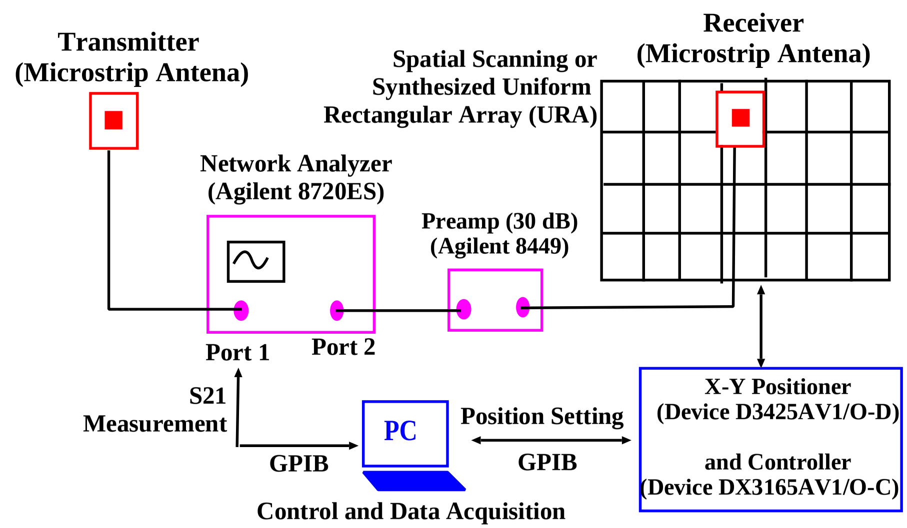
Background

- **The future mobile communication system development requires more detailed propagation model.**
- **Microscopic scattering models are required to reflective properties of the environmental objects. If they are not adequately modeled, the propagation prediction can result in large errors.**
- **Non-specular scattering due to the surface roughness can affect the channel characteristic as well as specular scattering.**

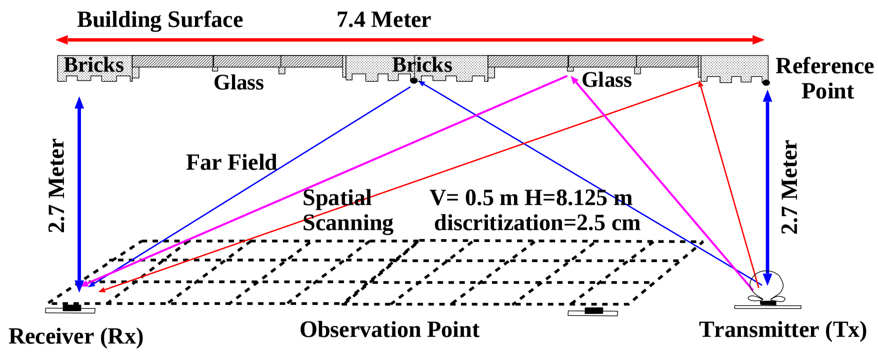
Research Metodelogy

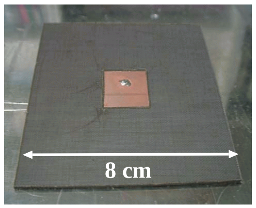


Equipment Arrangement

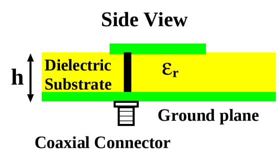


Propagation Measurement





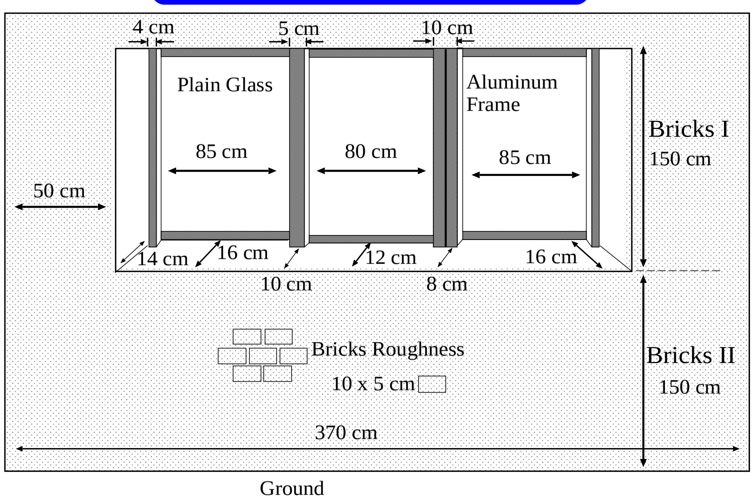
ε_r = 2.55
W = L = 1.79 cm
h = 0.16 cm
Freq = 4.95 GHz
Bandwith = 180 MHz
Beamwidth in E and H plane = 45°
Height of Antenna = 1.9 meter



Parameter of Data Measurement

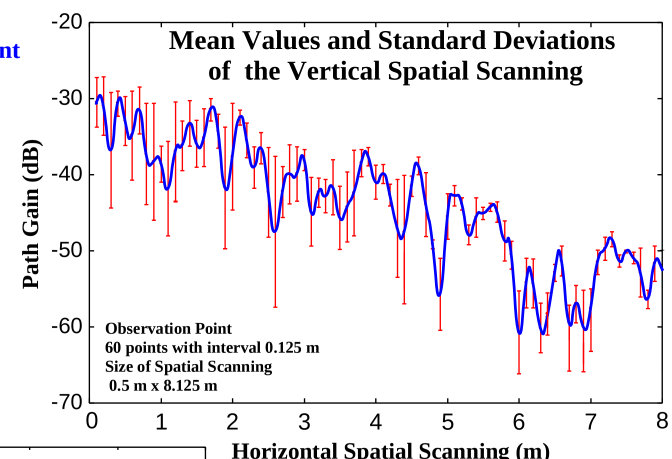
Measurement Points	: Spatially 10 x 10 points (25 mm interval) 21 points over frequency (4.85 - 5.05 GHz).
Observation Points	: 60 points with interval 12.5 cm
Snapshot	: 20 times
Estimated Parameters	: The number of waves, Angular Profiles (DOA), Delay Profiles (TOA) and path gain
Signal Processing	: Least Square 3-D Unitary ESPRIT
Smoothing	: Spatially 4 times and 7 times over frequency
Wave Polarization	: Vertical-Vertical
Antenna Calibration	: Face-to-face, the distance between Tx and Rx is 1 meter at experiment location

Building Surface Profile

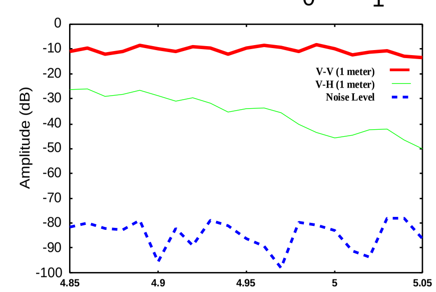


- The surface has non-uniformity and periodical irregularity along 5 periods
- Height of the roughness was comparable with or larger than the wavelength

Data Measurement



Data Calibration

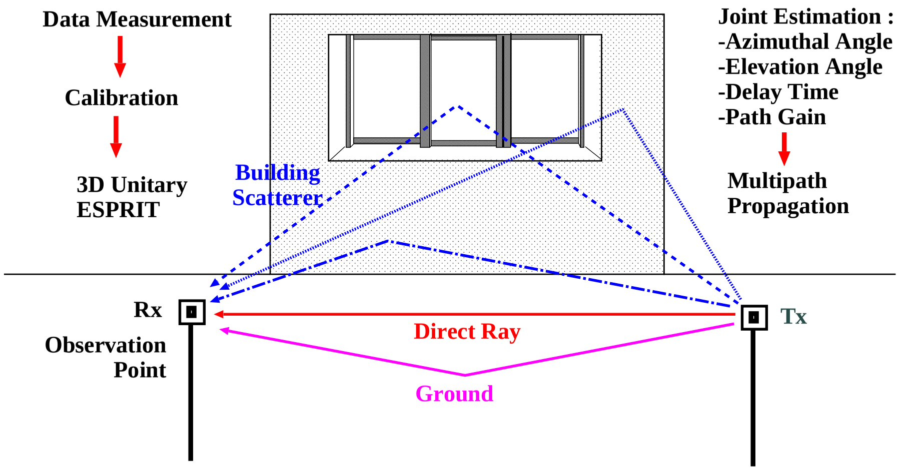


$$X_{calibr}(f) = \frac{X_{scatt}(f)}{G(f)}$$

$$G(f) = \frac{X_{1mtr}(f)}{H(f)}$$

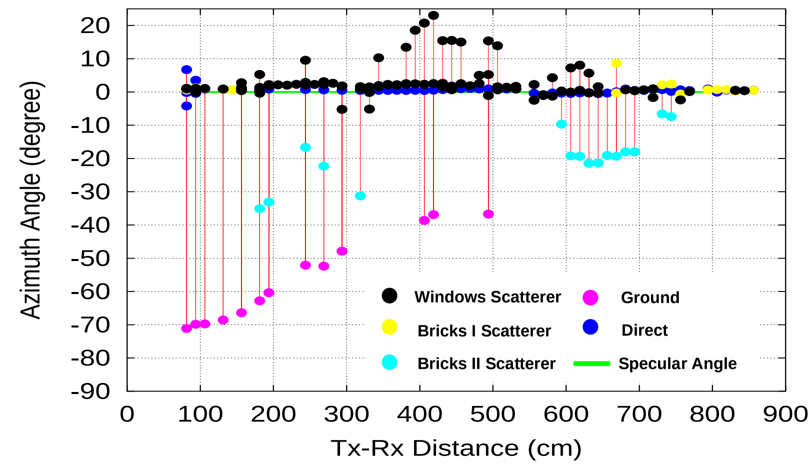
$$H(f) = \frac{\lambda}{4\pi d}\exp(-j\frac{2\pi}{\lambda}d)$$

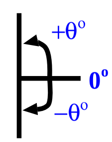
Experimental Result



- Multiple paths can be detected from many scatterers, such as ground, window glass, window frames, bricks I and bricks II.
- Estimated delay time based on geometrical ray tracing and DOA result is required for clarification of scatterer type.

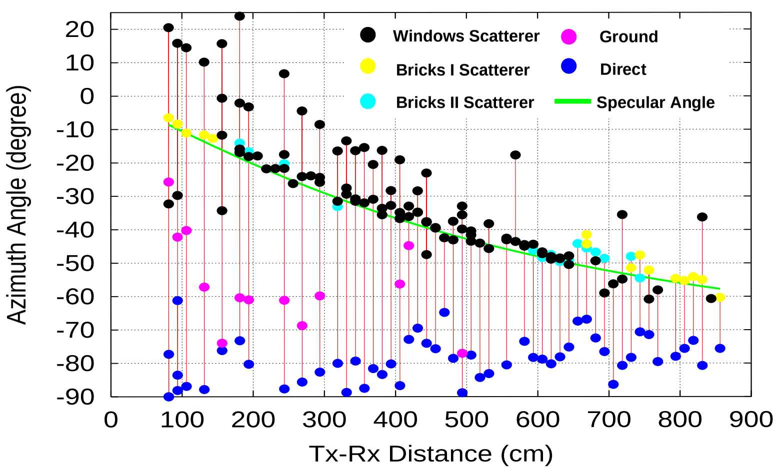
Direction of Arrival (Elevation Angle)

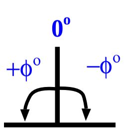




- The diffraction effects from windows frame can be observed.
- Non specular scattering from building surface is dominated more by window scatterers than by brick scatterers.

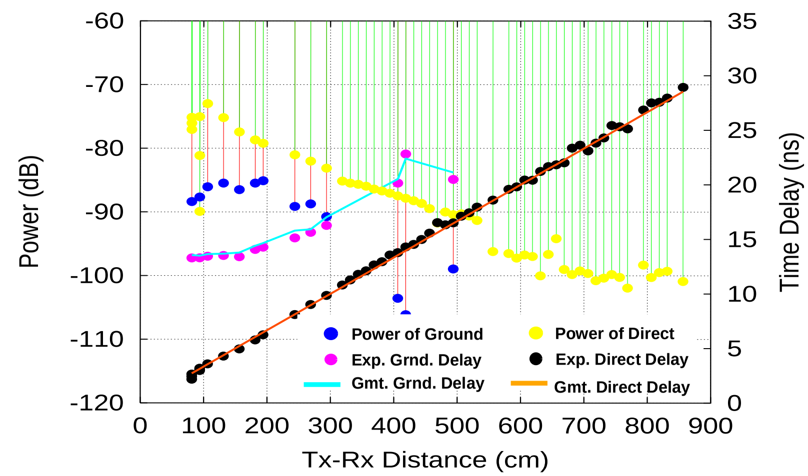
Direction of Arrival (Azimuth Angle)





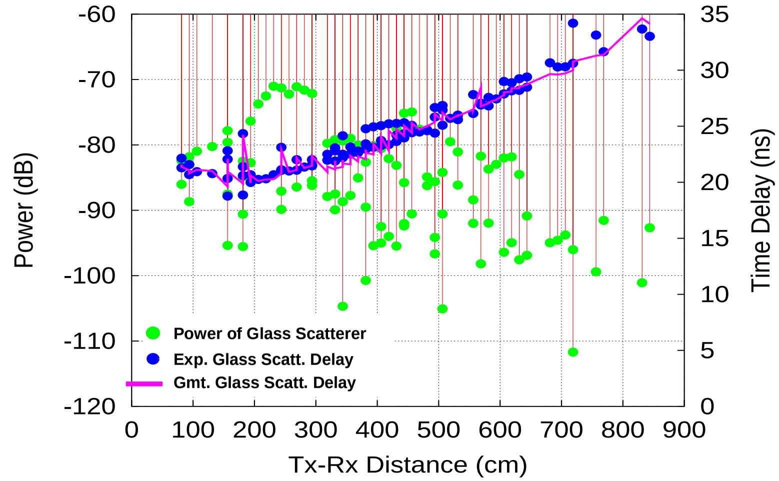
- The receiver gets the reflection from the support equipment of the antenna at the first and second observation point.
- The trend for its azimuthal angle can be estimated using angle of specular direction. Maximum deviation of the angle is 20°.

Delay Profile for Direct Ray and Ground



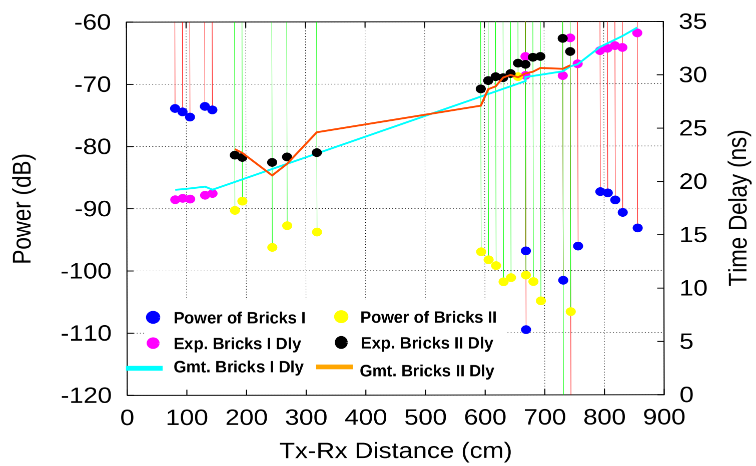
- The delay time directly estimated from the experimental results is in a good agreement with the experimental DOA and delay time based on geometrical ray tracing.
- Deviation of power between direct ray and another scatterer is less than 20 dB (bricks, window, ground).

Delay Profile of Windows Scatterer



- The second order scattering was discovered when the signal has with low power and large delay time.
- Arrival waves of glass scatterer have a particular characteristic.

Delay Profile of Bricks Scatterer



Scatterer	Avgr. Diff. Delay
Direct	0.25 ns
Ground	0.38 ns
Bricks I	0.83 ns
Bricks II	0.51 ns
Window	0.62 ns

- Power difference between bricks I and bricks II is significant enough compared to their delay time difference in spite of the same material.

Reflection Coefficient Estimation

- **The surface reflection coefficient of the building can be estimated by using signal parameters from the specular direction.**

$$TL = RC + Gtx + Grx + 20\log_{10}\frac{\lambda}{4\pi d}$$

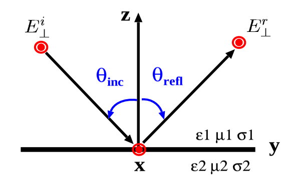
- **Fresnel Reflection Coef. for Semi-infinite Medium**

$$\Gamma_\perp = \frac{\eta_2\cos\theta_i - \eta_1\cos\theta_t}{\eta_2\cos\theta_i + \eta_1\cos\theta_t} \qquad \cos\theta_t = \sqrt{1-(\frac{k_1}{k_2})^2\sin^2\theta_i}$$

- **Fresnel Reflection Coef. for Finite Thickness Medium**

$$R_\perp = \frac{1-\exp(-j2\delta)}{1-\Gamma_\perp^2\exp(-j2\delta)}\Gamma_\perp$$

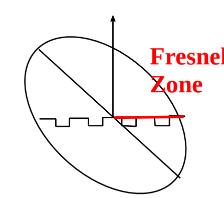
$$\delta = \frac{2\pi d}{\lambda}\sqrt{\eta_m^2 - \sin^2\theta_i}$$



- **Gaussian Scattering Loss Factor**

$$(\Gamma_\perp)_s = \rho_s\Gamma_\perp \qquad (R_\perp)_s = \rho_s R_\perp$$

$$\rho_s = \exp\left[-8\left(\frac{\pi\sigma_h\cos\theta_i}{\lambda}\right)^2\right] I_o\left[8\left(\frac{\pi\sigma_h\cos\theta_i}{\lambda}\right)^2\right]$$

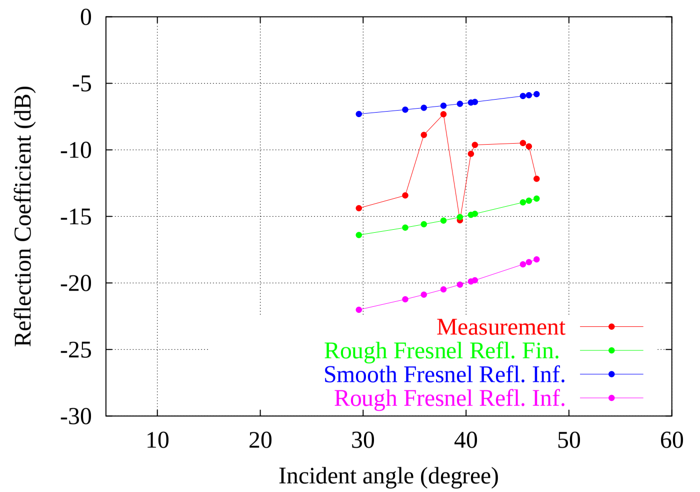


σ_h = Standard deviation of the surface height in the first fresnel zone of the illuminating antenna
Io = Modified Bessel Function

- **Roughness and Dielectric Parameters for Building Surfaces**

Parameter	Bricks	Glass
Mean of surface height	1.5	14.66
STD of surface height	0.267	2.31
Permitivity	4.44	5.0
Permeability	1.0	1.0
Conductivity	0.01	0.1

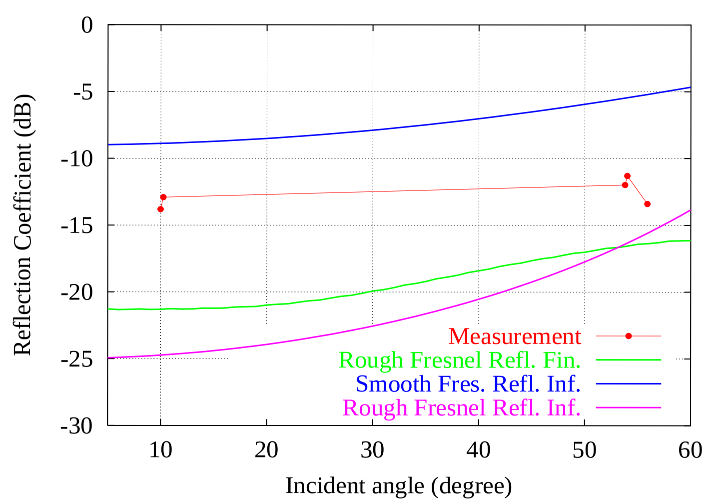
Reflection Coefficient for Glass Scatterer



- **Difference Average of Prediction Reflection Coefficient for Glass**

Type	Smooth Fress. Refl	Rough Infin	Rough Finite
Glass	4.75 dB	8.91 dB	3.91 dB

Reflection Coefficient for Bricks Scatterer



- **Difference Average of Prediction Reflection Coefficient for Bricks**

Type	Smooth Fress. Refl	Rough Infin	Rough Finite
Bricks	5.90 dB	6.87 dB	3.79 dB

Conclusions

- **The multiple paths characteristics of the non-specular wave scattering from 3-D building surface have been performed.**
- **The parameters of the arrival waves from the building surface have a tendency to be arround the angle of specular direction.**
- **The non-specular scattering from building surface is more dominated by window scatterers than by brick scatterers.**
- **The glass and bricks reflection coefficient were well bounded by the theoritical Fresnel reflection formulas for smooth surface and rough surface using the scattering correction of the modified Gaussian rough surface.**

Future Work

- **Cross polarization effect will be analyzed to more deeply Investigated of the Multipath Propagation Characteristic from Building Surface Roughness**
- **Numerical Estimation will be applied using Physical Optics Approximation.**