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Frequency–angle two-dimensional reflection coefficient modeling based on terahertz channel measurement

Key words: Terahertz communication; Reflection coefficient modeling; Incident angle; Building materials; Fresnel model

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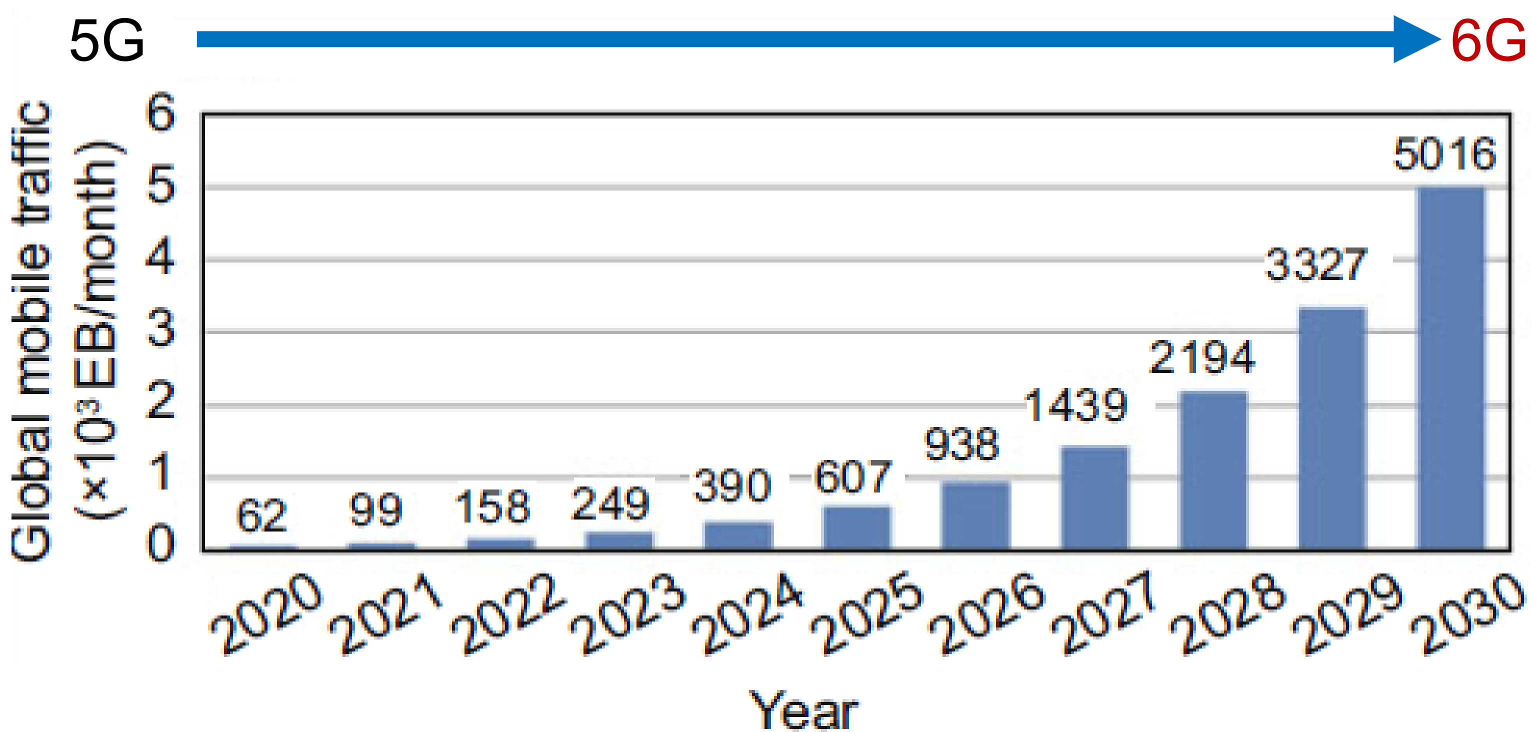
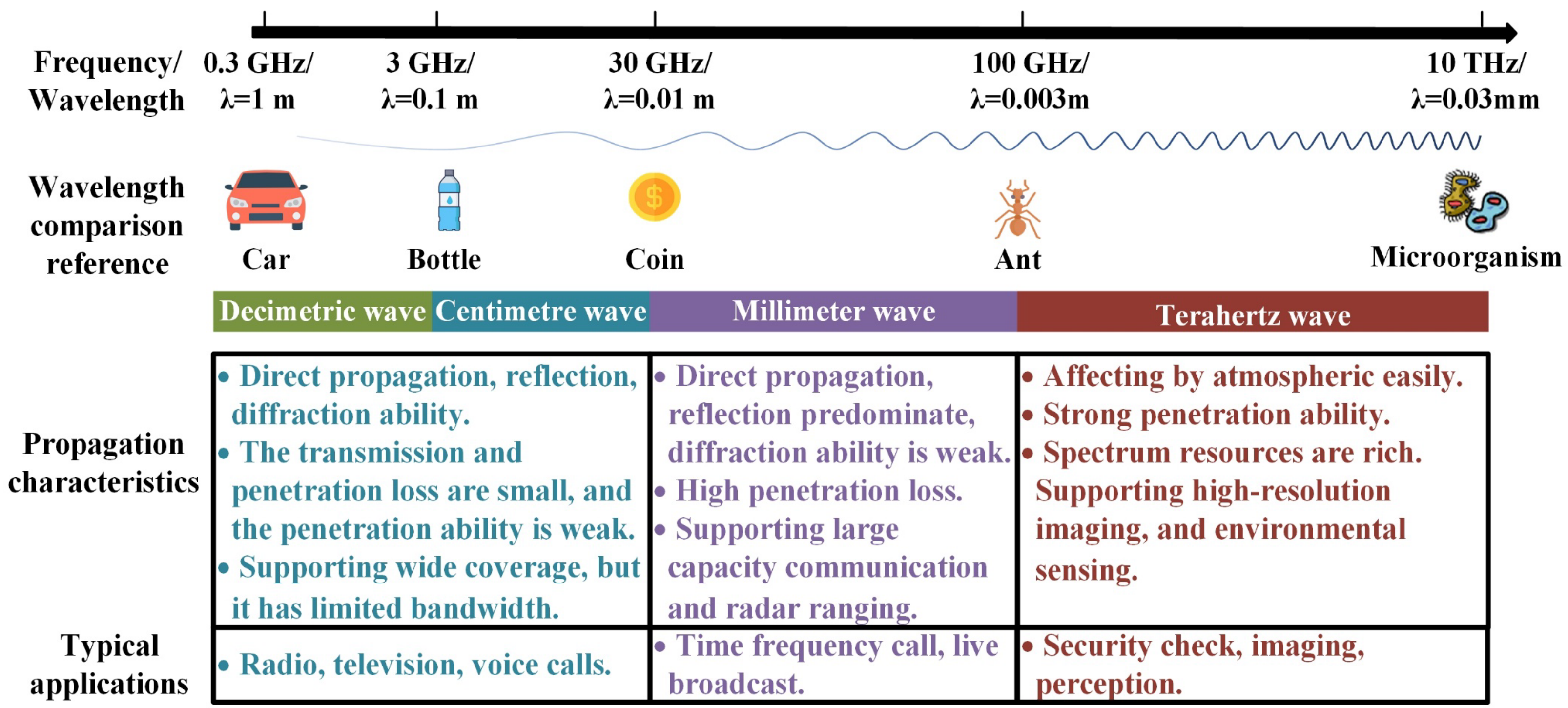
Challenges and tendency

- The 6G communication system shows an obvious expansion trend in the aspects of scene and technology.
- To meet the increasing demand for higher data rates, THz communication between 0.1 and 10 THz is attracting a great deal of attention due to its wide bandwidth, which can support much high data rates from tens of Gb/s to a few Tb/s.



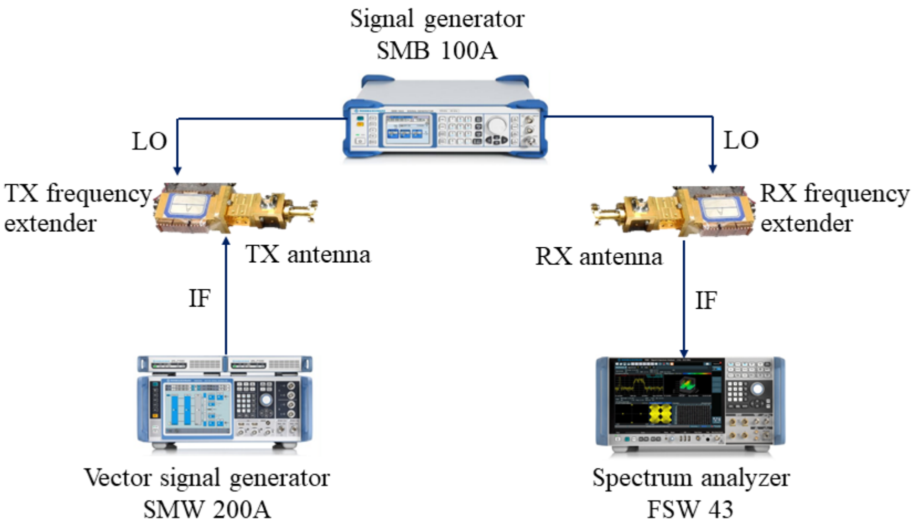
Motivation

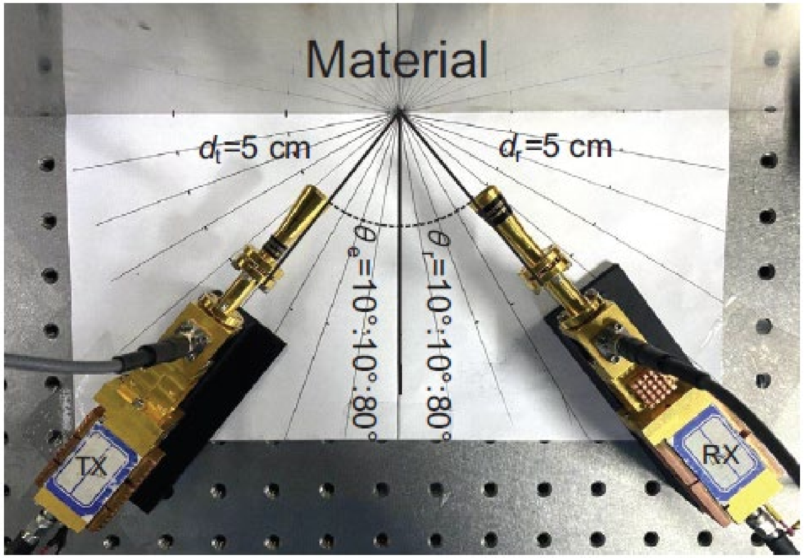
- THz channel propagation characteristics play an important role in the design, evaluation, and optimization of THz communication systems.
- Furthermore, due to the short wavelength at THz bands, the propagation mechanisms, i.e., reflection and diffraction, may change. Therefore, it is quite necessary to measure and model the reflection coefficients at THz bands.



1) THz reflection measurements

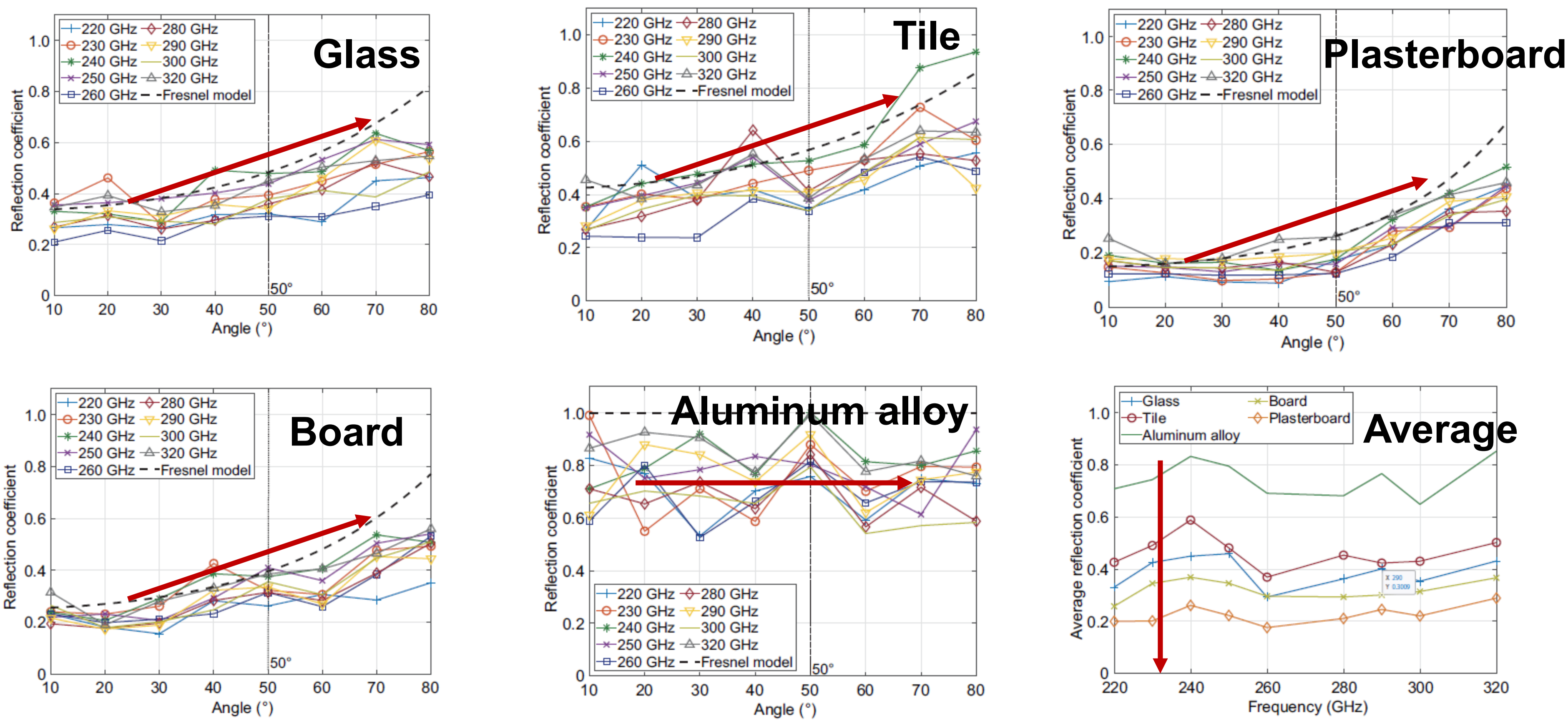
- The five building materials (i.e., glass, tile, board, plasterboard, and aluminum alloy) are fixed at the clamp successively with the transmitter (TX) and receiver (RX) antennas.
- The reflection coefficients of the vertically polarized signal are measured from 10° to 80° in a step of 10°.
- In addition, the measurement is performed from 220 to 320 GHz in a step of 10 GHz except 270 and 310 GHz.





2) THz reflection coefficient analysis

- The reflection coefficients and the growth rates of non-metallic materials increase with the increase of the incident angle. The reflection coefficients of metallic materials are stable at around 0.8.
- Aluminum alloy>tile>glass>board>plasterboard. The materials with larger complex dielectric constants can reflect more power.



3) THz reflection coefficient modeling

- Traditional reflection coefficient models are limited by unknown permittivity at THz. We propose a frequency–angle two-dimensional reflection coefficient model with small fitting deviation.

Frequency–angle reflection coefficient model: $\rho(f,\theta) =$

$$e^{-10^{a}f^{2}\cos^{2}\theta}\left(\frac{\cos\theta-\sqrt{1+\frac{10^{b}}{10^{c}-df^{2}-\mathrm{j}f}-\sin^{2}\theta}}{\cos\theta+\sqrt{1+\frac{10^{b}}{10^{c}-df^{2}-\mathrm{j}f}-\sin^{2}\theta}}\right) \qquad e^{-10^{a}f^{2}\cos^{2}\theta}\left(\frac{\cos\theta-\sqrt{1-\frac{10^{b}}{df^{2}+\mathrm{j}f}-\sin^{2}\theta}}{\cos\theta+\sqrt{1-\frac{10^{b}}{df^{2}+\mathrm{j}f}-\sin^{2}\theta}}\right)$$

with $\omega = 2\pi f$, a=lg($8\pi^2\sigma_h{}^2/c^2$), b=lg($\omega^2{}_p/(2\pi\gamma)$), c=lg($\omega^2{}_0/2\pi\gamma$), d=$2\pi/\gamma$

Fresnel model: $\rho_s = e^{-8\left(\frac{\pi\sigma_h\cos\theta}{\lambda}\right)^2}\left(\frac{\cos\theta-\sqrt{\boldsymbol{\varepsilon}-(\sin\theta)^2}}{\cos\theta+\sqrt{\boldsymbol{\varepsilon}-(\sin\theta)^2}}\right)$

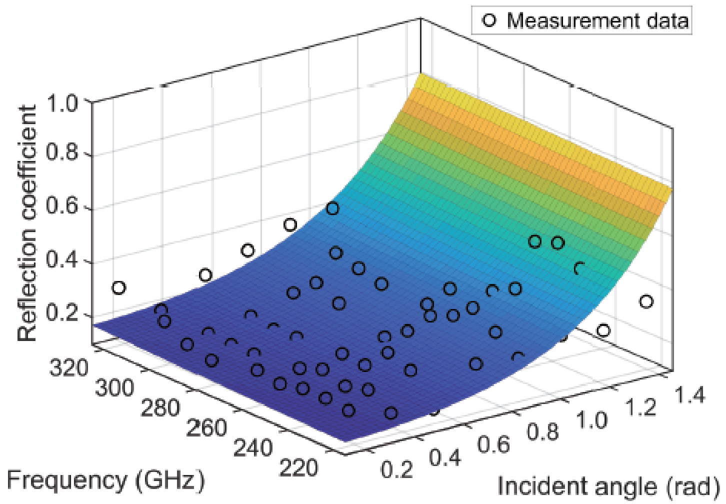
Substitute $\boldsymbol{\varepsilon}$

Lorenz model: $\boldsymbol{\varepsilon} = 1+\frac{\omega_p{}^2}{\omega_0{}^2-\omega^2-\mathrm{j}\gamma\omega}$ $\qquad \omega_p{}^2=\frac{Ne^2}{m\varepsilon_0}$ $\qquad$ Drude model: $\boldsymbol{\varepsilon} = 1-\frac{\omega_p{}^2}{\omega^2+\mathrm{j}\gamma\omega}$

ε: dielectric coefficient; N: number of electrons per unit volume; ε_0: permittivity of vacuum 8.85×10^{-12} F/m; e: unit positive charge 1.6×10^{-19} C; ω_0: the resonant frequency; m: the mass of an electron 9.3×10^{-31} kg; γ: damping constant; σ_h: the standard deviation of the surface roughness

3) THZ reflection coefficient modeling

- It is found that the FARC model fits the measurement results better than the Fresnel model at the dimension of angle.
- The points of measurement data fit well with the FARC model.



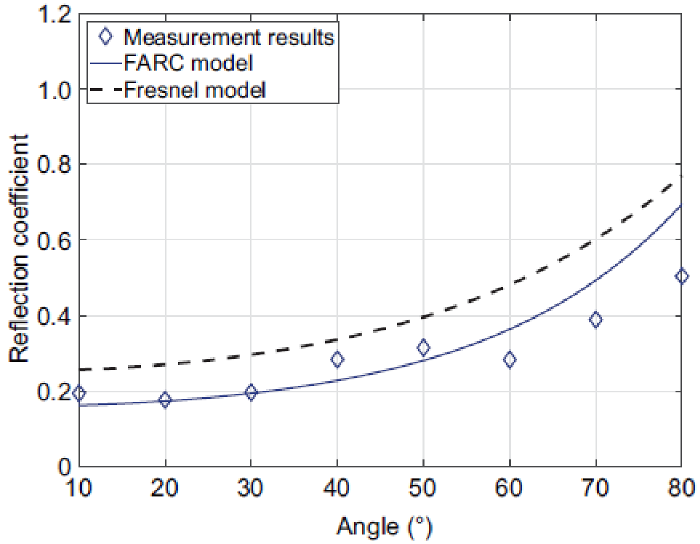


Table 2 Fitted parameters of five materials at nine frequency points

Material	a	b	c	d	RMSE
Glass	−15.45	3.93	3.97	0.06	0.11
Tile	−15.18	3.96	3.72	0.02	0.12
Board	−15.30	3.89	4.04	0.03	0.10
Plasterboard	−15.66	3.57	4.33	0.10	0.08
Aluminum alloy	−15.31	6.26	–	0.002	0.16

RMSE: root-mean-square error

Conclusions

- In general, the analysis and modeling of reflection coefficients of building materials in terahertz band are studied.
  - Based on an extensive measurement campaign from 220 to 320 GHz, the reflection coefficients of five building materials are obtained.
  - By comparing with the Fresnel model, the relationships between reflection coefficient and frequency, incidence angle and material are studied.
  - An FARC reflection coefficient model was proposed based on the Fresnel, Lorenz, and Drude models.
  - By fitting all the measured data with the FARC statistical model, the reflection coefficients of the five materials in continuous large band were obtained.
- Generally, this work is helpful in understanding THz channel propagation mechanisms and in simulating THz channels.

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