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

Submission Title: [Through wall propagation up to 60 GHz band]
Date Submitted: [12 August, 2006]

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Re: [Millimeter wave systems]

Abstract: [A study, validated by measurements at 60 GHz, shows that signals transmitted through a typical wall are attenuated dramatically above about 8 to 12 GHz, essentially confining the useful radiation and its multipath reflections to a single room.]

Purpose: [This is informative propagation study for 802.15.3c]

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Through wall propagation below 12 GHz and up to the 60 GHz band

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A study, validated by measurements at 60 GHz, shows that signals transmitted through a typical wall are attenuated dramatically above about 8 to 12 GHz, essentially confining the useful radiation and its multipath reflections to a single room.

Propagation vs. Frequency

- Reliable communication requires
  – That multipath delay spread be sufficiently limited
  – That sufficient signal margin be available for the link
- Wall transmission is attenuated significantly above 8-12 GHz when moisture content or wall materials is a factor thus
  – Multipath is confined to a single room above about 8-12 GHz
  – Long delayed multipath components (involving paths beyond one room) are significantly attenuated above 8-12 GHz

Model for the Study

- A detailed wall model reveals a “breakpoint” in wall attenuation near 8-12 GHz
- A room propagation model based on a ray-tracing model* shows that reflections involving paths outside the room can be important below 8 GHz, but are suppressed above 8-12 GHz
- Thus long multipath delays are suppressed as frequency increases, especially above the 8-12 GHz range

*Ref: IEEE P802.15.4a document 15-04-0505-04-004a

Signal Attenuation Through Walls

- Typical room separator wall comprises a parallel pair of gypsum wall board of 5/8 inch thickness and 4 inch gap between the wall boards, see Figure 1
- The analysis used in this study is validated by the measured data* at 60 GHz, normal incidence, *very* dry wall (F_w=1%)
- Typical wall is 2.5-5% moisture content and incidence angle is typically about 45 deg
- As noted above and shown in Fig 2 below reliable communications in a room in the presence of a typical walls requires a frequency above about 8-12 GHz

*Ref: IEEE P802.15.4a document 15-04-0094-00

Through Wall Transmission

- Transmission through walls is calculated using the well known ABCD Matrix method
- Planar reflection coefficients employed (valid for smooth surfaces)
- Wall parameters from measurements
- Water content added to wall materials

Transmission through wallboard wall with F_w% moisture

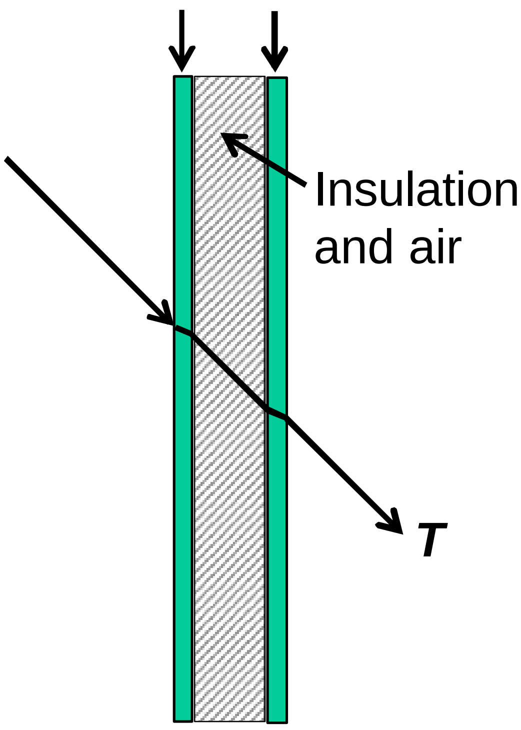


Figure 1

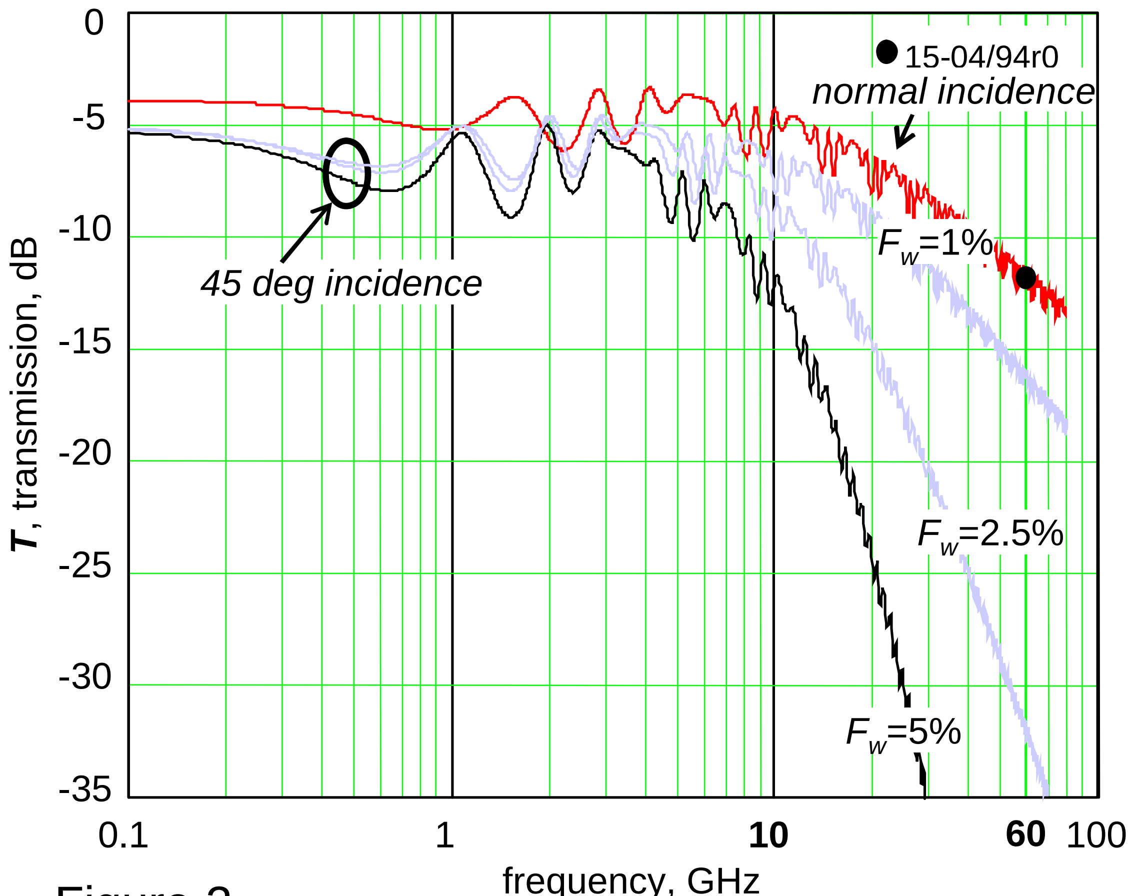


Figure 2

Average Behavior

- Slight alterations in the exact thickness of the wallboard, or wallboard spacing in Figure 1 will change locations of the fine structure of the peaks and valley of the curves in Figure 2
- An average curve can be drawn, Figure 3, through the oscillations to reveal an underlying behavior as a function of frequency

Average Transmission through a typical wallboard wall

The average transmission curves show that above 8-12 GHz the signals effectively are confined to a single room because wall attenuation increases significantly as frequency is increased, thus confining multipath to a single room requires operation at frequencies above about 8-12 GHz

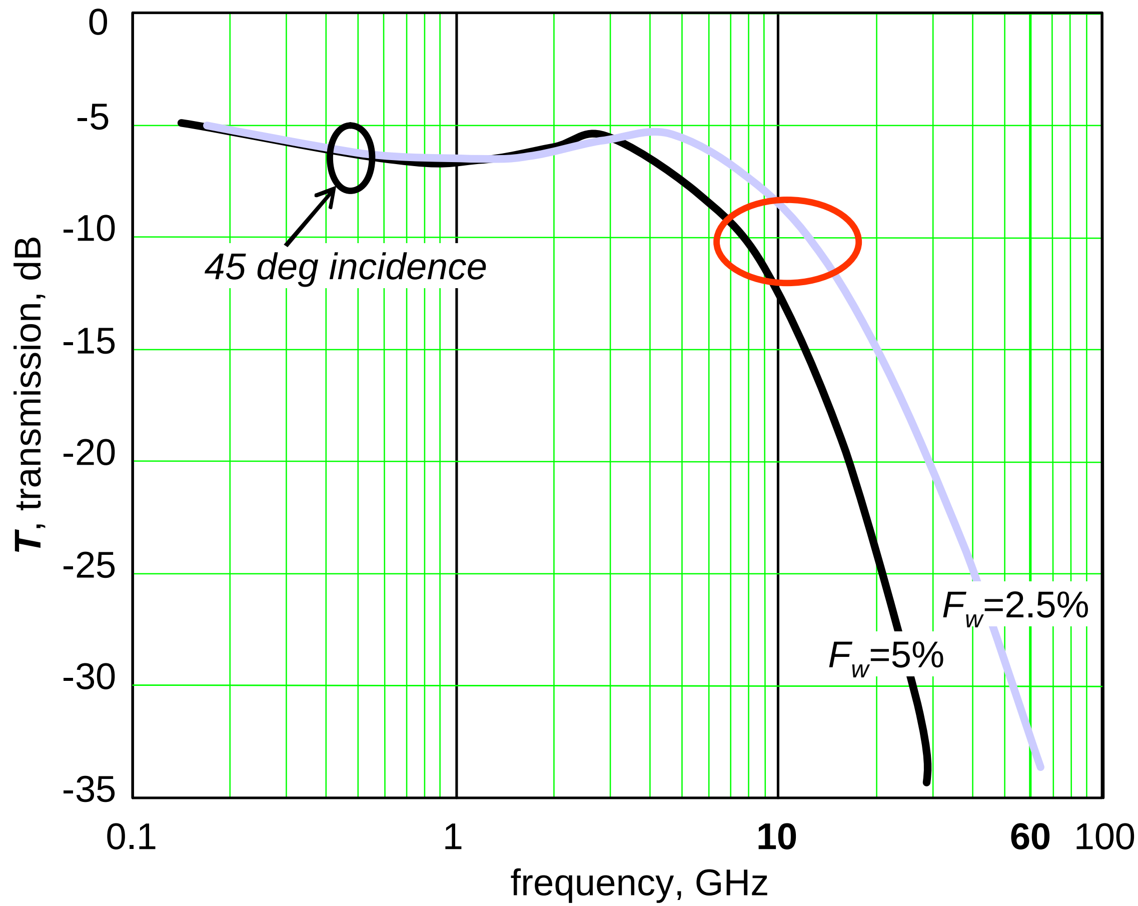


Figure 3

Average Transmission Behavior

- It becomes readily apparent: there is a dramatic increase in wall transmission losses (more negative decibel values) as frequency increases above about 8-12 GHz
- The effect becomes more pronounced as moisture content of the gypsum wall board increases from F_w= 2.5 % (moderate) to 5% (high)
- Effectively, wall attenuation confines the multipath to within a single room at frequencies above about 8-12 GHz, thus providing reliable communication

Paths between a Transmitter and Receiver in a Room

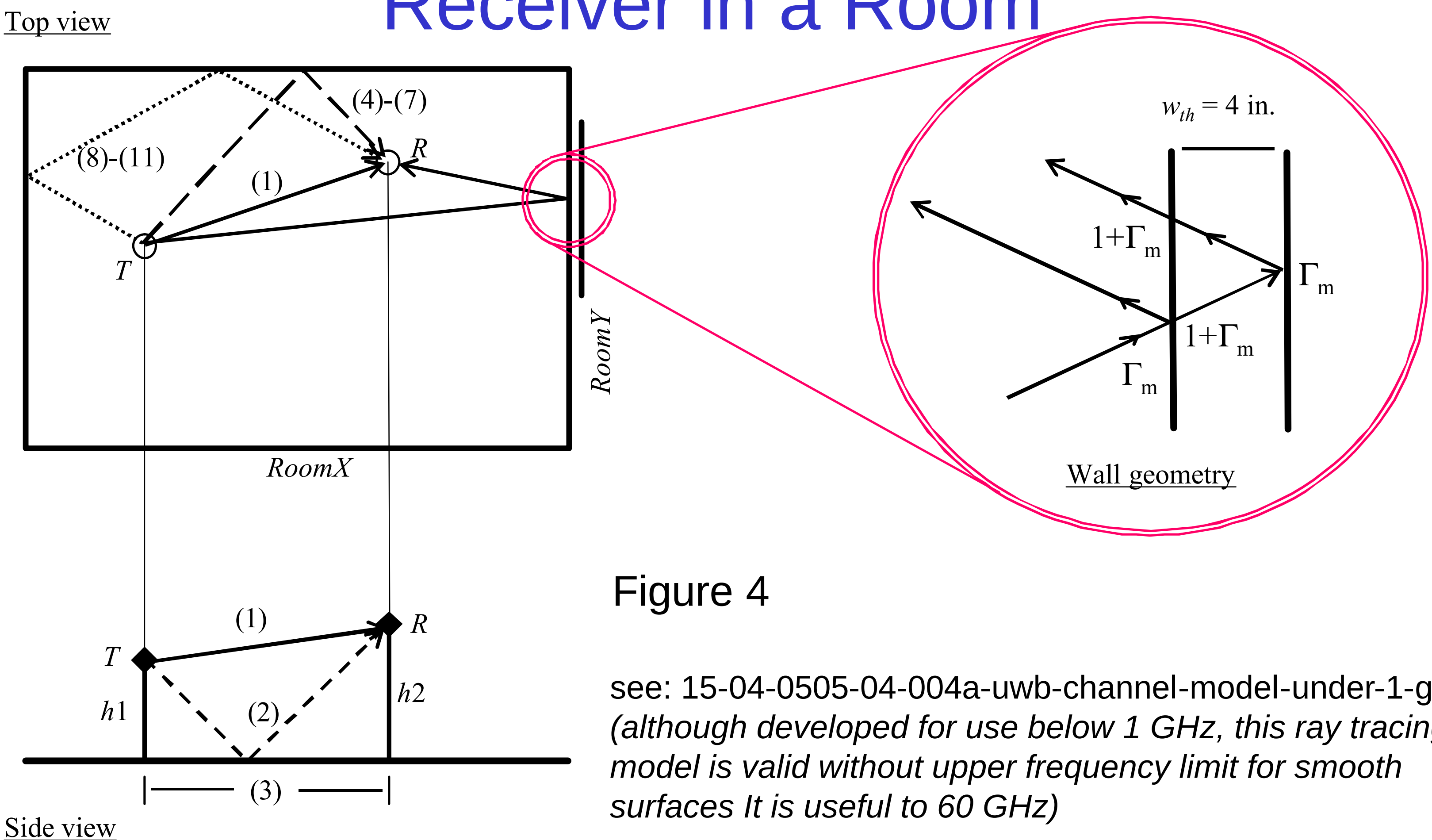
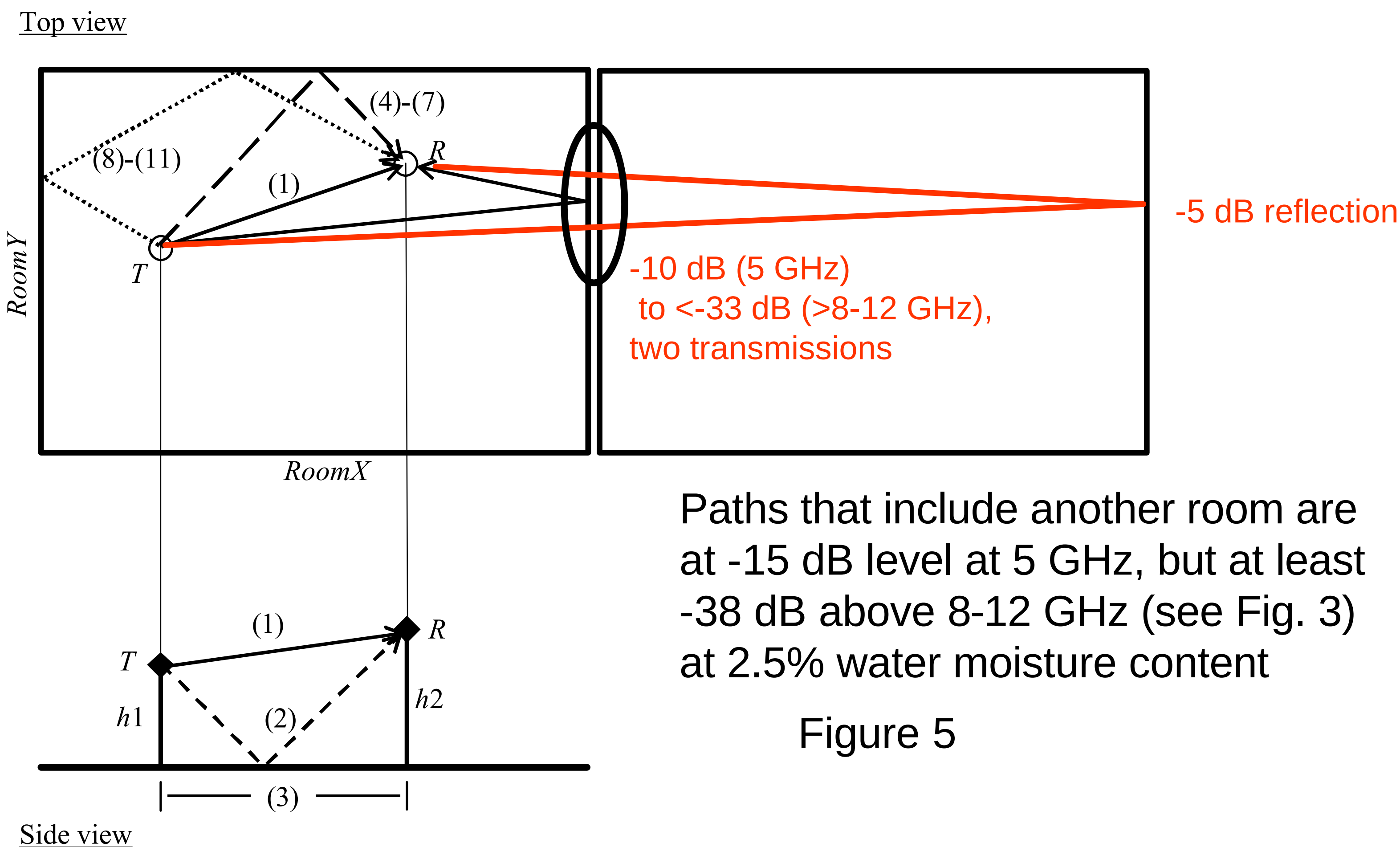


Figure 4

see: 15-04-0505-04-004a-uwb-channel-model-under-1-ghz.zip
(although developed for use below 1 GHz, this ray tracing model is valid without upper frequency limit for smooth surfaces It is useful to 60 GHz)

Paths Including Another Room



Paths that include another room are at -15 dB level at 5 GHz, but at least -38 dB above 8-12 GHz (see Fig. 3) at 2.5% water moisture content

Figure 5

Two Room Propagation Model

- Room dimensions are: *RoomX* and *RoomY*
- Multipath derived from a direct and 13 primary reflections:
  - 4 principal reflections from the walls (-5 dB)
  - 1 ground reflection (-7 dB)
  - 4 principal corner reflections (-10 dB)
  - 4 secondary reflections from walls (-21 dB)
- *Strongest reflection involving another room is:*
  - *-15 dB at 5-6 GHz [comparable to some in-room reflections]*
  - *-38 dB at and above 8-12 GHz [well below in-room reflection levels]*
  - Propagation and multipath above 8-12 GHz is essentially confined to a single room
  - Paths below 6-8 GHz can include significant multipath from reflections beyond a single room
- Room model: see: 15-04-0505-04-004a

One Realization: In-room Multipath

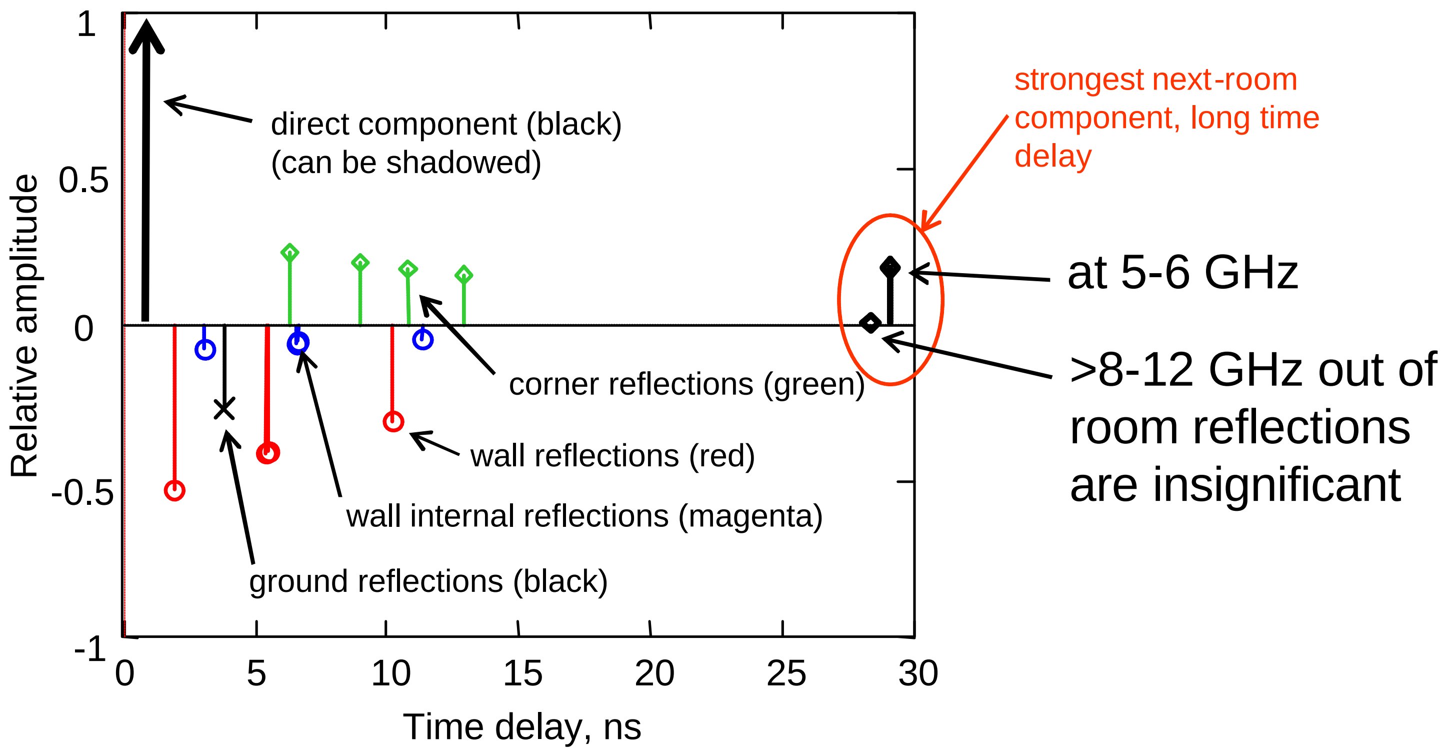
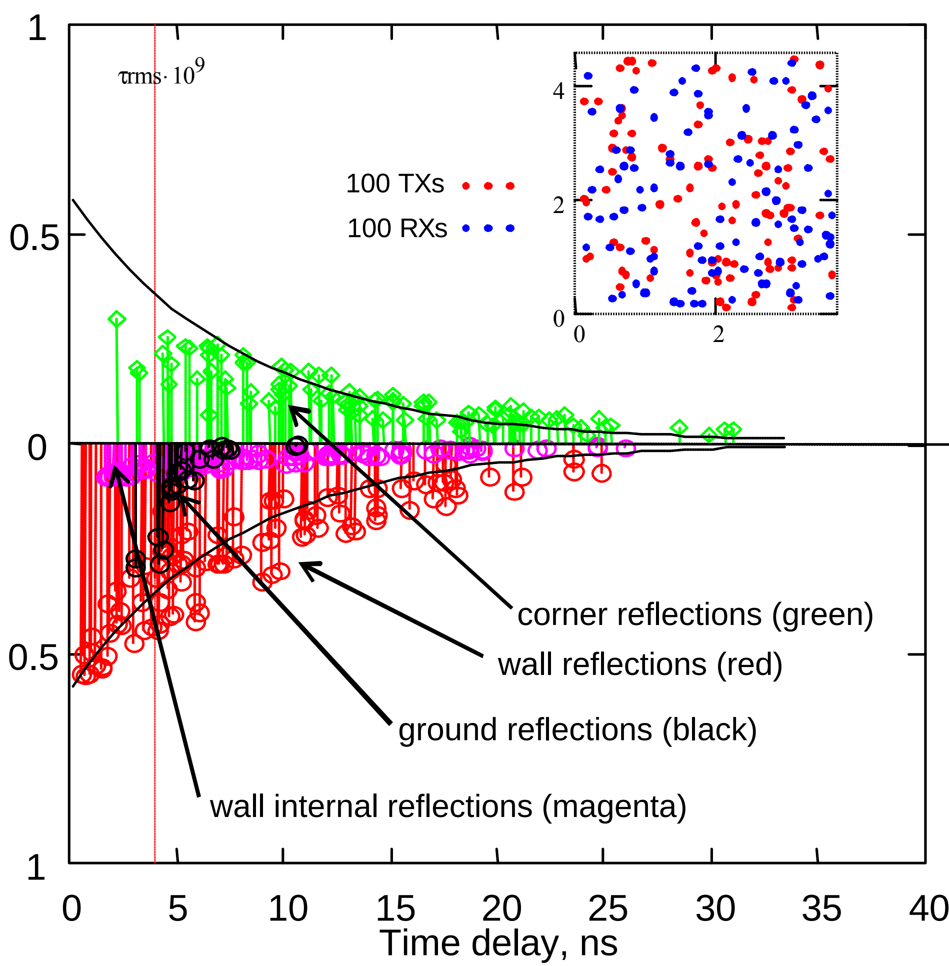
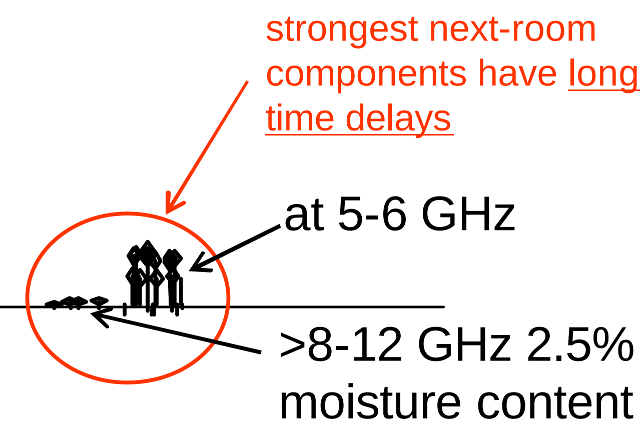


Figure 6

ref: 15-04-0505-04-004a

100 Realizations of paths within one Room





Multipath from outside a room is significant below 8 GHz (5-6 GHz), but small and insignificant above 8-12 GHz

Figure 7

Summary

- Through the wall transmission decreases dramatically above about 8-12 GHz with increase in water content of wall materials
- Multipath below 8 GHz can involve significant components with long delays due to reflections beyond the immediate room
- *Multipath at frequencies above about 8-12 GHz is essentially confined to the single room; and long delayed multipath is suppressed significantly*