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

Submission Title: [Data transmission at 2.5 Gb/s with THz and IR Signals through Fog]
Date Submitted: [8 November, 2011]
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Abstract: [We demonstrate weather impact on THz and IR links]

Purpose: [Invited presentation given at meeting]

Data transmission at 2.5 Gb/s with THz and IR Signals through Fog

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IEEE 802, November 8, 2011

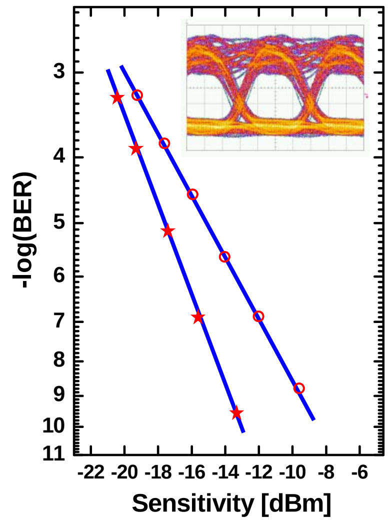
Talk Outline

- Setup for 2.5 Gb/s @ 625 GHz signaling
- 2.5 Gb/s IR link design
- Fog generation and characterization
- Studying fog impact on THz/IR links
- Conclusions

Three main industrial appl's for THz technology

ALU focuses on THz communications as fast growing research area with big potential for commercial applications

Ultra wideband free space communications



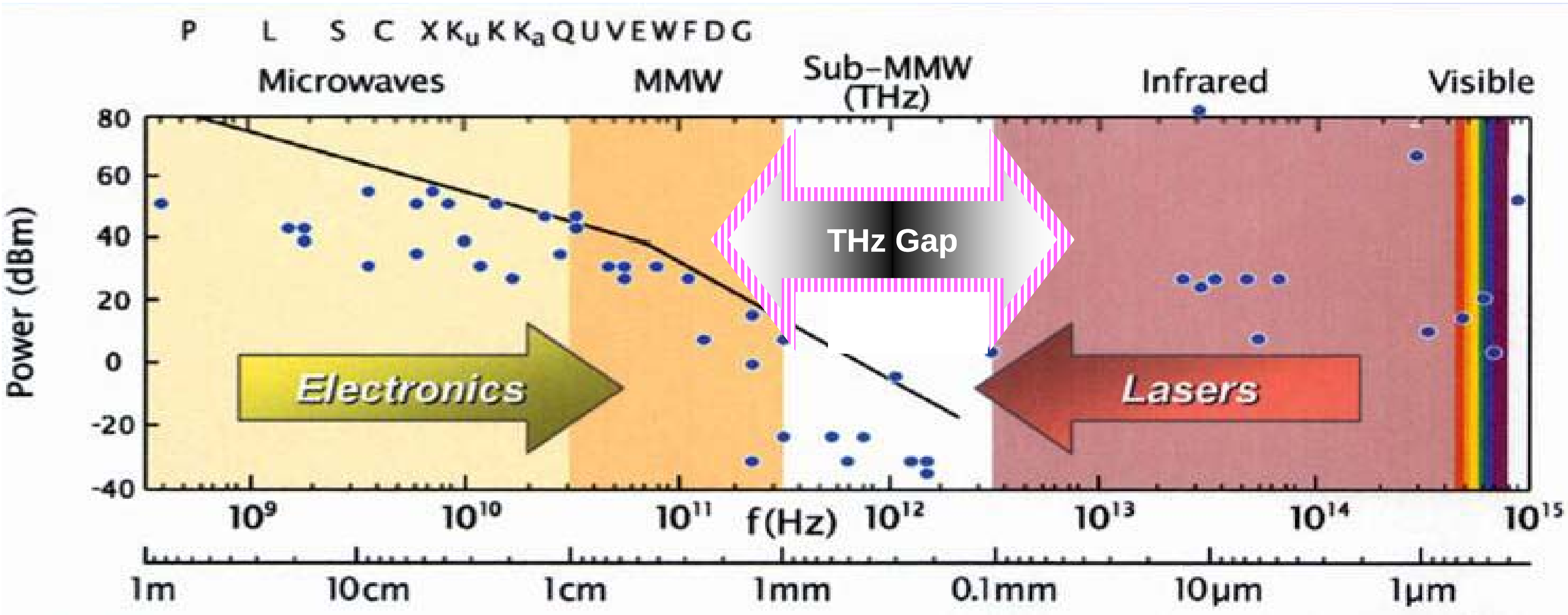
Non Destructive Evaluation

Imaging and Spectroscopy

Security Scanning

Detecting concealed weapons

THz Communication demonstrated with electrical and optoelectronic signal processing



- Fully electronic approaches can have cost and SWAP advantages.
  - Optoelectronic setup allows to cover full THz spectral range.

THz Communications in Future:

Modulation, detection and applications of ultra-high speed wireless data signals on THz carriers

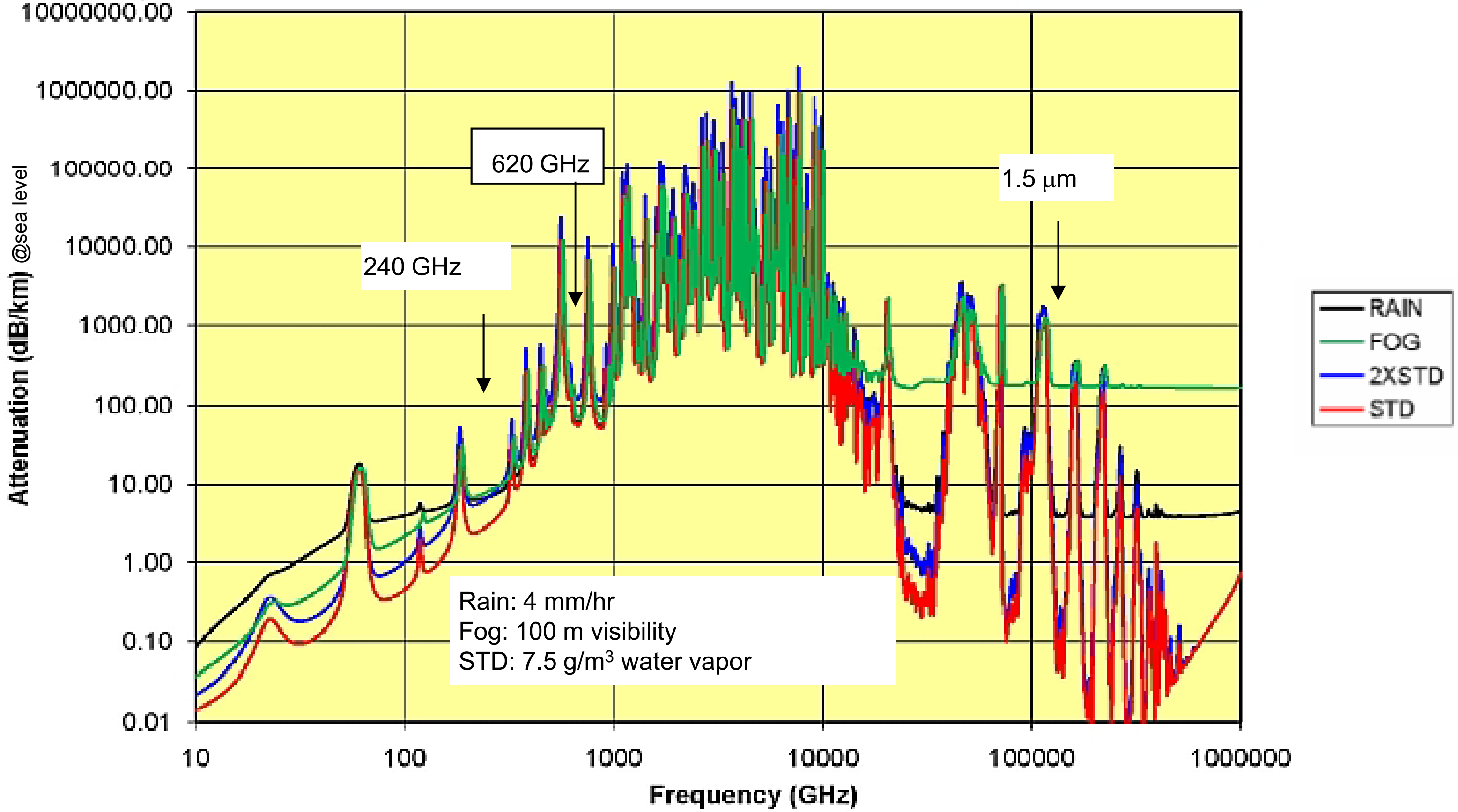
$f_{carrier} > 100$ GHz & $R \leq 100$ Gb/s

- Reliable communication under different weather conditions.
- Secure signaling (technology advantage), high directivity.
- Potential for ultra-high capacity links.
- Regulations for THz frequency bands need to be established.

J. Federici, L. Moeller, “Review of terahertz and sub-terahertz wireless communications,” J. of Applied Physics, 2010.

Simulated THz beams outperform IR links in fog

Current research focus on experimental studies of weather impact on THz and IR links

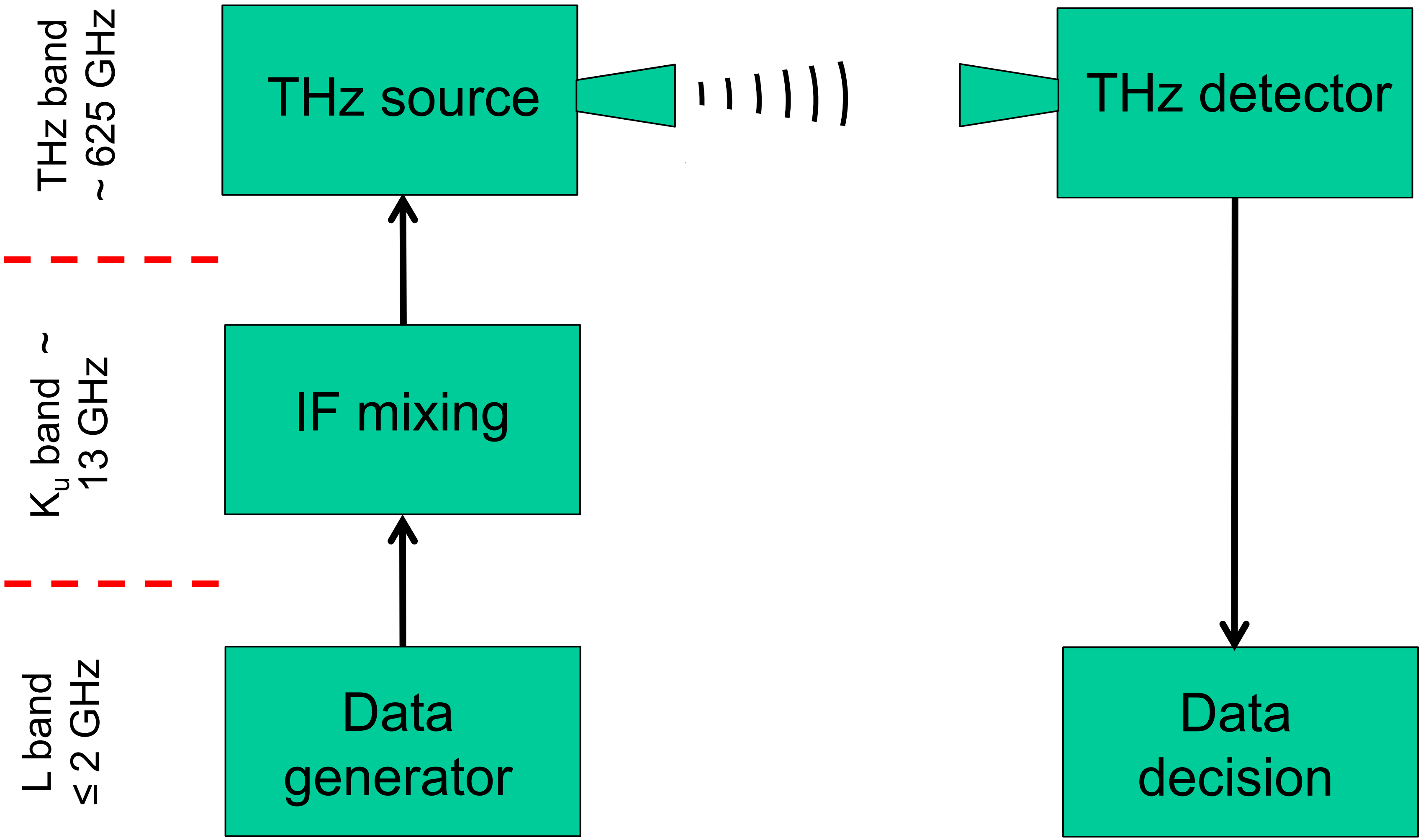


Simulated attenuation in foggy air (www.mmwconcept.com): T-rays @ 240 GHz ~8dB/km, IR ~200dB/km

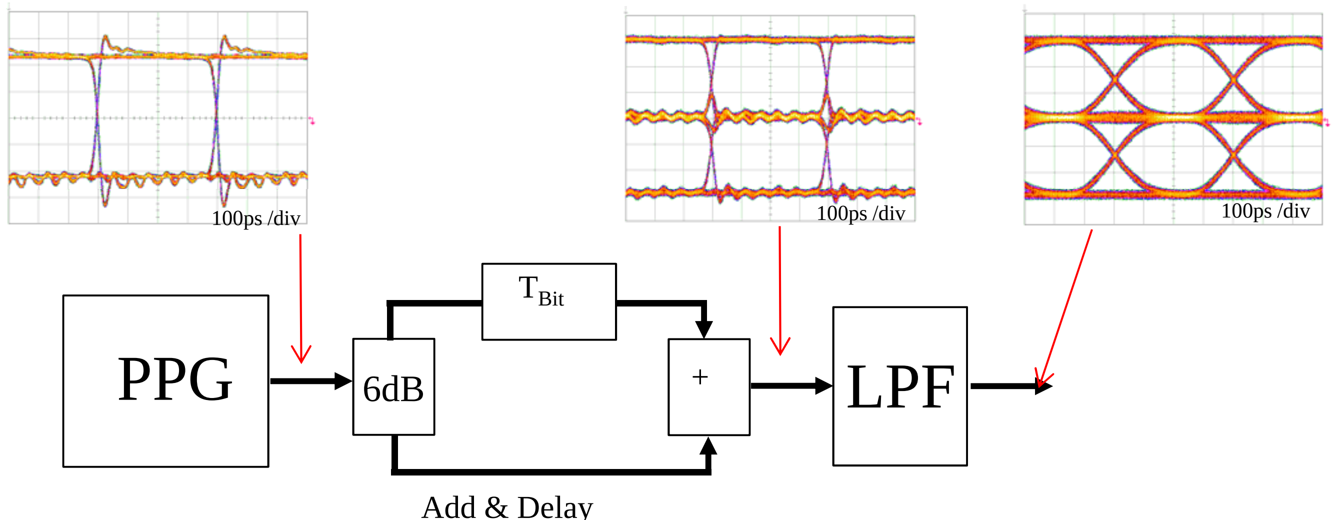
Experimental setup

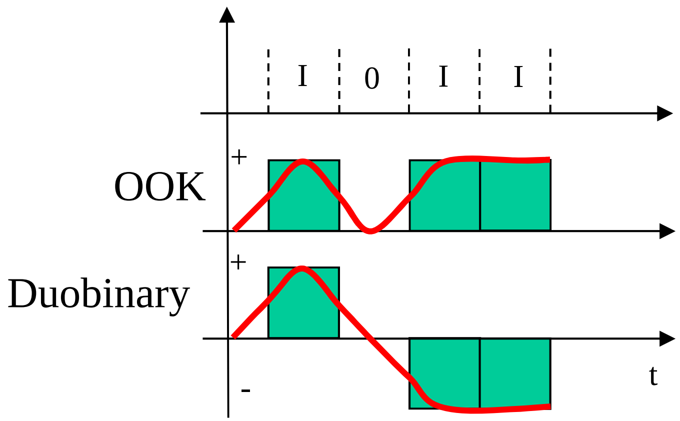
Part I: THz Communication Link

Frequency bands of 2.5 Gb/s @ 625 GHz experiment

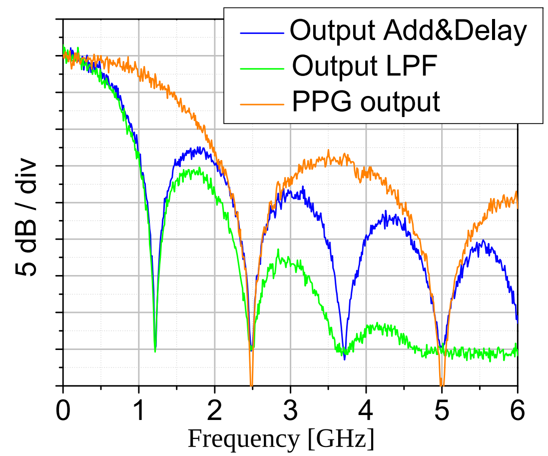


Generating narrow bandwidth 2.5 Gb/s baseband signal using Duobinary coding



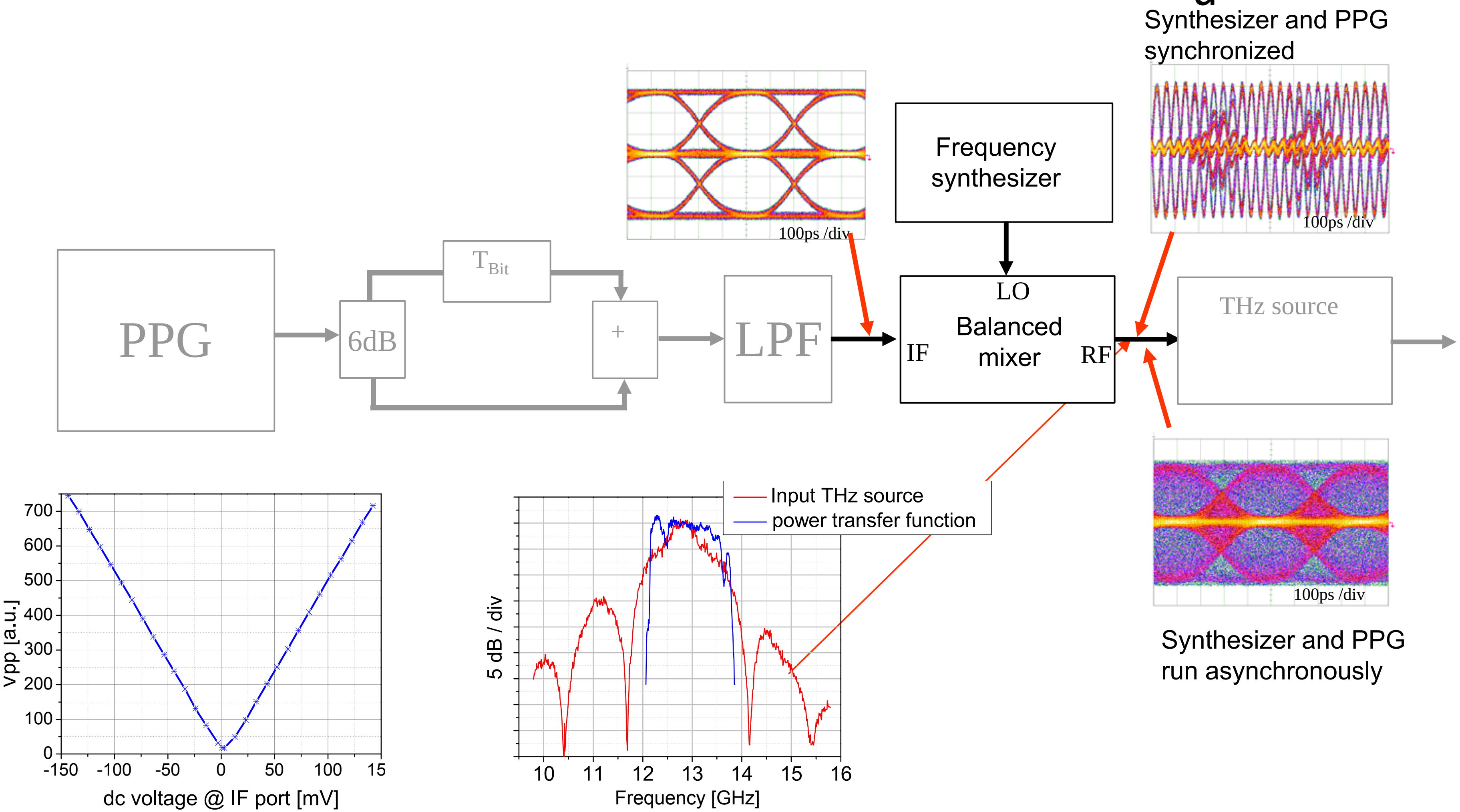


Phase coding for bandwidth reduction



Spectra of baseband signals

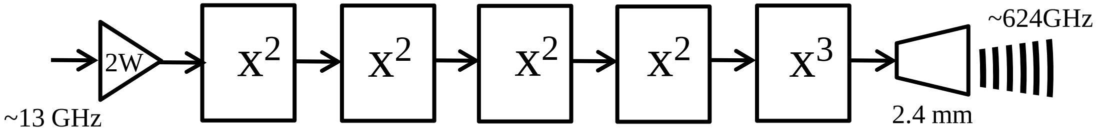
Up-converting baseband signal into K_u band

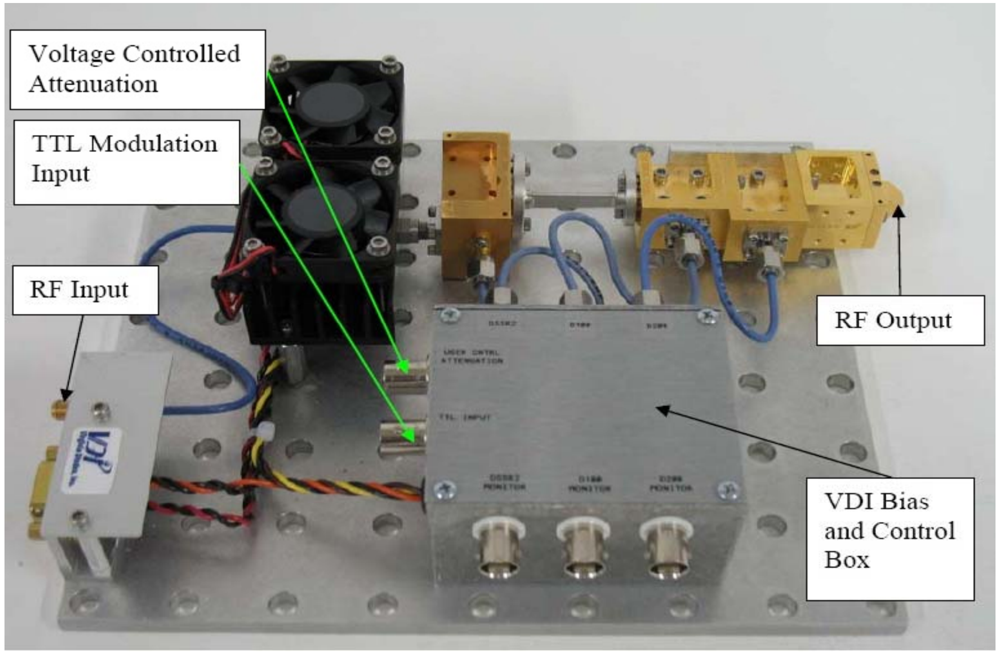


DC mixer characteristic
Small signal leaking @ 0V

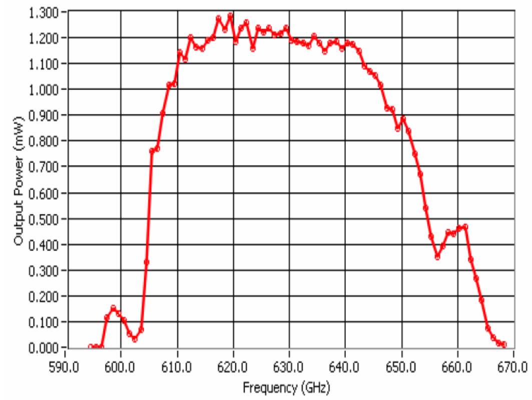
RF spectrum at RF output of mixer

Frequency multiplier chain based 1 mW THz source

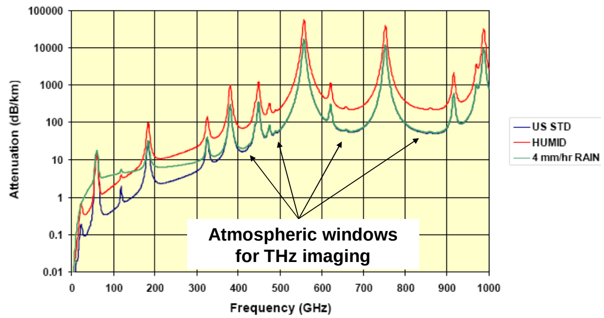




THz source from Virginia Diodes, Inc.
Four doublers and one trippler up-convert a 13 GHz input tone to a 624 GHz output beam.

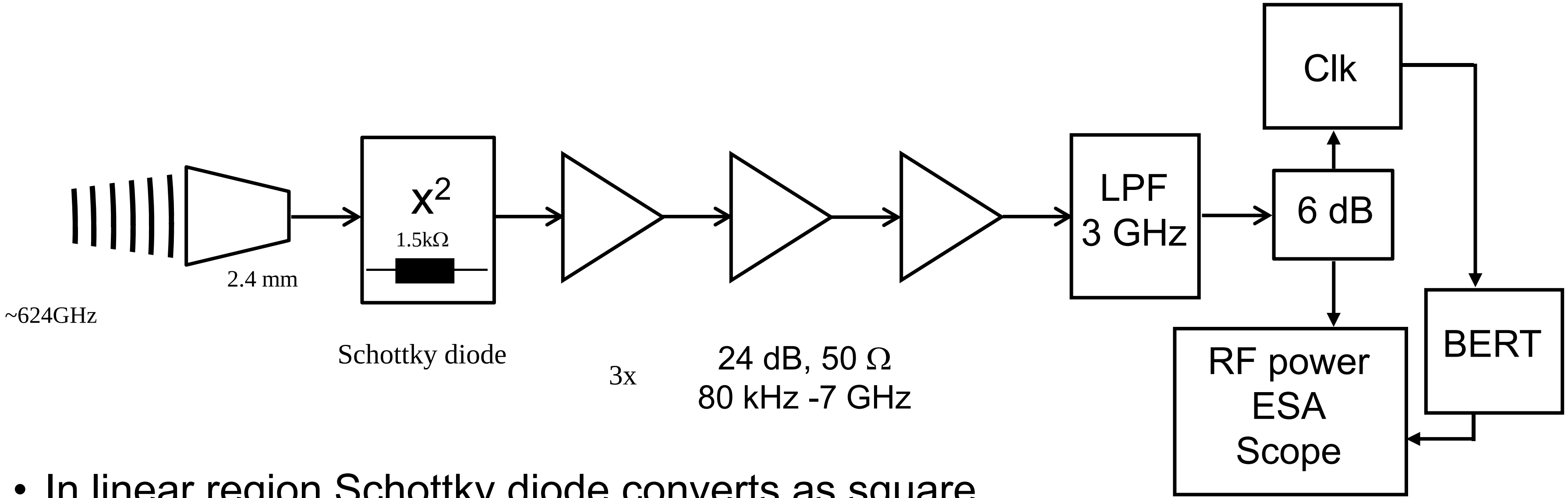


50 GHz source tuning range.

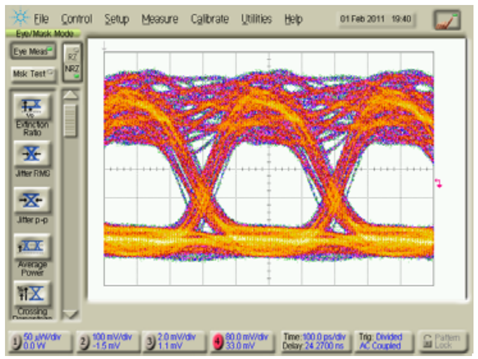


Simulated atmospheric attenuation.

Zero-biased Schottky diode based 2.5 Gb/s receiver

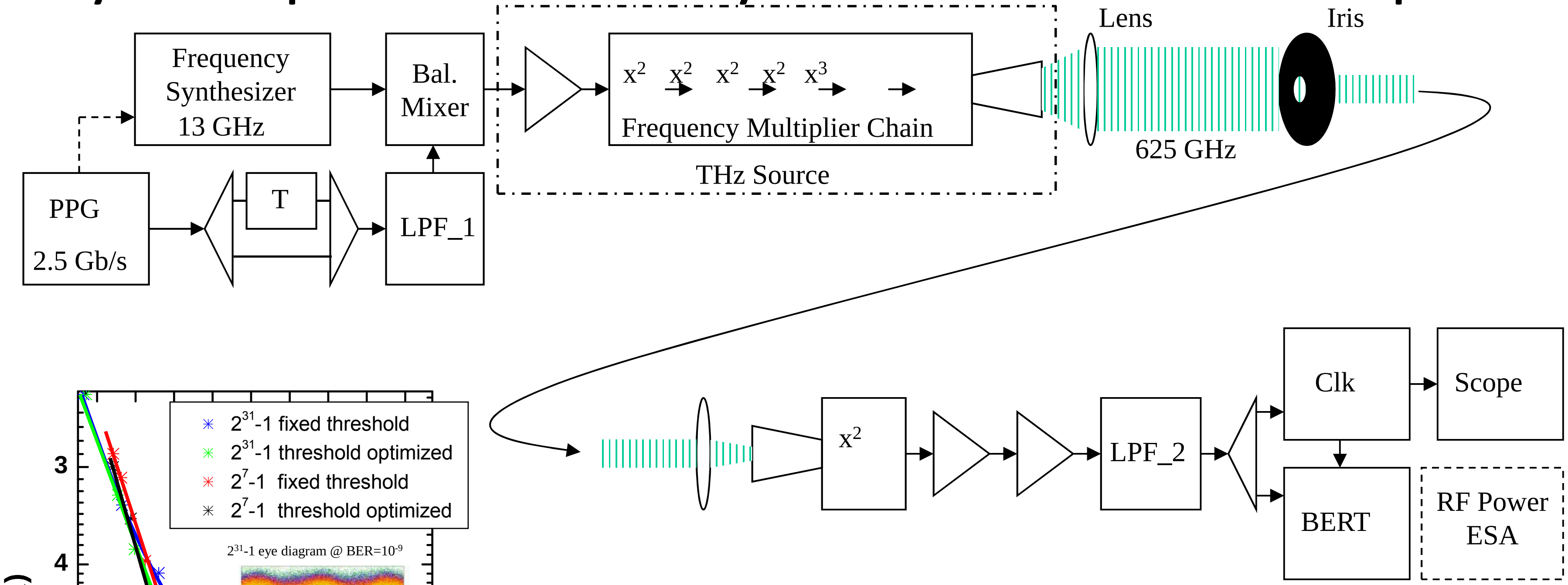


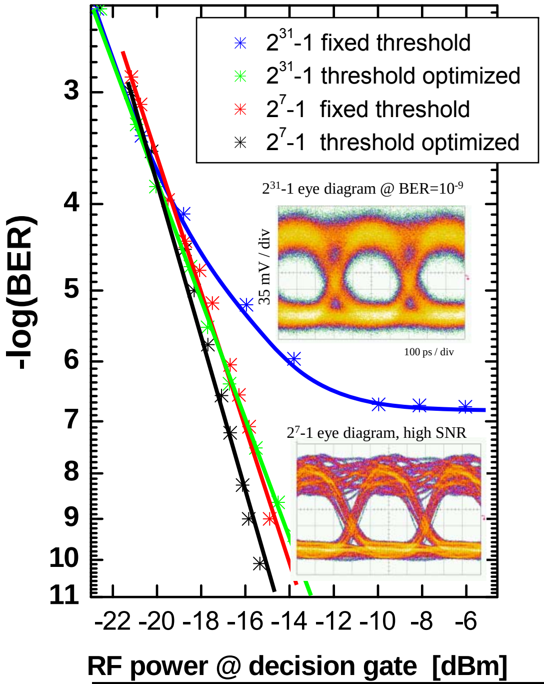
- In linear region Schottky diode converts as square law detector converting THz signal into baseband.
- Un-modulated THz beam generates about 70 mW output voltage.
- ~ -30 dB voltage coupling loss into 50 Ω amplifiers (video impedance of Schottky diode ~1.5 kΩ)
- Large receiver sensitivity improvement expected after impedance matching using amplifier with high input impedance.

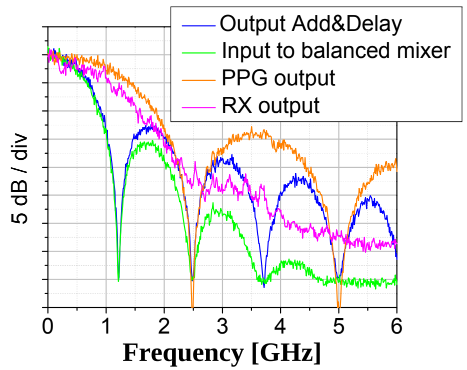


Received eye diagram at high SNR and short PRBS

System performance by BER vs. detected RF power







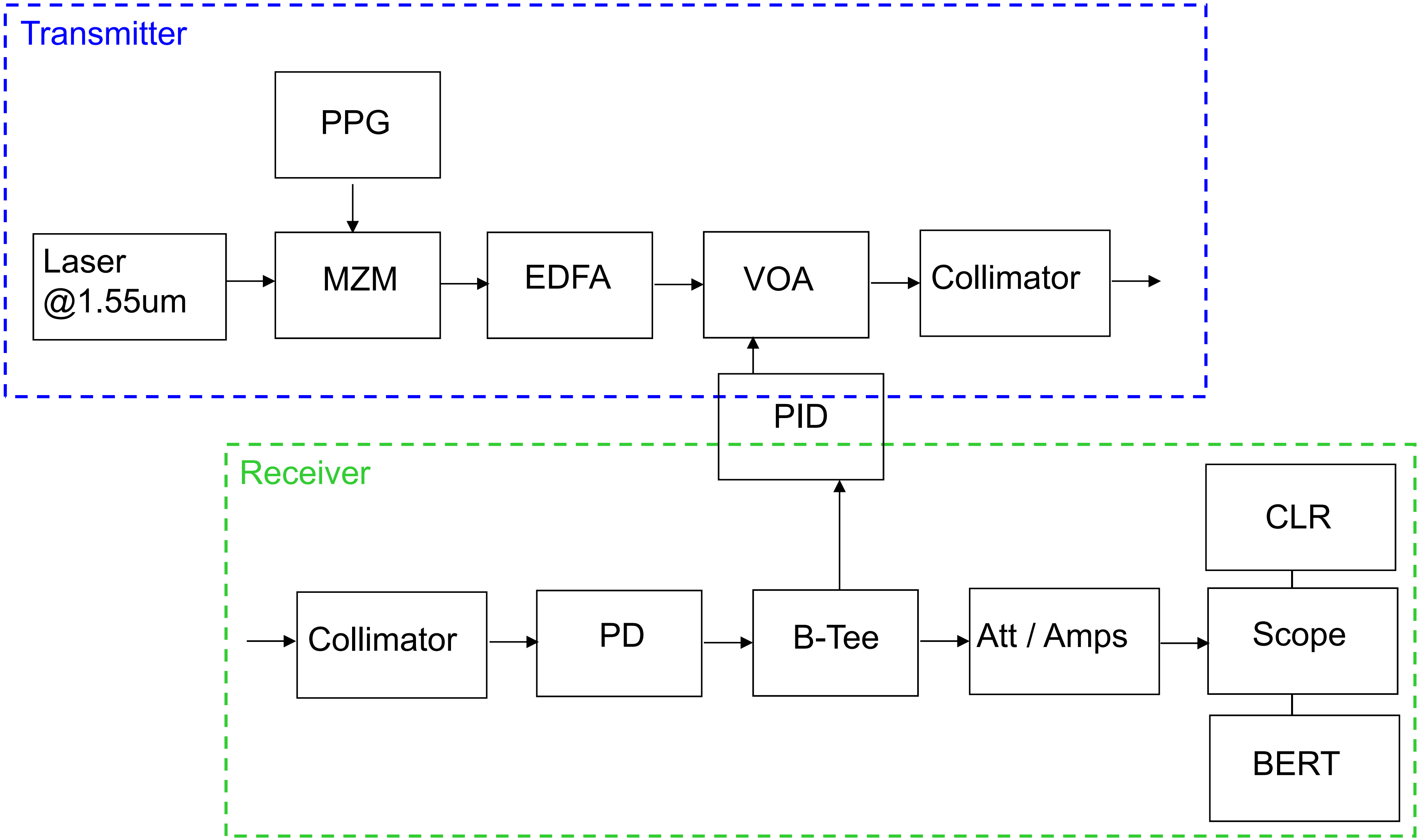
Baseband signal spectra

- 2.5 Gb/s error-free transmission over lab distance
- BER depends on PRBS and received power
- NRZ baseband signal at RX output
- Iris adjusts received power

Experimental setup

Part II: IR Communication Link

2.5 Gb/s IR Communication link

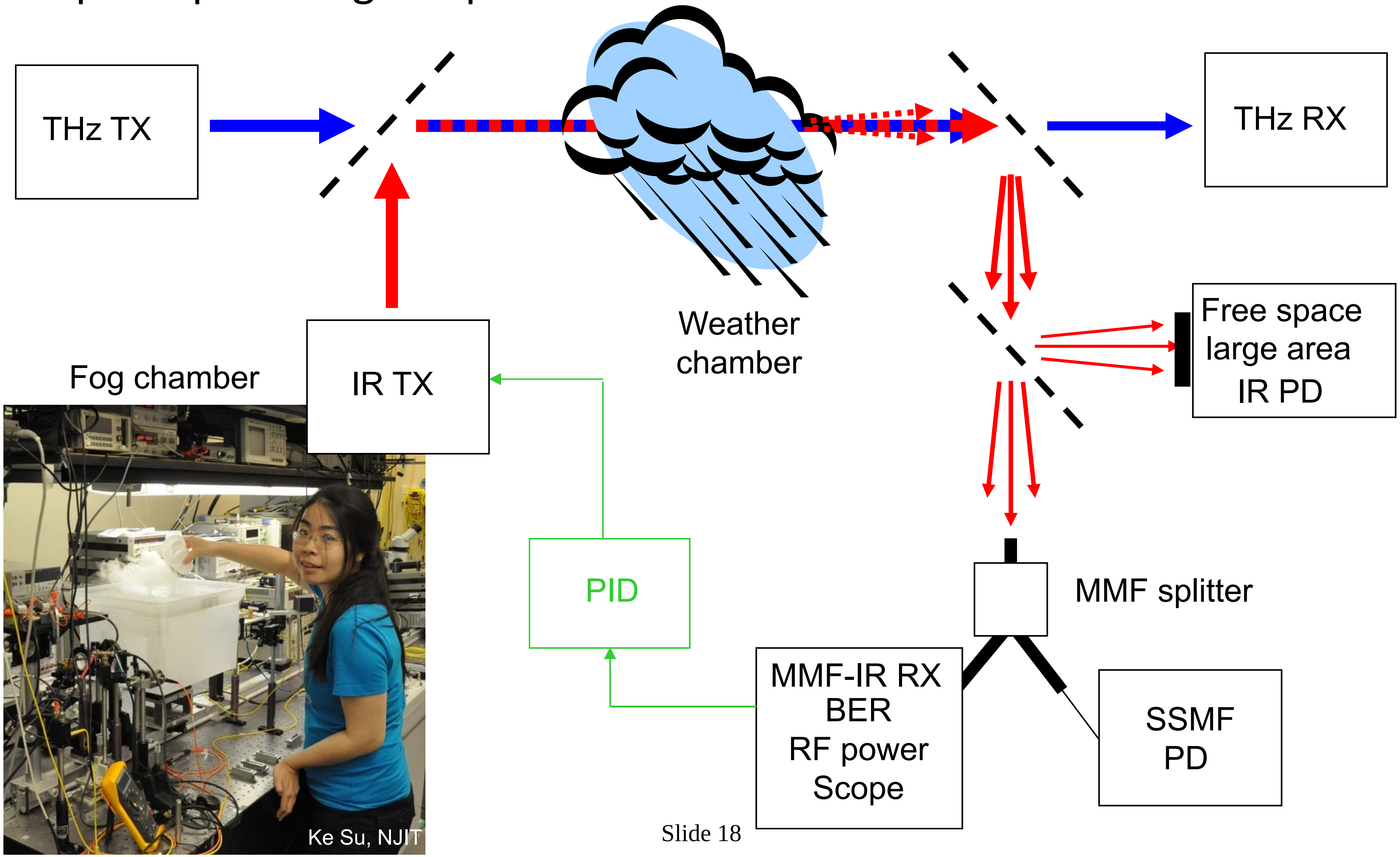


Experimental setup

Part III: Fog emulating chamber

Comparing weather impact on 2.5 Gb/s THz & IR links

Superimposed signals pass same local refraction index variations



Natural and artificial fog appearance

Fog

Collection of suspended water droplet or ice crystals near the earth's surface reducing horizontal visibility < 1km.

Atmospheric Visibility

defined as a distance where collimated light at 550 nm wavelength is attenuated to 5% or (2%) of original power.

Types of Fog	Drop Size	Water Content	Formation
Advection fog	20µm	>0.20g/m3	Coastal fog
Radiation fog	4µm	0.01-01 g/m3	Inland

Artificial fog

generated by dripping liquid Nitrogen into a cup filled with hot water (~80 ºC).
Measured average particle diameter ~8µm.

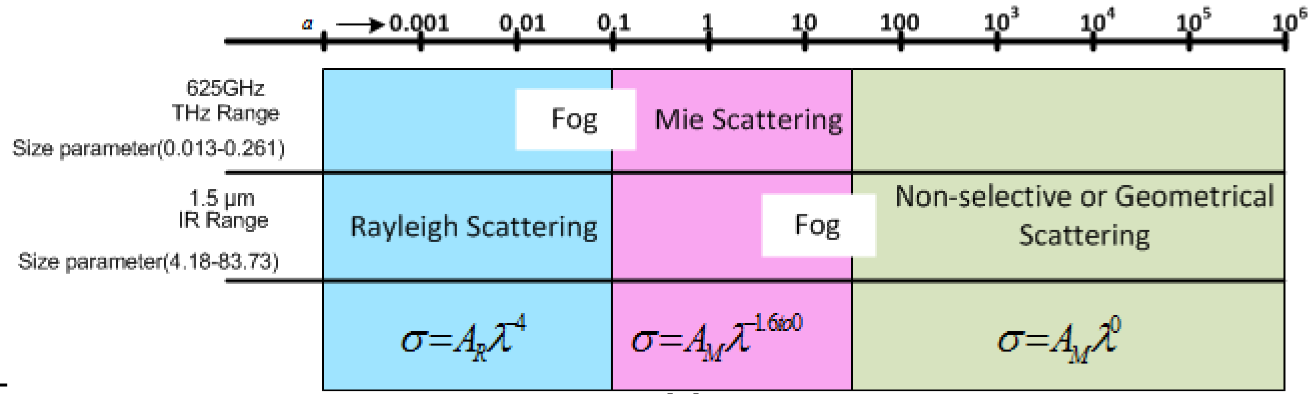
Particle size / wavelength ratio determines dominant type of scattering

Scattering	Size parameter	Description
Rayleigh Scattering	$a << 1$	Particle size is much smaller than the wavelength
Mie Scattering	(0.1 ~50) $a \approx 1$	Particle size is comparable in size to the wavelength
Nonselective scattering (Geometric Scattering)	$a >> 1$	Particle size is much larger than the wavelength

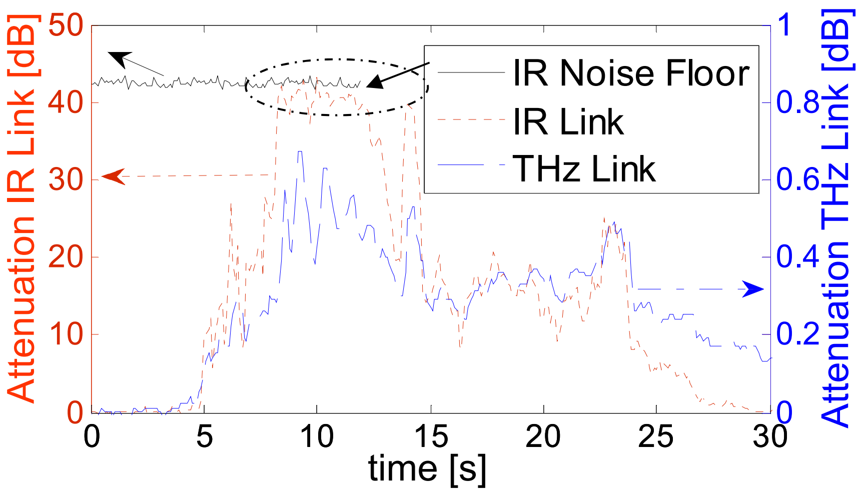
$$a = \frac{2\pi r}{\lambda}$$

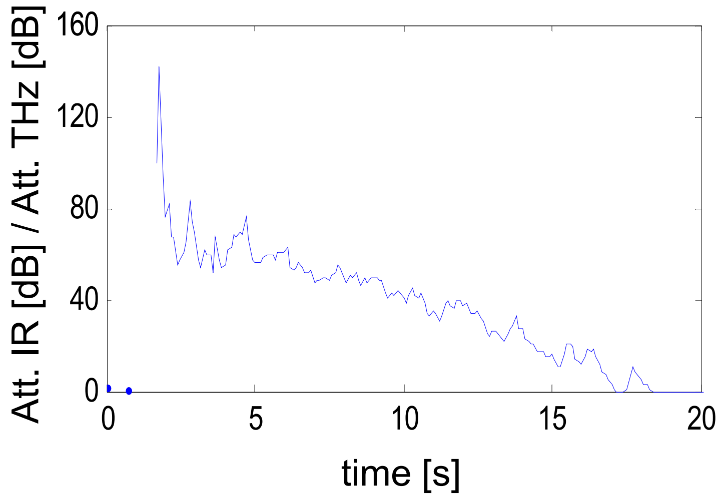
r = radius of the particle
λ = wavelength of radiation

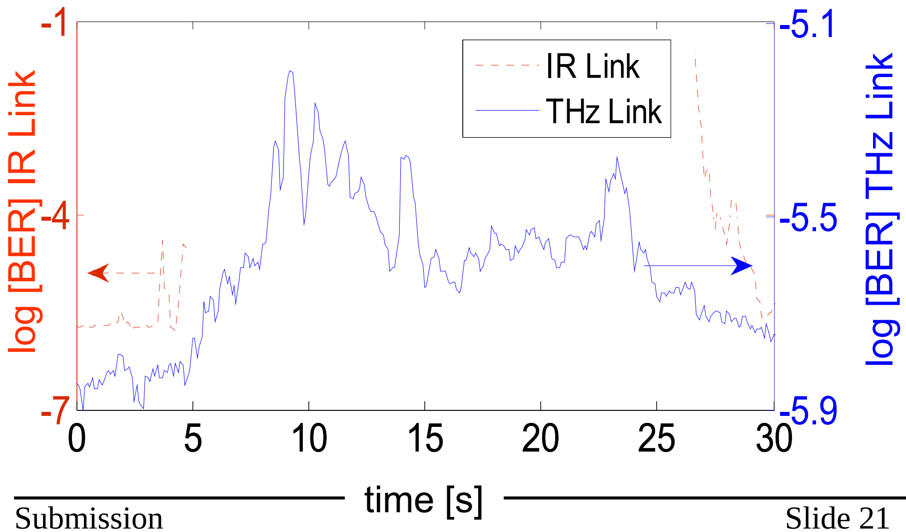
Scattering at 625 GHz and 1.5 um (IR) with fog particle sizes (1-20 μm)



Attenuation and BERs for THz & IR links







- Fog attenuates IR much stronger than THz.
- Attenuation is not proportional to fog density.
- Fog is likely converted into humidity impacting THz link.

Kim model* for estimating visibility in fog chamber

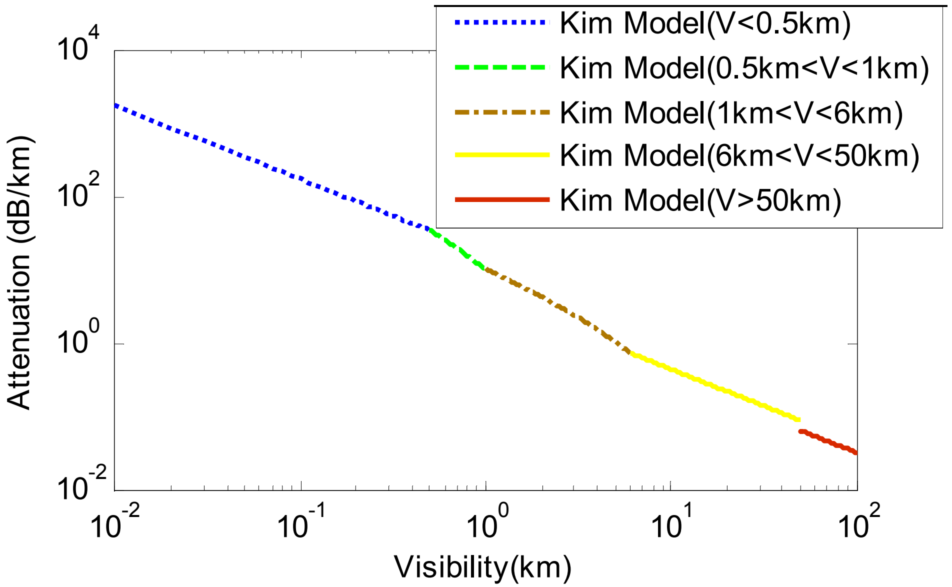
Attenuation coefficient approximated by:

$$\gamma(\lambda) = \frac{3.912}{V}\left(\frac{\lambda}{550}\right)^{-q}$$

V: visibilty
q: fct of particle size distribution

$$q = \begin{cases} 1.6 & V > 50km \\ 1.3 & 6km < V < 50km \\ 0 & V < 500m \\ V - 0.5 & 500m < V < 1km \\ 0.16V + 0.34 & 1km < V < 6km \end{cases}$$

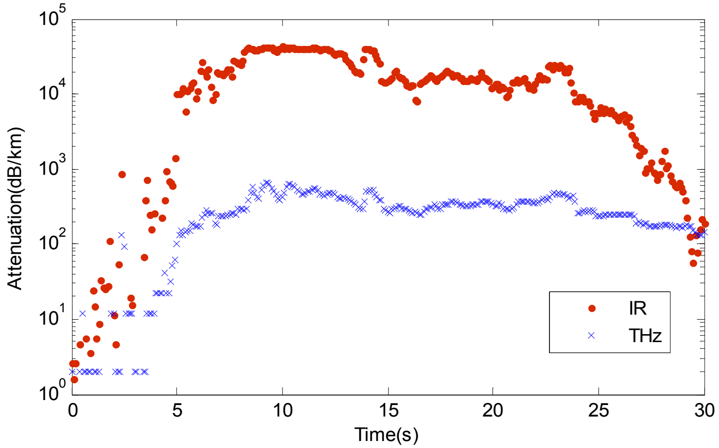
relation between q and V.



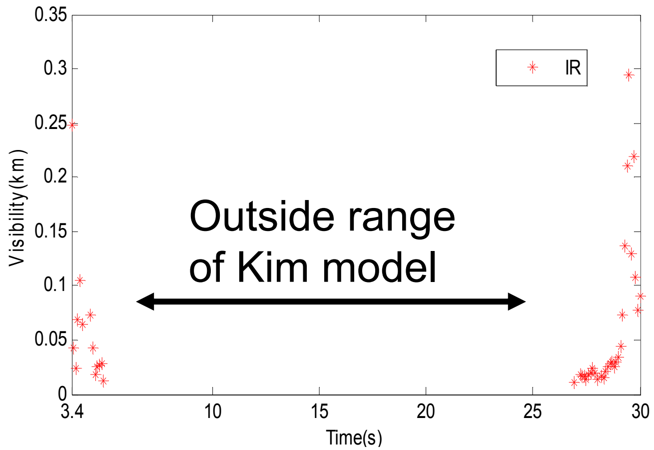
$$a_{spec}(dB/km) = \frac{10}{\ln(10)}\gamma(\lambda)$$

*Kim, I., B. McArthur, and E. Korevaar. "Comparison of laser beam propagation at 785 and 1550 nm in fog and haze for opt. wireless communications." in Proc. SPIE 2001.

Fog density specified by visibility



Specific attenuation of THz link and IR link over time



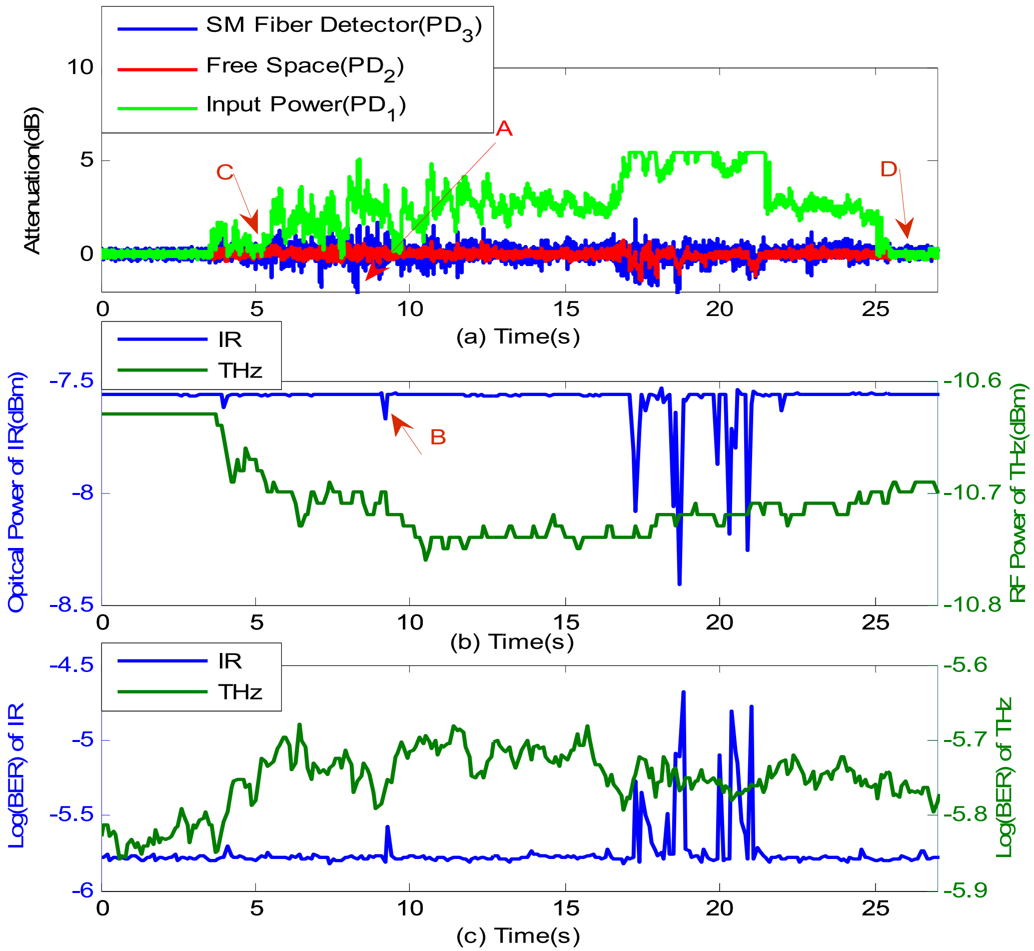
Visibility over time simulated by Kim model

Visibility (m)	Water Density (g/m³)	Experimental Specific Attenuation (dB/km)	Theoretical Specific Attenuation (dB/km)
300	0.05	2	1.40
50	0.5	14	12
10	1	28	22

Comparison of THz experimental and theoretical specific attenuation at different visibilities using Double-Debye model*

* H.J. Liebe et al.,"A model for the complex permittivity of water at frequencies below 1THz," Int. J. of Infrared and Millimeter Waves, Vol.12, No. 7,1991.

Scintillation effects in Fog chamber impact IR link



Scintillation Effects

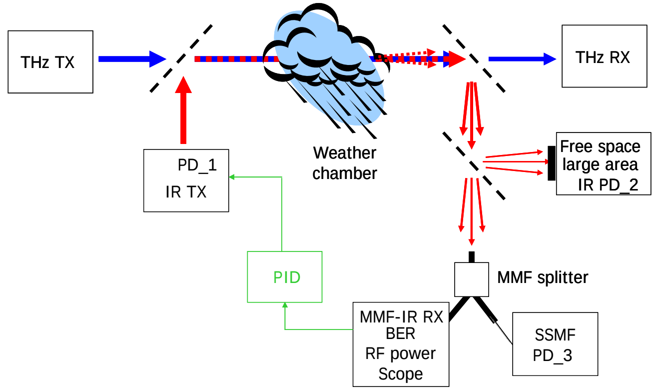
Pointer A:
Fluctuations PD_1 >> PD_2 & RX power const.

Humidity impact

Pointers C and D:
IR attenuation ~ 0 & attenuation THz ~ 0.1dB
-> Conversion of fog into humidity

Unstable operation of PID loop

Pointer B:
small kinks indicate fast changing attenuation than controller bandwidth



Conclusions

- THz signaling can have propagation advantages under fog conditions compared to IR links.
- Demonstration of error-free 2.5 Gb/s (SDH 16) transmission over lab distance at 625 GHz using a 1mW THz source.
- Duodinary modulation yields compact baseband spectrum thin enough to fit through the resonance of THz source.
- Developed setup that allows studying THz and IR links propagating at the same time the same fog cloud.
- Fog degrades THz link much less than IR link – error free operation possible when IR link has collapsed.
- Scintillation effects in IR link observed.