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

Submission Title: 30-Gbps-class terahertz transmission using optical sub-harmonic IQ mixer for backhaul/fronthaul directly connected to optical networks

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Abstract: 30-Gbit/s-capacity transmission using multi-level modulation at 300 GHz are briefly presented as information for future 100-Gbit/s terahertz point to point link.

Purpose: Informing 802.15SG100G on coherent communication technologies for fixed point-to-point link

30-Gbps-class terahertz transmission using optical sub-harmonic IQ mixer for backhaul/fronthaul directly connected to optical networks

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Abstract

- Introduction of realization of multi-level-modulated 300-GHz signal transmission technique by optical technology.
  - Broad bandwidth optical modulator with bandwidth > 40 GHz.
- Optical sub-harmonic quadrature mixer (sub-harmonic IQ mixer) is configured with conventional and advanced optical fiber communication components.
- The technique is capable of the terahertz backhaul/fronthaul directly connected to broadband optical networks.

Bandwidth Issues on Tx and Rx Devices

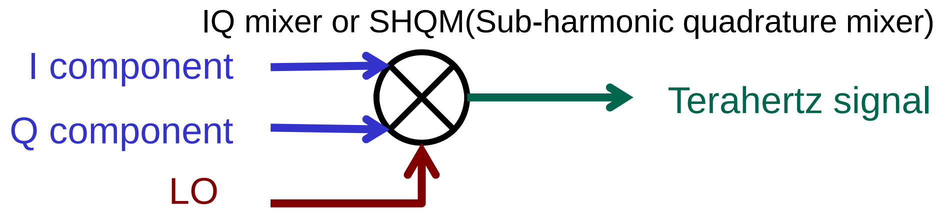
- Available bandwidth of conventional RF devices:
  - Fractional bandwidth (FBW) of electrical amplifier and IQ mixer: ~ 10-15%

    e.g. At 300 GHz, BW will be approximately **30-45 GHz**.
  - For example, bandwidth of 30 and 45 GHz at 300-GHz carrier meets 22.5-Gbaud and 31-Gbaud QPSK with rectangular pulse shape because identical and empirical required bandwidths for modulation are a half and 70% of available bandwidth, respectively.
- Realization of 40-Gbps and 100-Gbps capacity requires higher-order multi-level modulation such as quadrature phase-shift keying (QPSK) and quadrature amplitude modulation (QAM).

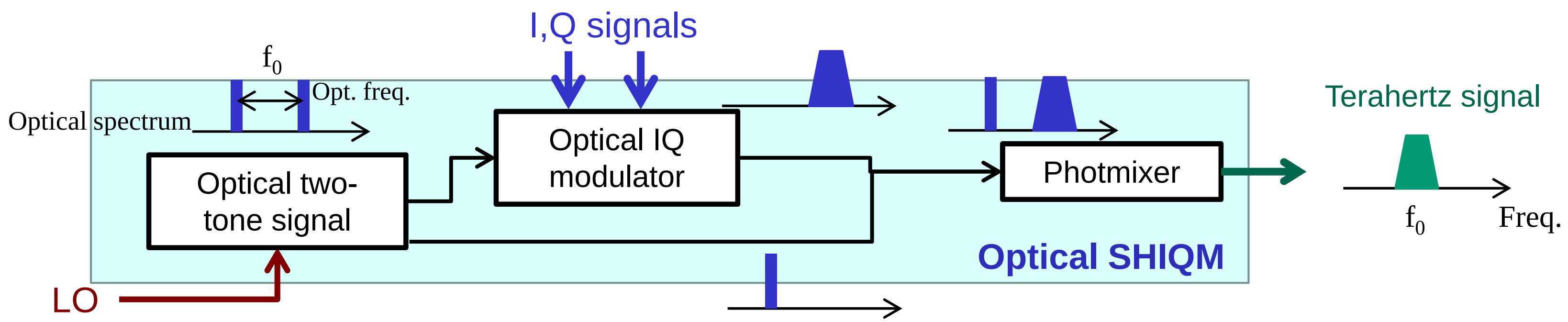
	OOK	QPSK	16 QAM	64 QAM
22 Gbaud	22 Gbps	44 Gbps	88 Gbps	132 Gbps
31 Gbaud	31 Gbps	62 Gbps	124 Gbps	186 Gbps

How to Generate Multi-level Signal

- Using electrical IQ modulator/sub-harmonic quadrature mixer
  - Pros.: Robustness, small footprint
  - Cons.: Narrow bandwidth (30~40GHz at 300GHz)



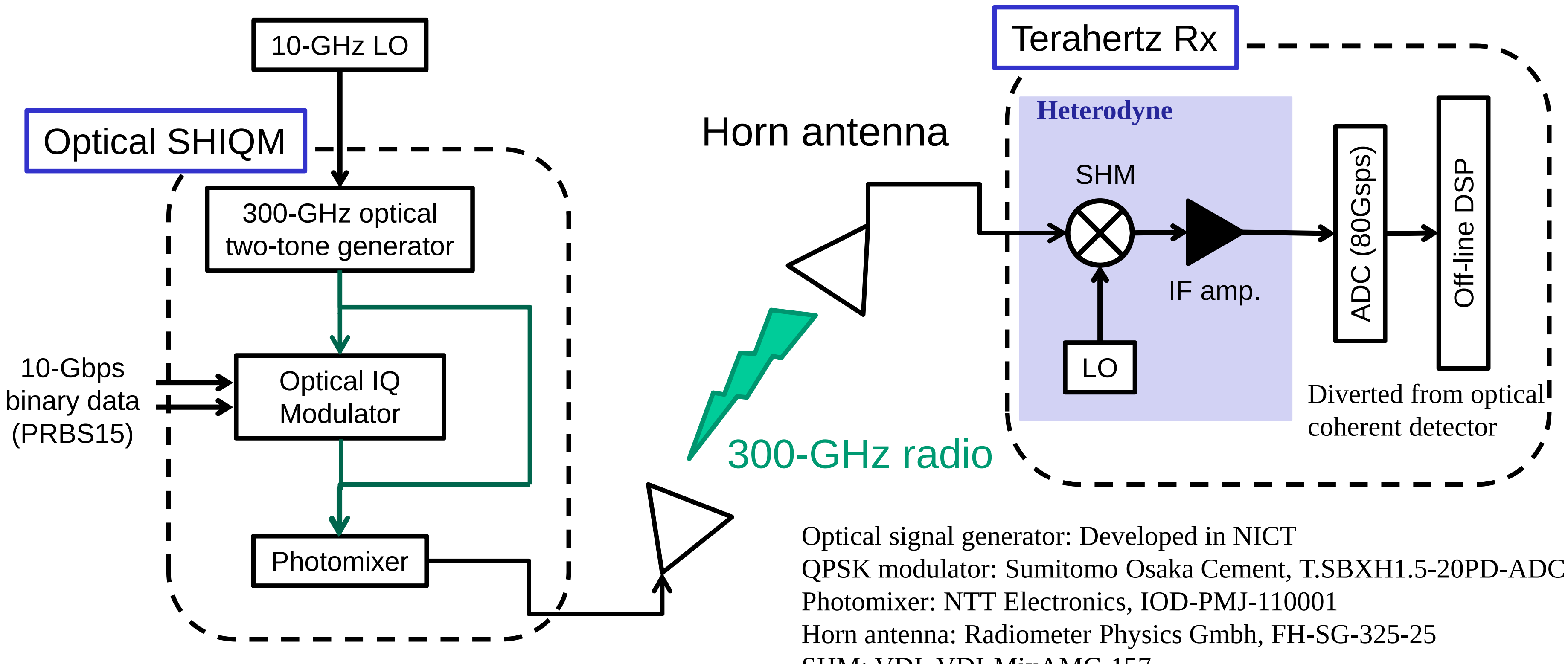
- **<u>Optical IQ mixer/SHIQM configured with optical two-tone generator, IQ modulator and photomixer</u>**
  - Pros.: Broad bandwidth (>>40GHz), frequency tunability over the band
  - Cons.: Quite large footprint, complexity



How to Demodulate Multi-level Signal

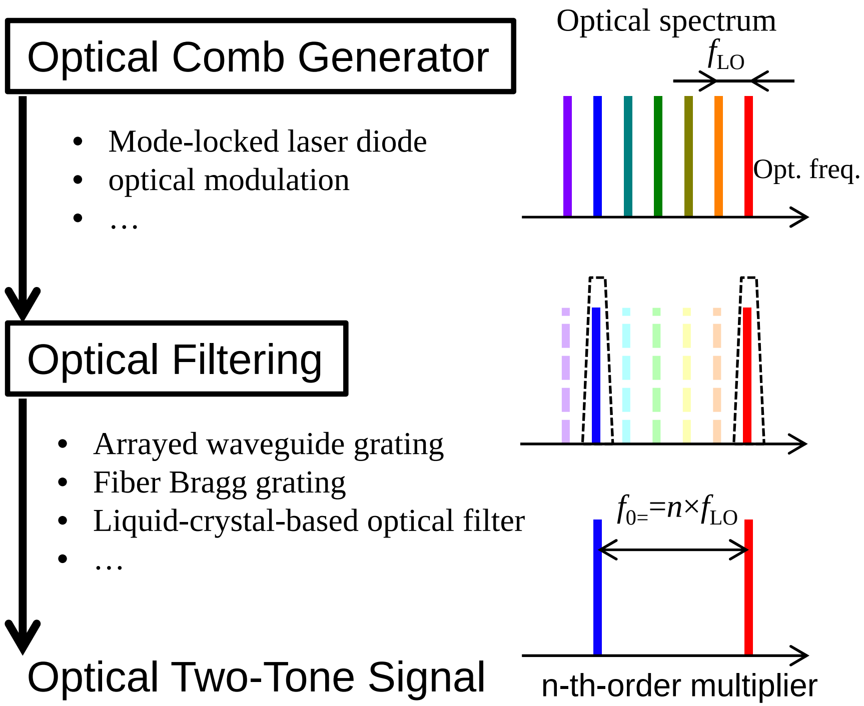
- To demodulate the multi-level signal, coherent detection technique is indispensable.
  - ex.) 3GPP Rel. 10: 20-MHz-BW OFDM-256QAM
  - IEEE802.11ad: 2.16-GHz-BW 16QAM
- High-speed digital signal processing technologies can be diverted from advanced optical communication technology, so-called “digital coherent detection.”
  - In advanced optical communication, 28-Gbaud dual-polarization quadrature phase-shift keying (QPSK) has been already standardized in the Optical Internetworking Forum (OIF) and installed for 100-Gb/s optical transport system.

Block Diagram of Optically-Synthesized Terahertz Signal Transmission



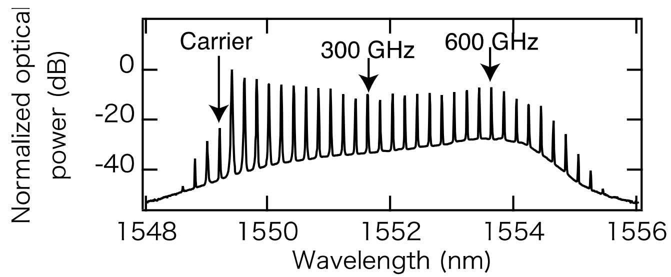
Optical signal generator: Developed in NICT
QPSK modulator: Sumitomo Osaka Cement, T.SBXH1.5-20PD-ADC
Photomixer: NTT Electronics, IOD-PMJ-110001
Horn antenna: Radiometer Physics Gmbh, FH-SG-325-25
SHM: VDI, VDI-MixAMC-157
IF amp.: SHF, 804TL
ADC: LeCroy, WaveMaster 830Zi
Off-line DSP: Developed by NICT and Osaka Univ.

300-GHz Optical Two-Tone Generator Based on Optical Frequency Comb Source

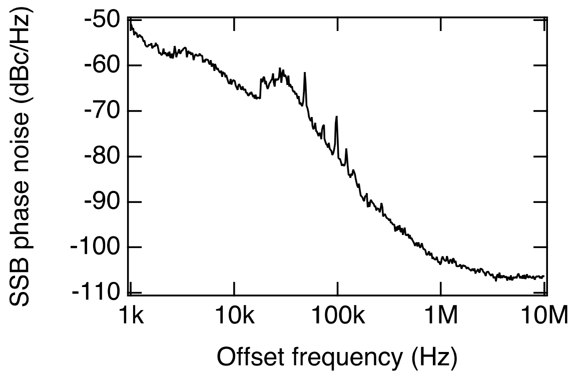


Photomixer works as an envelop (square-low) detector to generate the RF signal f_0 from the optical two-tone signal with the frequency separation f_0.

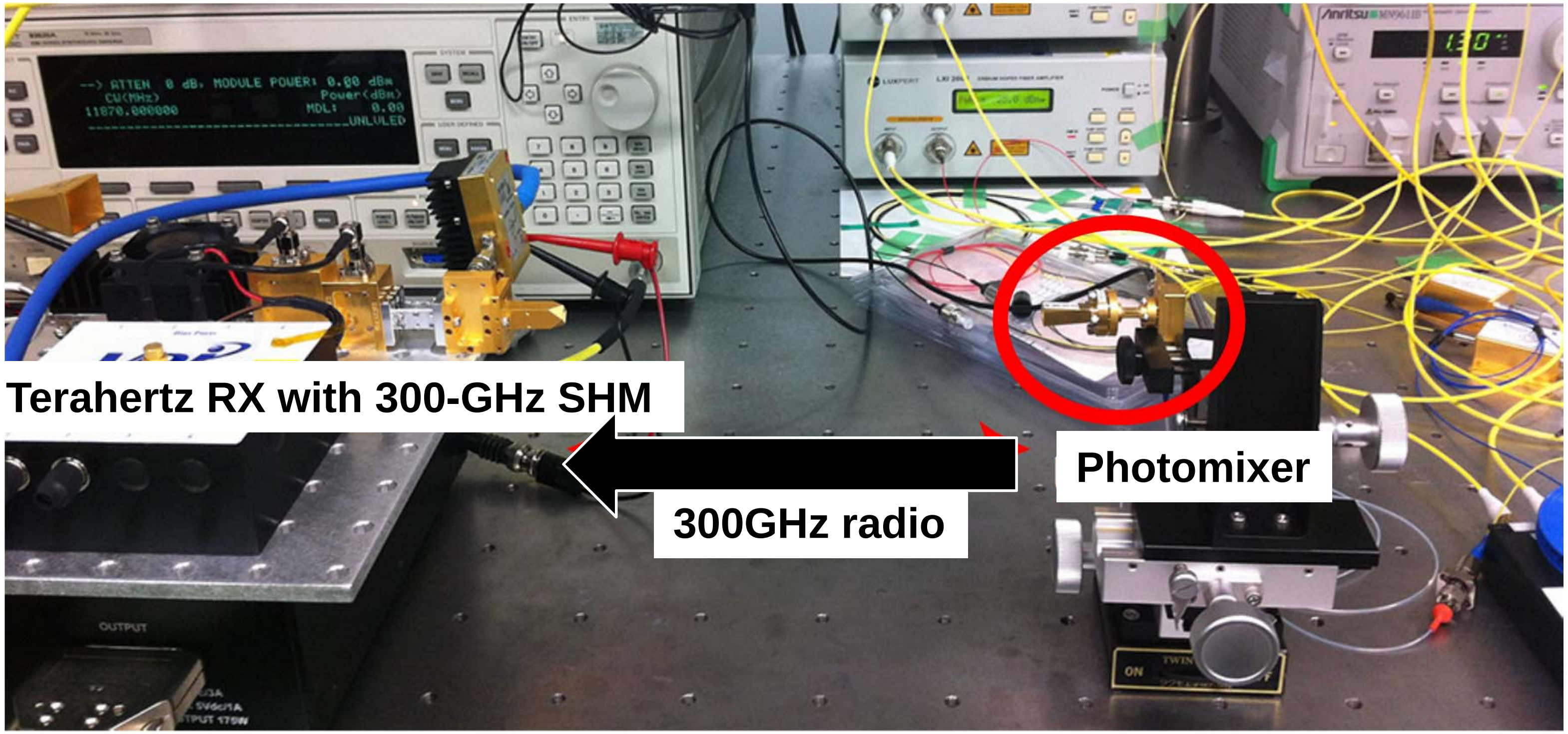
ex.) optical spectrum of modulator-based optical frequency comb



ex.) obtained SSB phase noise of 300 GHz signal down-converted by SHM into 15 GHz



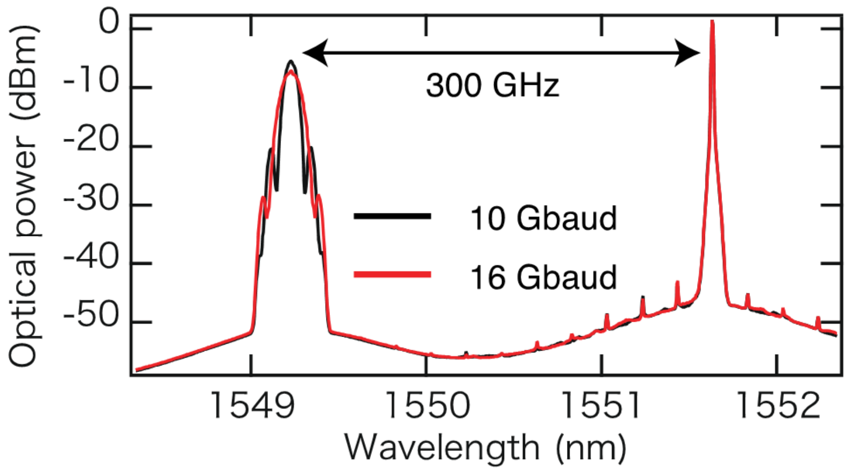
Picture of Terahertz Transmission Section between Terahertz Converter and Rx

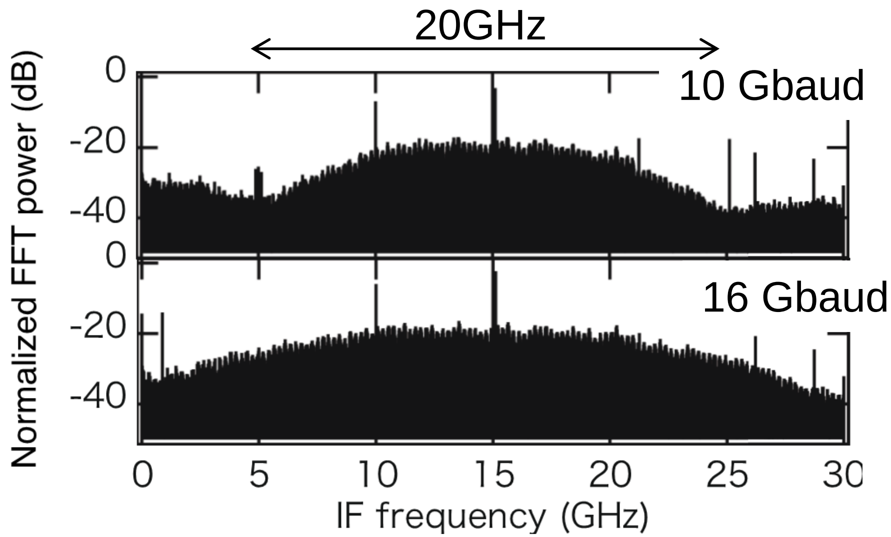


For proof-of-concept demonstration, short-distance transmission was performed because the output RF power of the photomixer was much less than 100 uW.

=> **Insertion of 300-GHz amplifier will extend the transmission distance >10 m.**

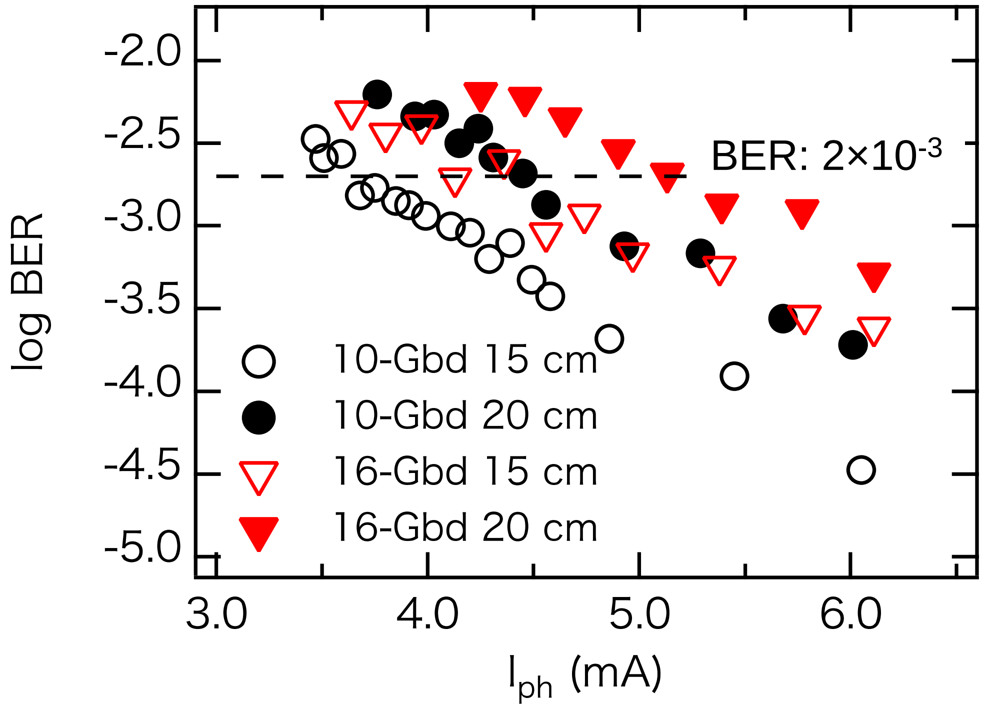
Spectra of Optical Signal at Optical Tx, and Received IF Signal at Terahertz Rx

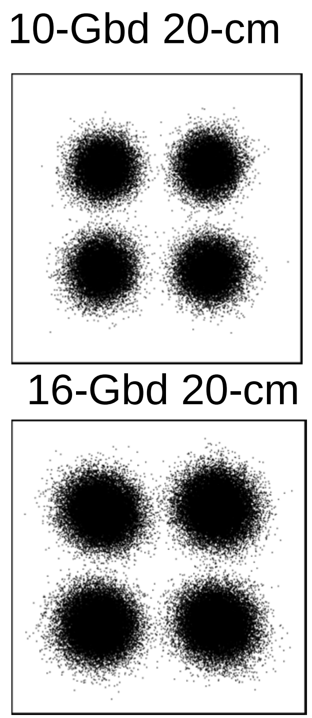




- 10-Gbaud (line rate: 20-Gbps) and 16-Gbaud (line rate: 32-Gbps) QPSK signals at 300 GHz are received successfully.
- There is no significant degradation of obtained IF spectra.

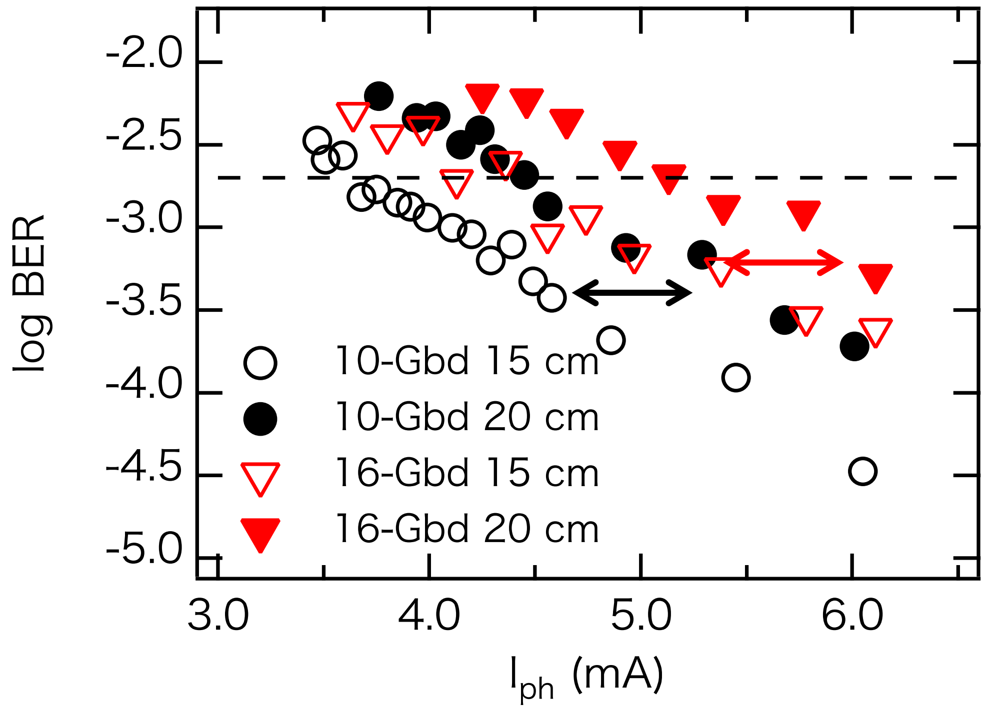
Observed Bit Error Rates and Constellation Maps





- Clear BERs and Constellations are shown at the receiver within a forward error correction limit of BER of 2×10^{-3}.
  - FEC: for example, RS(1023,1007)/BCH(2047,1952) super FEC code descried in ITU-T Rec. G.975.1 (2004).

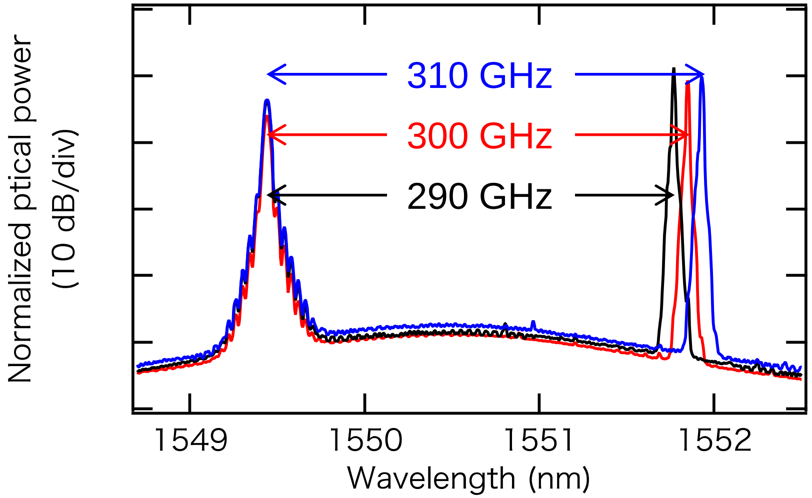
Power Penalties on Observed BERs



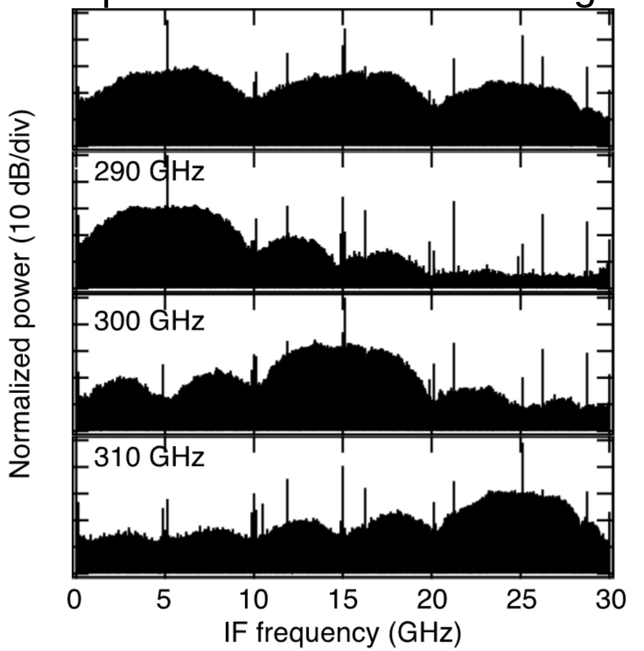
- Possible origins of power penalty corresponding to approx. 2.5 dB in each arrow, which is evaluated with conversion ratio of the photomixer, are
  - Transmission distance difference betw. 15 cm and 20 cm (black arrow)
    . Estimated propagation loss: approx. 3.0 dB using simple Friis eq.
  - Difference of symbol rates of 10-Gbd and 16-Gbd (red arrow).
    ADC bandwidth of 30 GHz cannot fully demodulate 16-Gbaud signal.

Channelization for 300-GHz Frequency Division Multiplexing/Frequency Division Duplexing

Optical spectra

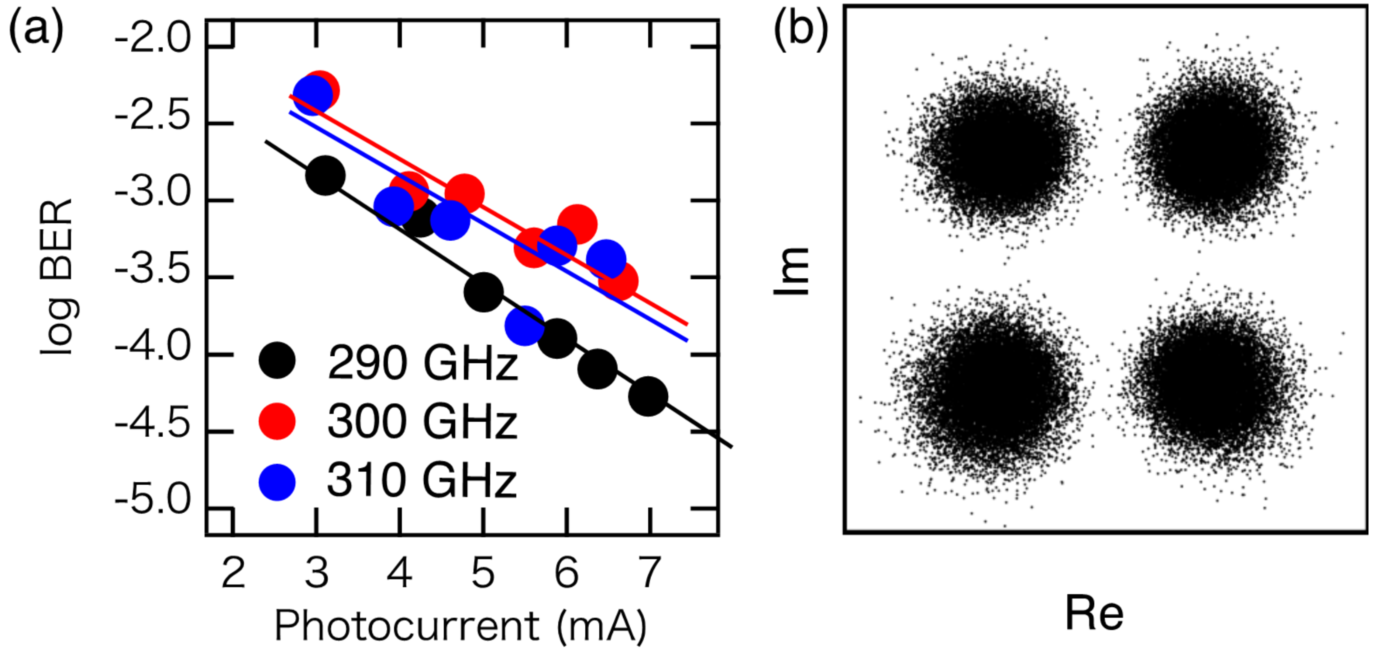


IF spectra of received THz signal



- Proof-of-concept demonstration with frequency-division-multiplexing (FDM) or frequency-division-duplexing (FDD)
  - 5-Gbaud QPSK at 290 GHz (ch. #1), 300 GHz (ch. #2) and 310 GHz (ch. #3).

Observed BERs of FDM configuration



- Power penalty of observed BERs is caused by the frequency response of a photomixer and an SHM.

Summary and Consideration

- Coherent terahertz transmission with multi-level modulation was proposed and demonstrated by optical SHIQM and digital coherent detection with heterodyning.
- Optical SHIQM has advantages on its broad bandwidth and center frequency tunability.
- 20-Gb/s- and 30-Gb/s-class-capacity transmission over air were realized by 10- and 16-Gbaud QPSK modulation.
- As a length of an optical fiber can be extended easily, remote terahertz radio head configuration is capable of realization of terahertz backhaul/fronthaul directly connected to optical fiber networks.

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