OPTOELECTRONIC COMPONENT CHARACTERIZATION FOR SEAMLESS ACCESS COMMUNICATION

Asst. Prof. Ukrit Mankong
Chiang Mai University, Thailand
ukrit.m@cmu.ac.th

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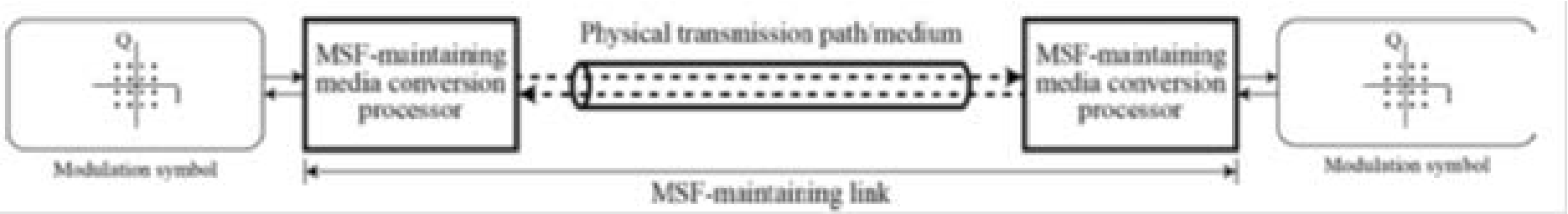
Preparatory activity proposal

- This presentation is a part of preparatory study for **short-distance communication and imaging**

- Short-distance (<5 km) communication technology
  - millimeter-wave radio, free space optics, or optical fiber links to achieve cost-effective connections to end-users
- Future last-one-mile access technology in the mobile communication, so-called 5G,would have a throughput of 10 Gb/s to users
- seamless connectivity between a radio access network and an optical backend network will become more important to optimize the throughput and user experiences

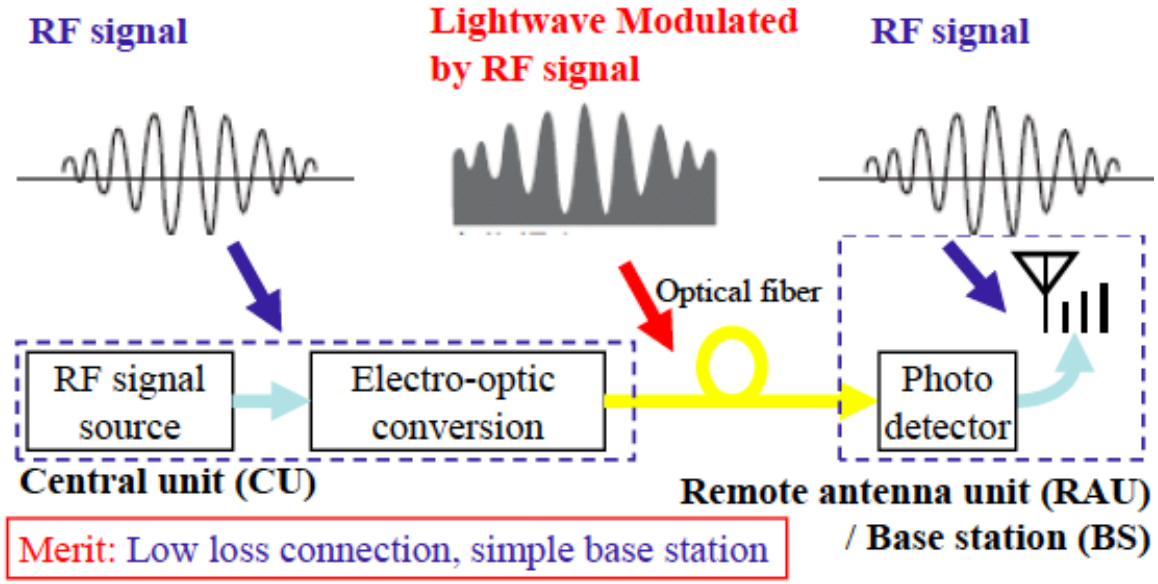
Seamless wired-wireless communication



Modulation Symbol Format (MSF) maintaining transmission

- Modulation symbol format is transmitted over several physical media seamlessly such as optical fibers, air

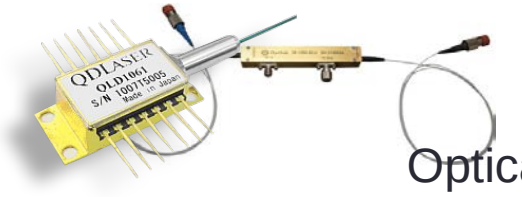
Applications: resilient access networks, mobile fronthaul/backhaul, Indoor networks, broadcasting remote antennas, foreign object debris detection



Radio-over-Fiber

(source: Kawanishi, waveform transfer for seamless network showcasing APT/ITU Conformance and and Interoperability event (2015)

Component requirements in radio-over-fiber systems



Optical Fiber

Microwave Freq. Signal → Driver Circuit → Laser diode/ Modulator → Photodetector → Amplifier → Output

E/E E/O O/O O/E E/E

E/E parameters include return loss, insertion loss, nonlinearity, noise figure

O/O parameters include attenuation, reflection, dispersion, amplifier noise, nonlinearity

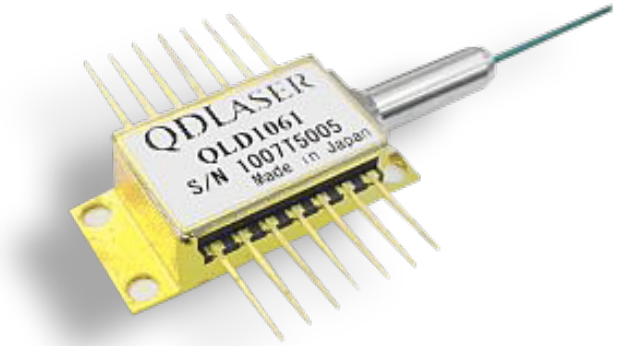
O/E and E/O conversion efficiency, bandwidth and precise frequency response are important.

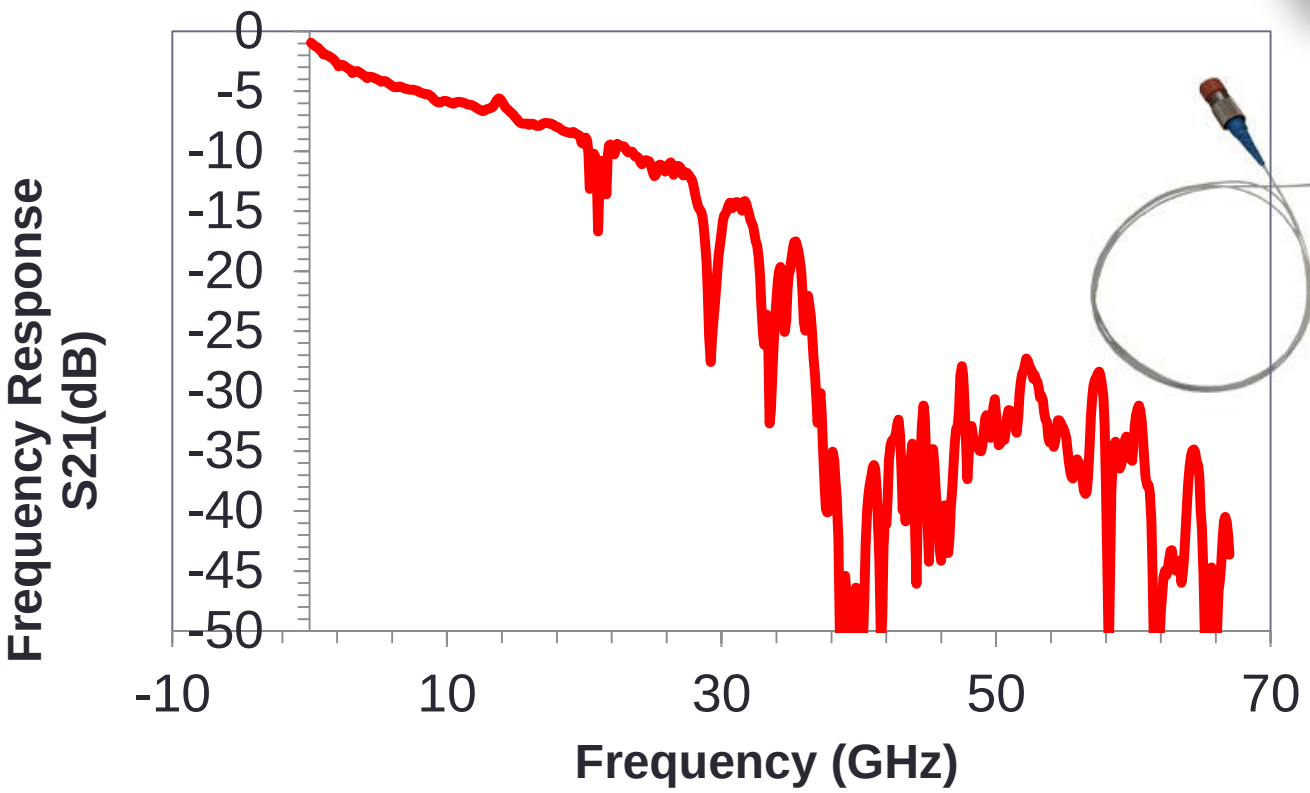
Research topics and activities

- Component characterization
  - **Frequency response of optoelectronic components**
  - Amplitude and phase modulation of modulators
- Asia-Pacific Standardization activity
  - ASTAP
- Other ICT applications
  - Biomedical
  - Aging society

Frequency response of optical components

- Precise frequency response of O/E and E/O components
  - Modulation bandwidth
  - Slope Responsivity (Conversion efficiency)
  - Response Flatness

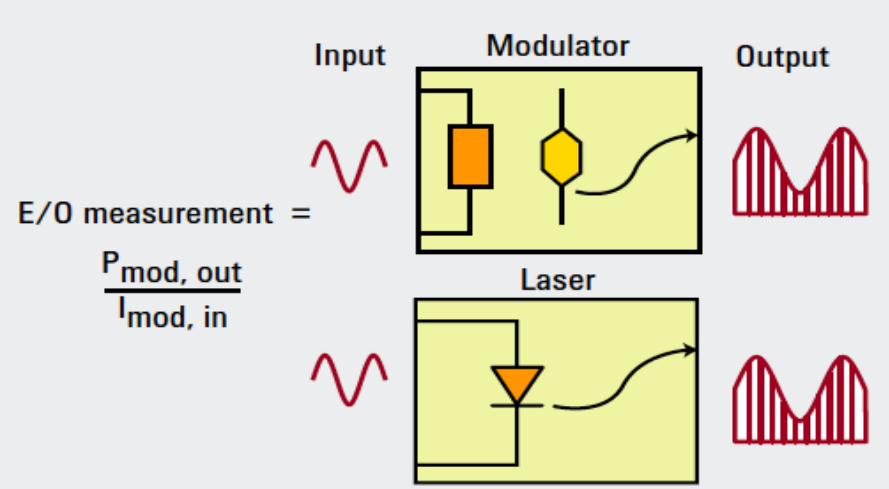




Optoelectronic Frequency Response Characterization

Scattering parameter definition

E/O device



E/O measurement = $\frac{P_{mod,\,out}}{I_{mod,\,in}}$

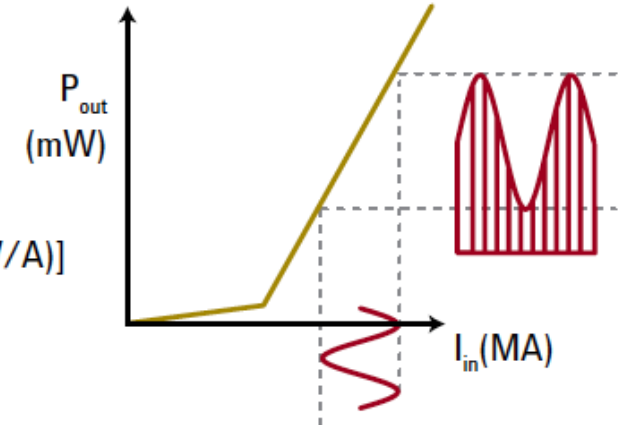
$$S^{E/O} = \begin{bmatrix} S_{11}^{E/O} & \eta_R \sqrt{Z_0}\left(1 - S_{22}^{E/O}\right) \\ \dfrac{\eta(1 - S_{11}^{E/O})}{\sqrt{Z_0}} & S_{22}^{E/O} \end{bmatrix}$$

$$= \begin{bmatrix} S_{11}^{E/O} & 0 \\ \dfrac{\eta(1 - S_{11}^{E/O})}{\sqrt{Z_0}} & 0 \end{bmatrix}$$

Reverse transmission is zero and no optical reflection at output

Responsivity $R_S\,(W/A) = \Delta P_{out}/\Delta I_{in}$

$R_S\,(dB) = 20 \log_{10} [R_S(W/A)/1(W/A)]$



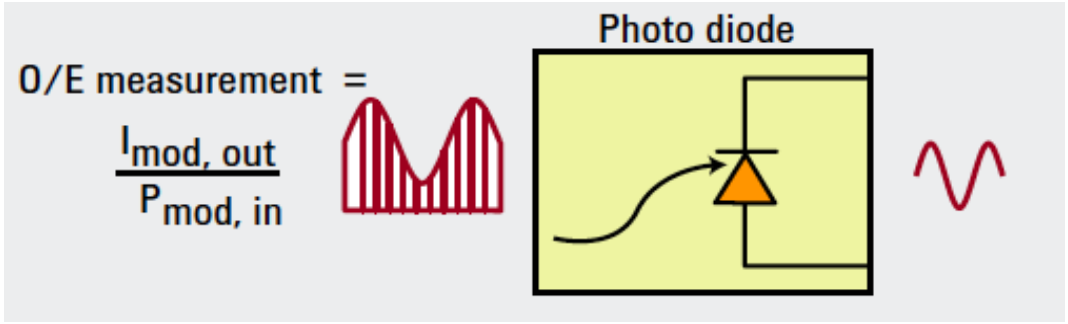
B. Stockbroeckx, et al. Microwave and Optical Technology Letters, Vol. 7, No. 17, Dec1994.

Optoelectronic Frequency Response Characterization

Scattering parameter definition

O/E device

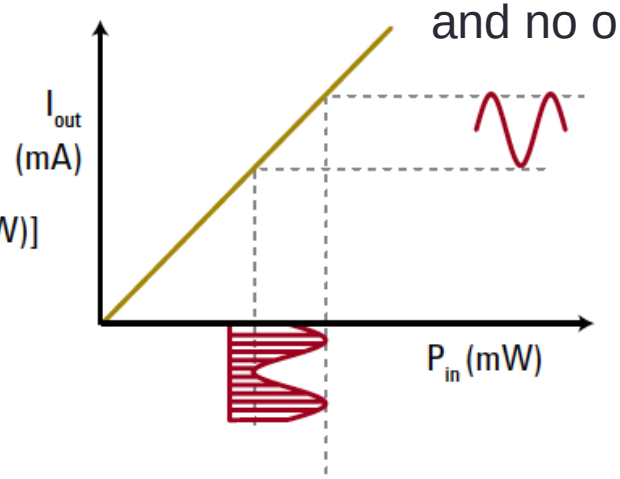
$$S^{O/E} = \begin{bmatrix} S_{11}^{O/E} & \dfrac{\kappa_R\left(1-S_{22}^{O/E}\right)}{\sqrt{Z_0}} \\ \sqrt{Z_0}\left(1-S_{11}^{O/E}\right) & S_{22}^{O/E} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ R\sqrt{Z_0} & S_{22}^{O/E} \end{bmatrix}$$



Reverse transmission is zero and no optical reflection at input

Responsivity $R_r\ (A/W) = \Delta I_{out}/\Delta P_{in}$

$R_r\ (dB) = 20\ \log_{10}[R_r(A/W)/1(A/W)]$



B. Stockbroeckx, et al. Microwave and Optical Technology Letters, Vol. 7, No. 17, Dec1994.

Optoelectronic Frequency Response Characterization Methods

- **RF Network Analyzer + Calibrated Lightwave test set**
  - **Keysight Lightwave Component Analyzer (LCA)**

  (NIST Standard Traceable)
- **Two-tone Photodetector (O/E) frequency response measurement NIST standard**

  (P. D. Hale et.al. *Lightwave Technology, Journal of,* vol. 14, 1996.)
- **Two-tone Photodetector (O/E) frequency response using MZM two-tone light generator**

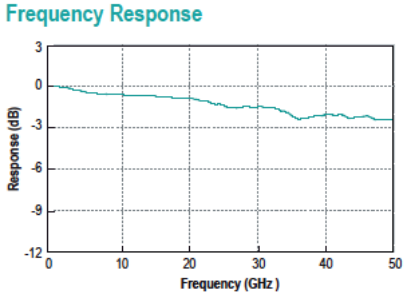
  (K. Inagaki, et.al., IEICE Electronics Express, vol.9, no. 4 2012.)

  (IEC 62803 standard)

  (Also reported in ASTAP REP03.Rev2, CMU-NICT Collaboration)

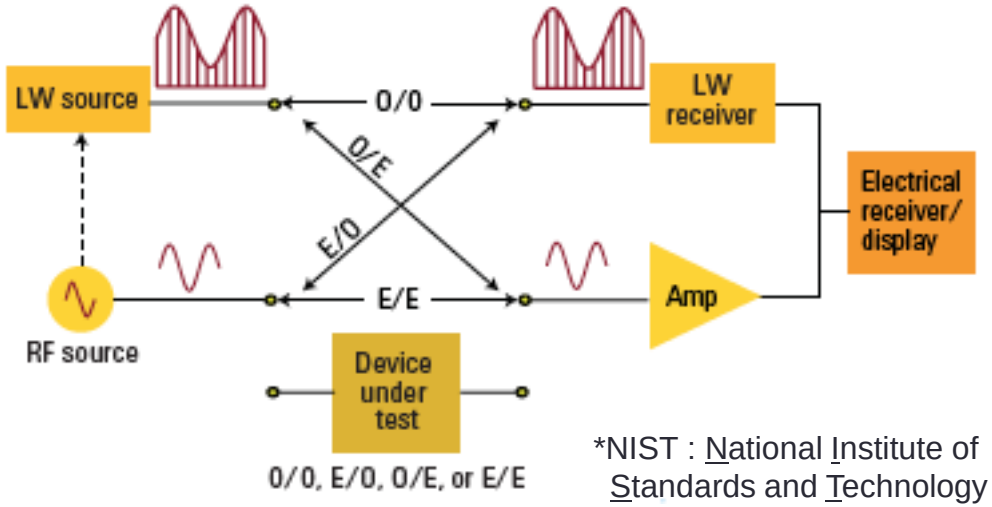
O/E and E/O calibration method
Keysight LCA

- Frequency Response of Photodiodes (PD)



- Measuring Instrument
  - Lightwave Component Analyzer (LCA) by Keysight (formerly Agilent)
  - RF Network Analyzer + Lightwave Test-set

NIST* Traceable !

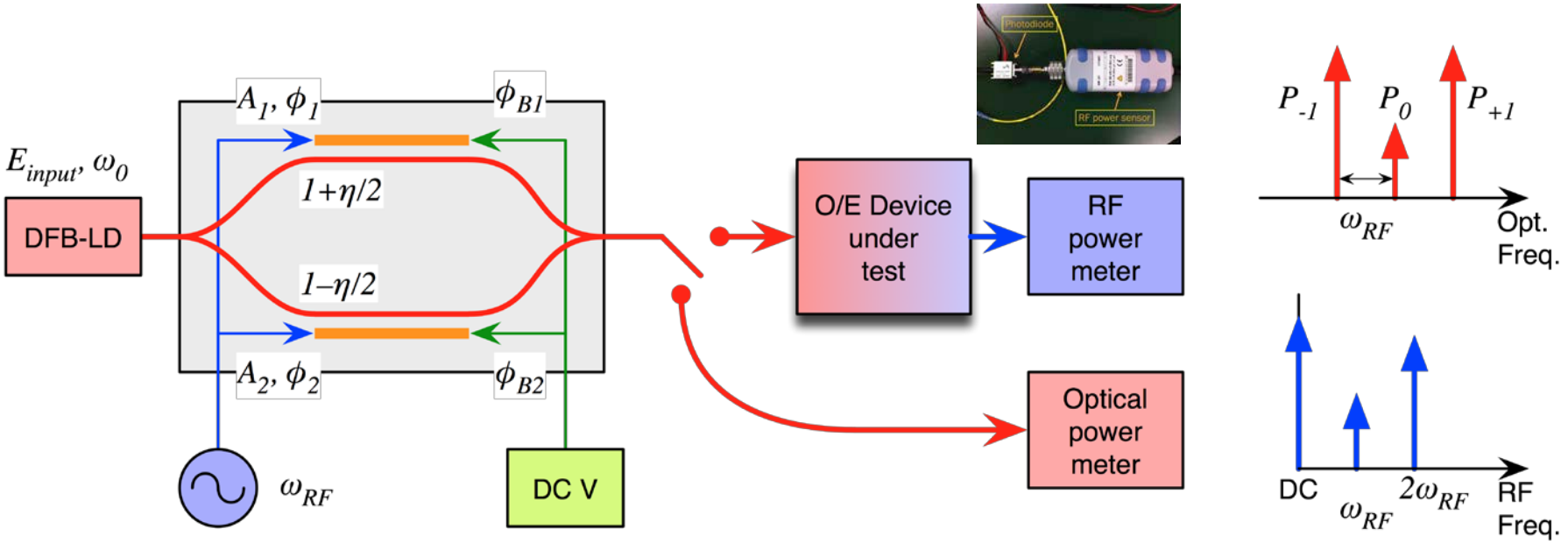


*NIST : National Institute of Standards and Technology

(from K.Inagaki, T.Kawanishi, Measurement Technology of Photodiodes and International Standardization, presented @CMU, March 2012)

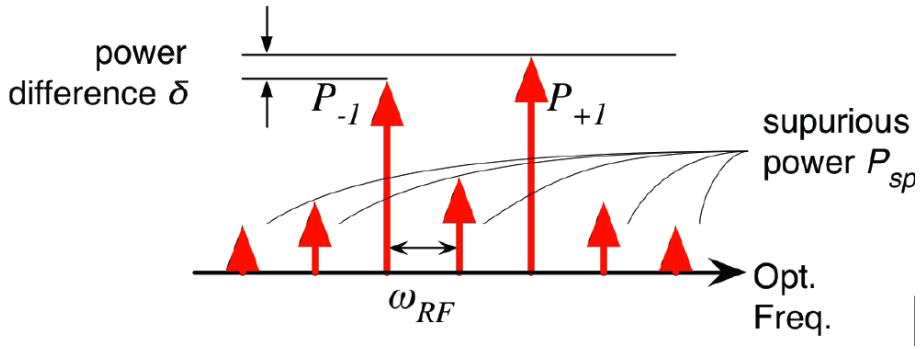
Two-tone Photodetector (O/E) frequency response using MZM two-tone light generator

- Operate MZM at the “Null” bias point.
  （Double Side Band-Suppressed Carrier, DSB-SC）
- In this case, the carrier power becomes minimum.
- Simultaneously, the powers of USB and LSB are balanced.



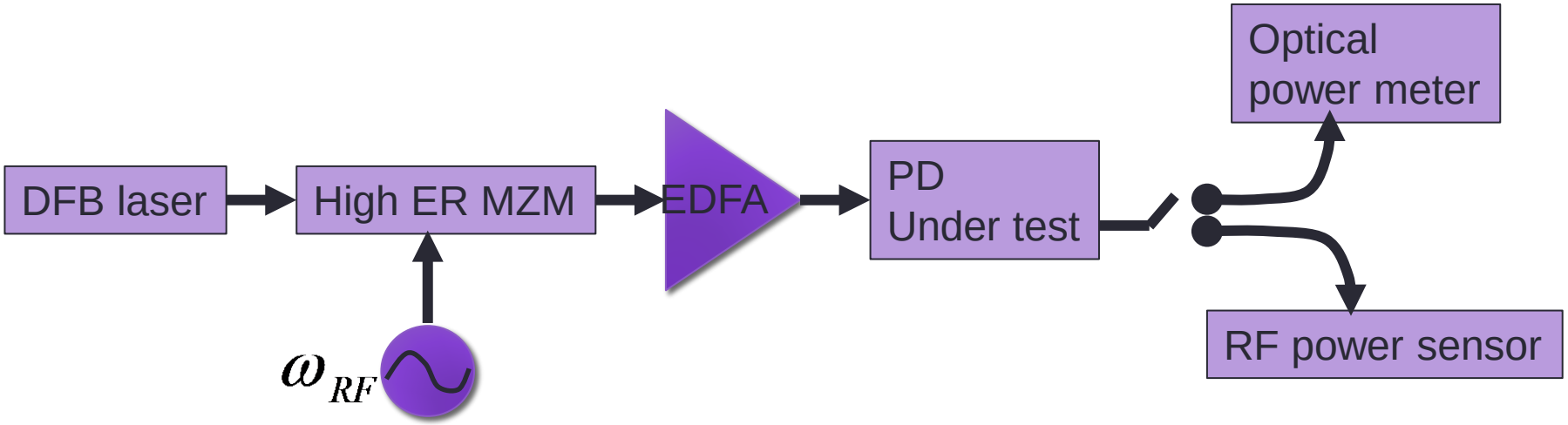
Measurement errors / Using optical amplifiers to increase signal to noise ratio

- Two-tone power difference (d)
- Spurious Tones (P_{sp})
- Third-order modulation harmonics (P_3)
- Optical Power Measurement uncertainty
- RF Power measurement uncertainty



(K. Ingaki, U. Mankong and T. Kawanishi, ICOCN 2012)

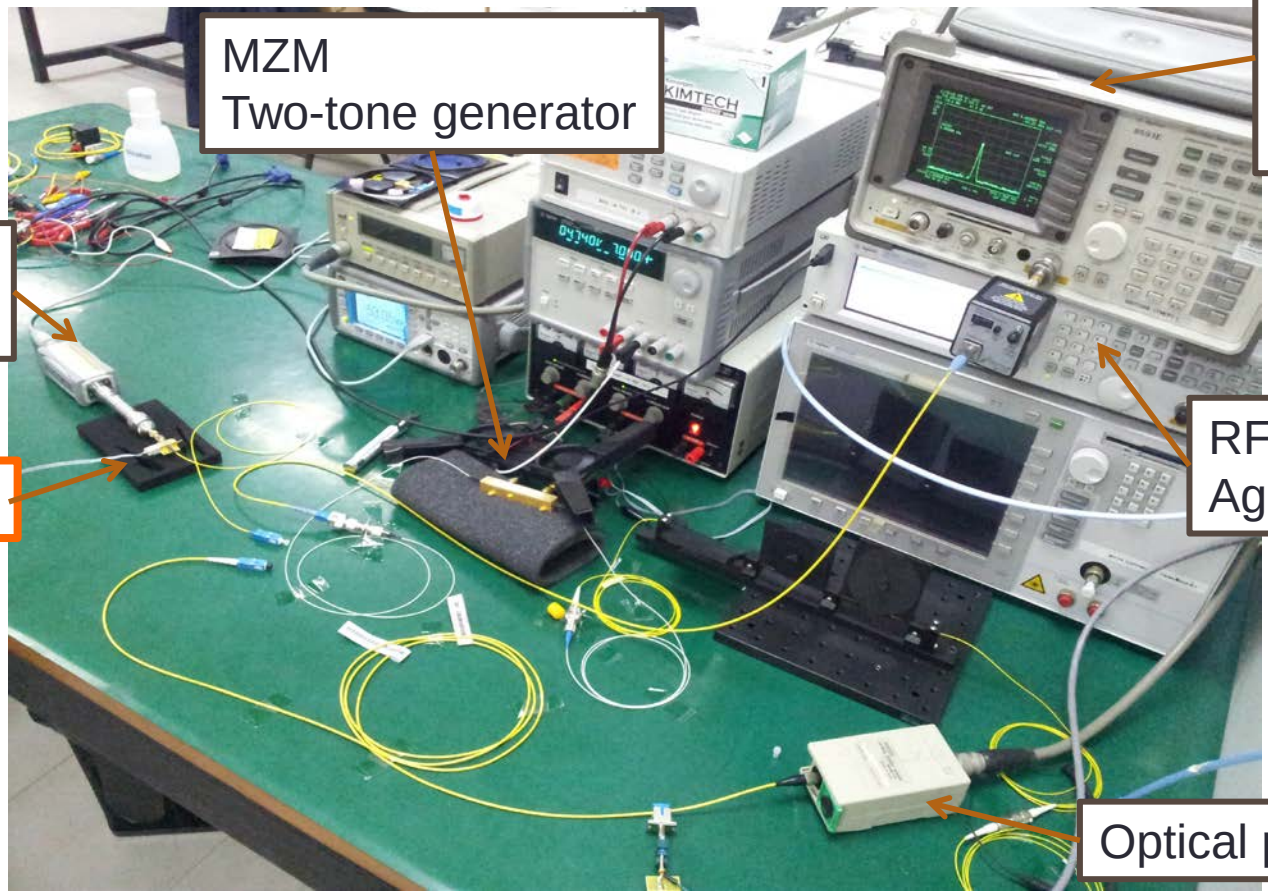
Optical amplifier may be included to reduce power measurement error



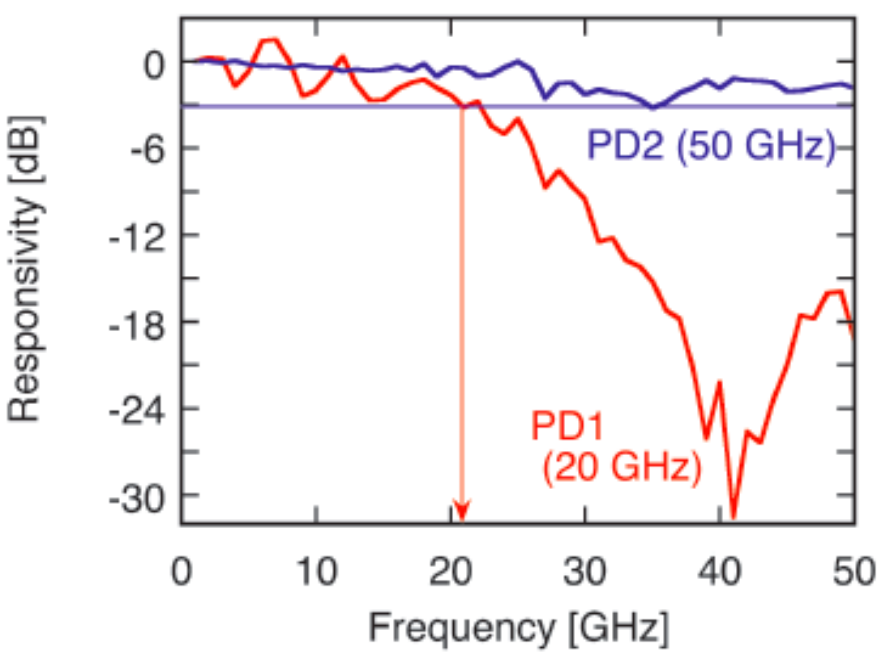
(T. Tangmala, U. Mankong, K. Inagaki, T. Kawanishi, CLEO-PR 2013)

Setup at CMU

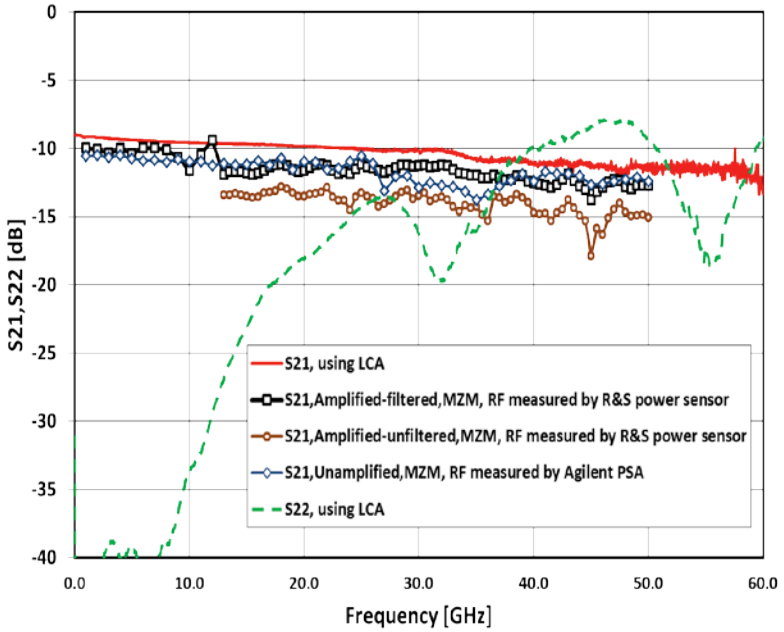
Two-tone Photodetector (O/E) frequency response using MZM two-tone light generator



Measured results of various photodetectors

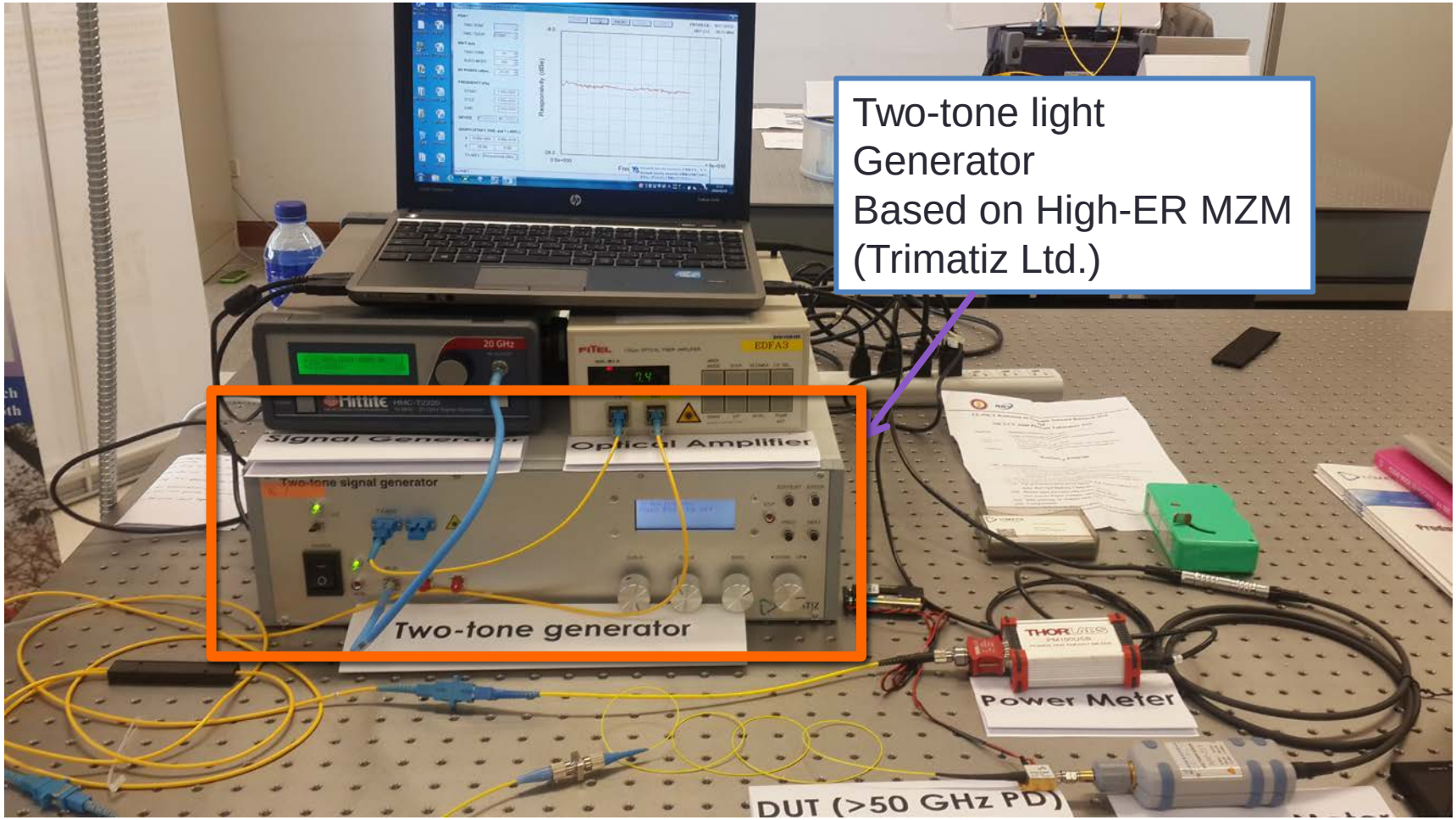


Frequency response of
PDs with different bandwidths



Comparison with
LCA measurement

Frequency Response Analyzer (FRA) System Based on two-tone light by MZM



Summary

- We have measured the frequency response of photodetectors (O/E) using two-tone light generated by MZM and using EDFA to increase the power level and improve RF SNR.

- The technique has been submitted to become an International standard.
  - International Electrotechnical Commission (IEC)
  - Asia Pacific Telecommunity (APT)

Future challenges

Detectors and Modulators for higher speeds

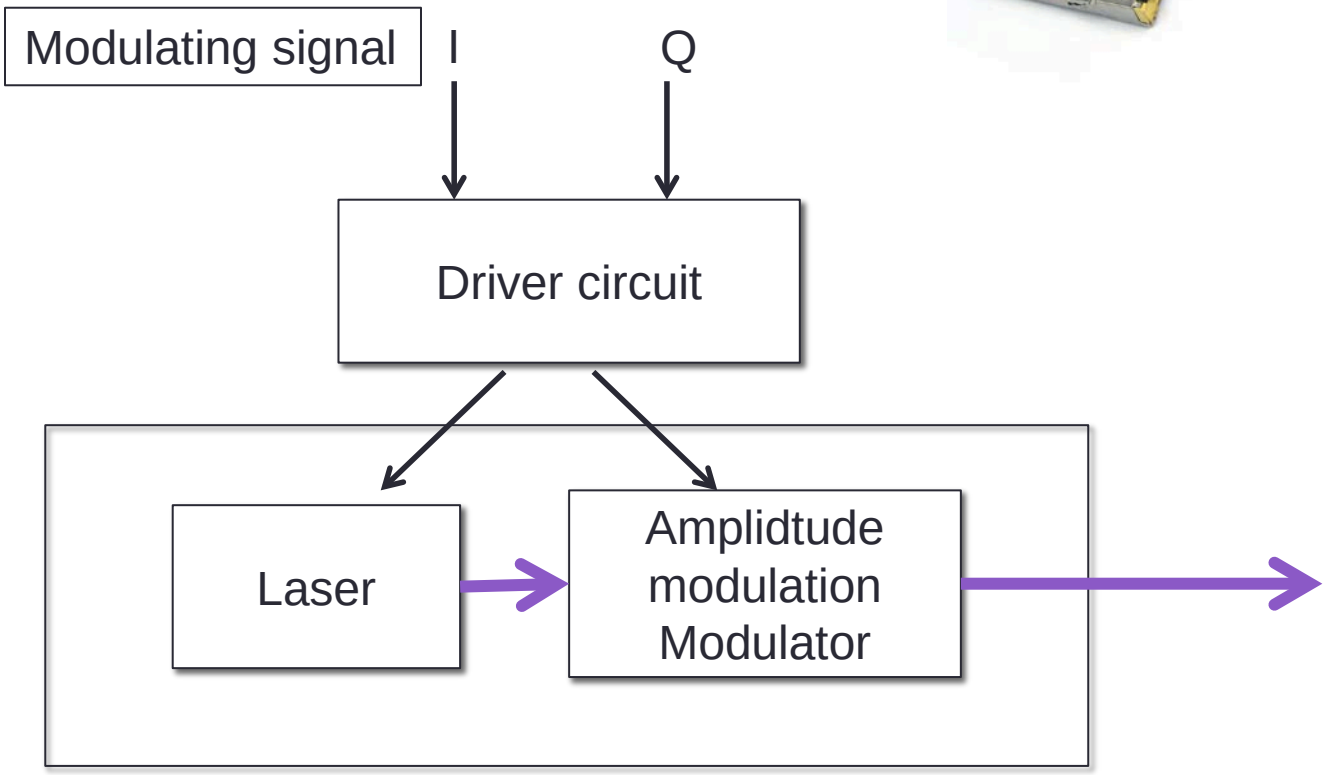
- Measurement of optical coherent detector
- QAM modulation using combined amplitude and phase modulators

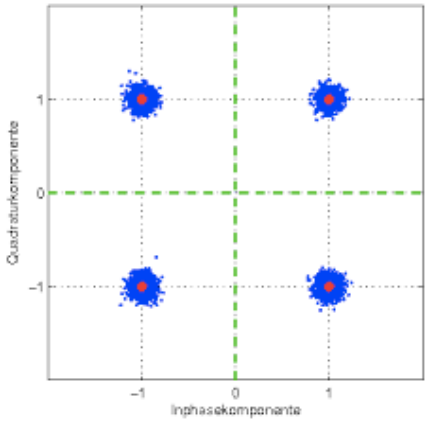
Activities at Chiang Mai University (CMU)

- Component characterization
  - Frequency response of optoelectronic components
  - **Amplitude and phase modulation of modulators**
- Asia-Pacific Standardization activity
  - ASTAP
- Other ICT applications
  - Biomedical
  - Aging society

QAM modulation of optical transceiver

Transceiver Trends
Smaller form factor
Larger data rate
- Using multilevel modulation / amplitude and phase modulation





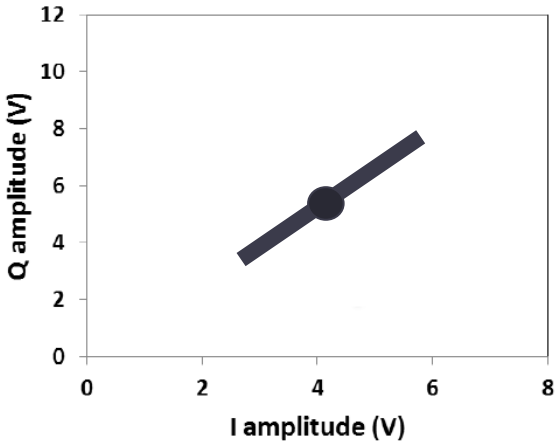
Chirp definition

- Alpha parameter is the phase shift due to intensity modulation

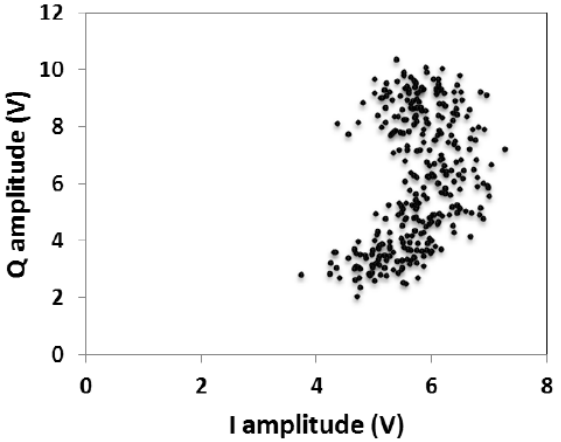
$$\alpha = \frac{d\phi / dt}{\frac{1}{E} dE / dt}$$

(Koyama and Iga, Journal of Lightwave Technology vol.6, 1988)

Response to sine wave modulation



$\alpha = 0$



$\alpha \neq 0$

Chirp measurement methods

- Network analyzer method using dispersive medium

  (F. Devaux, Y. Sorel, and J. F. Kerdiles, J. Lightwave Technol., vol. 11, no. 12, pp. 1937-1940, 1993)

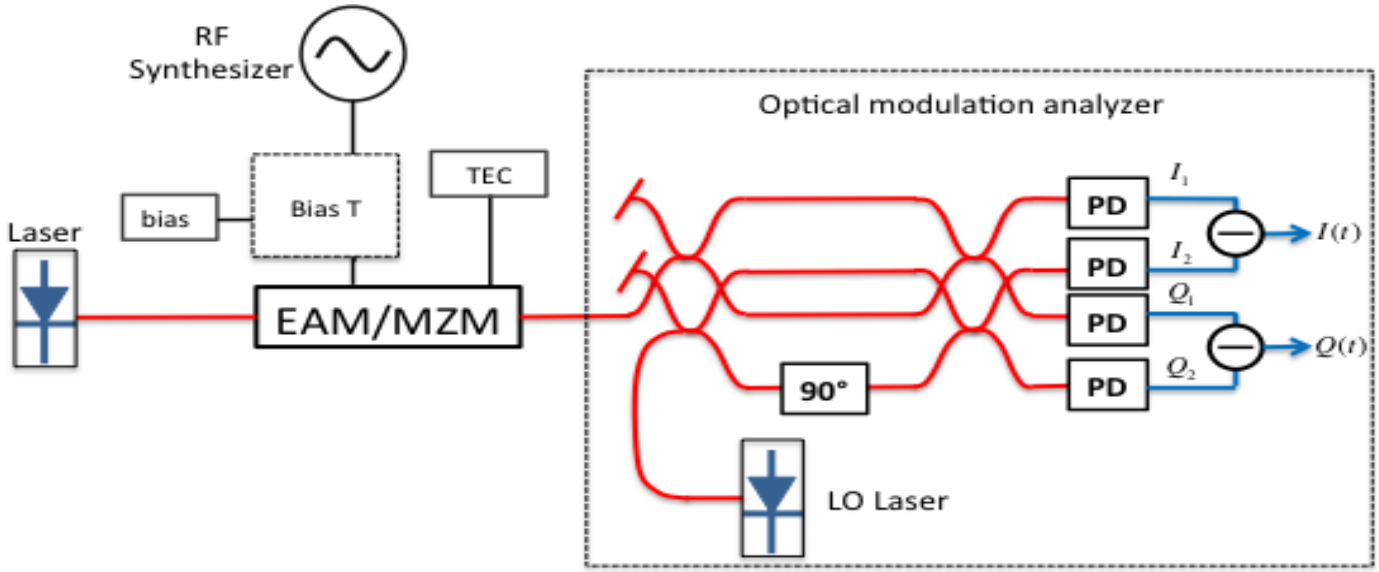
- Optical Spectrum Analyzer method

  (T. Kawanishi, K. Kogo, S. Oikawa and M. Izutsu, Optics Communications, vol. 195, pp. 399-404, 2001.)

- Quadrature demodulation method

  (Mankong, U. ; Tangmala, T. ; Inagaki, K. ; Kanno, A. ; Kawanishi, T. Optical Communication (ECOC), 2014 European Conference on)

Heterodyne quadrature demodulation technique



(U. Mankong, et.al., ECOC 2014, MWP 2014, MWP 2015)

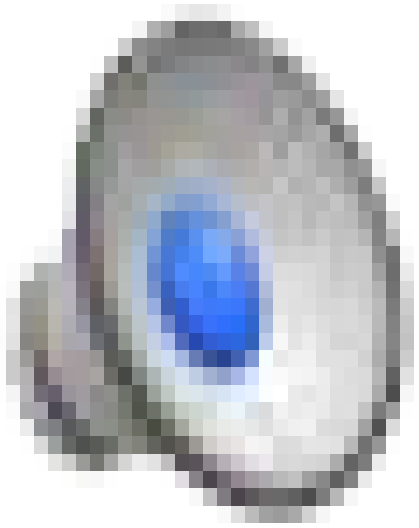
EAM output

$$E_{EAM}(t) = E_{LO}(t)\exp\left[jkn(t)L\right]$$
$$= A_{LO}\exp(-kn''(t)L).\exp\left[j(\omega_{LO}t + \phi_{LO} + kn'(t)L)\right.$$

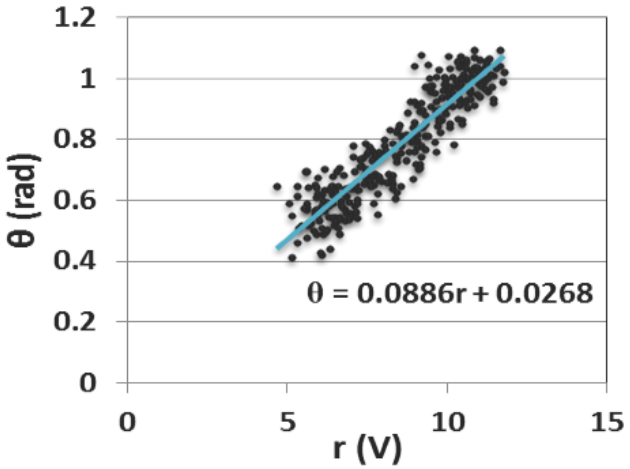
Demodulated signal

$$I(t) \propto 4A_{LO}A_{EAM}(t)\cos(\phi_{EAM}(t) + \Delta\psi),$$
$$Q(t) \propto 4A_{LO}A_{EAM}(t)\sin(\phi_{EAM}(t) + \Delta\psi).$$

Heterodyne quadrature demodulation technique

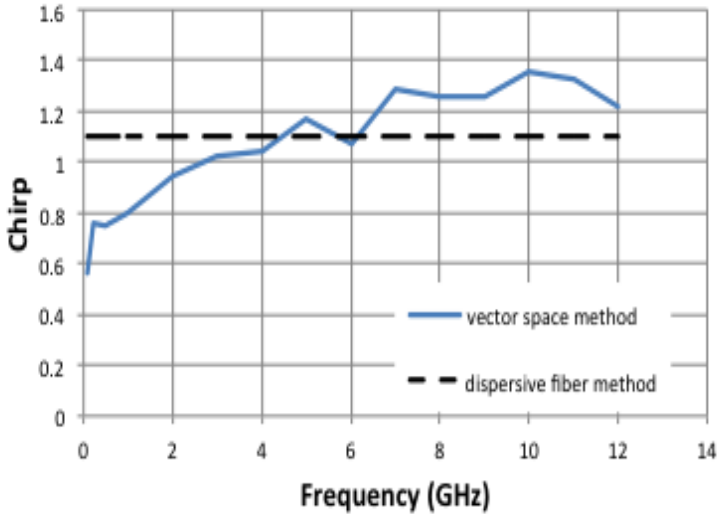


Chirp characteristic of Mach Zehnder Modulator

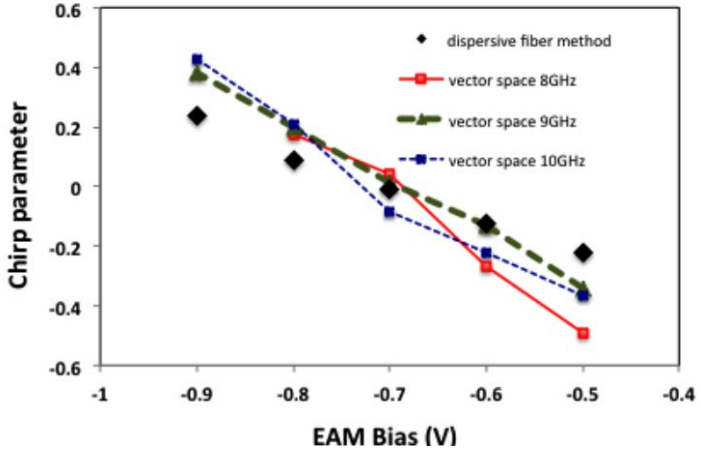


Varying Frequency

Chirp characteristic



- Chirp can be measured directly at specific frequency
- Applicable to other external modulator and integrated modulator, e.g. in an EML module



Summary

- Chirp frequency characteristics can be measured
- Both discrete external modulators and integrated modulators may be characterized

Future challenges

- Chirp characteristics allow the realization of optical QAM using combined phase and amplitude modulators
- Extend the measurement to higher frequencies

Activities at Chiang Mai University (CMU)

- Component characterization
  - Frequency response of optoelectronic components
  - Amplitude and phase modulation of modulators
- **Asia-Pacific Standardization activity**
  - **ASTAP**
- Other ICT applications
  - Biomedical
  - Aging society

Asia Pacific Standardization Program Forum (ASTAP)

NICT and CMU singed a collaborative research agreement in the topic "***Standardization of a method for optoelectronic frequency response measurement***"

Scope: 1. Photodiode measurement method
2. International Standardization

International Electrotechnical Commission (IEC)
Transmitting equipment for radiocommunication technical committee (TC 103)

Asia Pacific Standardization Program forum (ASTAP)
Millimeter wave communication system expert group (until Sep 2013)
Seamless access communication system expert group (from Sep 2013)

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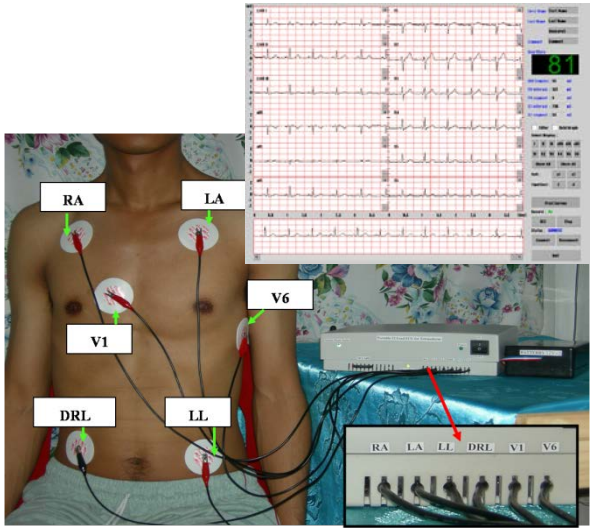
  - **Biomedical**
  - **Aging society**

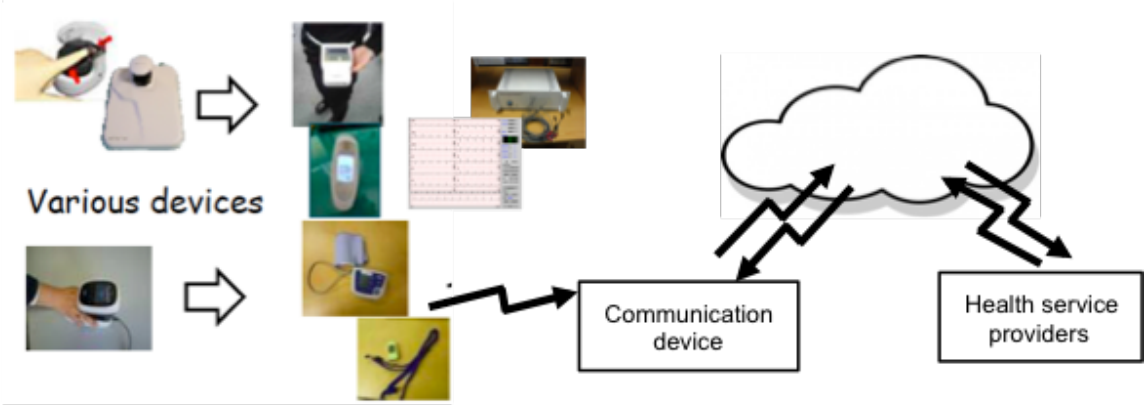
Communication techniques in biomedical applications (computational intelligence group)

- 3D eye gazing
- Portable ECG
- Fall detector
- Sign language translator
- Biophotonics

Planned preparatory activity in accessible E-health and spatio-temporal health information

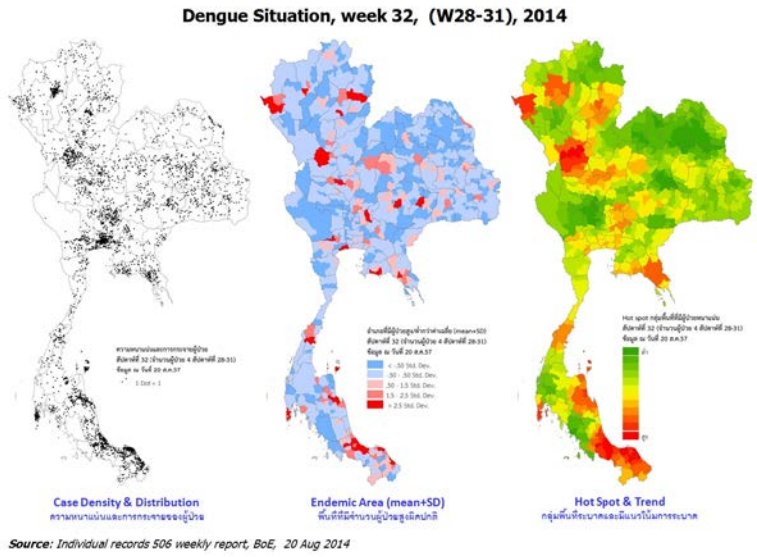


Preparatory activity in accessible E-health and spatio-temporal health information



Blood pressure, temperature, glucose, EKG, fall detector, etc

Discuss portable/wearable E-health platform



High resolution spatio-temporal data of infectious outbreak

Applicable to disaster management such as floods, fires, seasonal smokes (which are common issues in many ASEAN countries.

Expected workshop, February 2016 @ CMU, Chiang Mai, Thailand

Thank you

We welcome collaboration from ASEAN IVO members