

# Proposal of RoF Relay Transmission Usage Model

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## Abstract

**RoF (Radio on Fiber) relay transmission link is proposed as one of usage models of 802.11aj. RoF relay link can extend wireless access area to the different location without additional requirements. RoF relay link has broadband transmission capability due to O/E and E/O broadband conversion characteristics and can transmit RF signals at 45-GHz and 60-GHz bands simultaneously.**

**The aim of this contribution is to add a new usage model for IEEE 802.11aj Usage Models Document IEEE 802.11-12/1245r4.**

**The contents of this contribution are based on IEEE 802.11-12/0177r4.**

# Overview of WFA VHT usage models for 802.11ad

| Category                            | #  | Usage Model                                       |
|-------------------------------------|----|---|
| <b>1.Wireless Display</b>           | 1a | Desktop Storage & Display                         |
|                                     | 1b | Projection to TV or Projector in Conf Rom         |
|                                     | 1c | In room Gaming                                    |
|                                     | 1d | Streaming from Camcorder to Display               |
|                                     | 1e | Broadcast TV Field Pick Up                        |
|                                     | 1f | Medical Imaging Surgical Procedure Support        |
| <b>2.Distribution of HDTV</b>       | 2a | Lightly compressed video streaming around home    |
|                                     | 2b | Compr. video steaming in a room/ t.o. home        |
|                                     | 2c | Intra Large Vehicle (e.g. airplane ) Applications |
|                                     | 2d | Wireless Networking for Small Office              |
|                                     | 2e | Remote medical assistance                         |
| <b>3.Rapid Upload / Download</b>    | 3a | Rapid Sync-n-Go file transfer                     |
|                                     | 3b | Picture by Picture viewing                        |
|                                     | 3c | Airplane docking                                  |
|                                     | 3d | Movie Content Download to car                     |
|                                     | 3e | Police / Surveillance Car Upload                  |
| <b>4.Backhaul</b>                   | 4a | Multi-Media Mesh backhaul                         |
|                                     | 4b | Point to Point backhaul                           |
| <b>5.Outdoor Campus /Auditorium</b> | 5a | Video demos / telepresence in Auditorium          |
|                                     | 5b | Public Safety Mesh                                |
| <b>6.Manufacturing Floor</b>        | 6a | Manufacturing floor automation                    |
| <b>7.Cordless computing</b>         | 7a | Wireless IO / Docking                             |

## Overview of the New 802.11aj Usage Models\*

| Category                              | #  | Usage Model   |
|---------------------------------------|----|---|
| <b>8.Portable Device Applications</b> | 8a | Peer-to-Peer Communication Between Portable Devices               |
|                                       | 8b | Rapid Download Mass Data from Fixed Devices (e.g. Kiosk)          |
|                                       | 8c | Cloud Computing /Storage & Mass Data Synchronization              |
|                                       | 8d | Wireless Peripheral Application (e.g. HD Display , printer, etc.) |
| <b>9.Wireless Networking</b>          | 9a | Access to Internet/intranet via Millimeter-Wave AP                |

**Note: These new usage models differ from those considered by 11ad. They highlight the mobile and portable devices application for its size and power consumption limitation, enormous market scale, etc.**

**\* IEEE 802.11-12/1245r4**

# Proposal

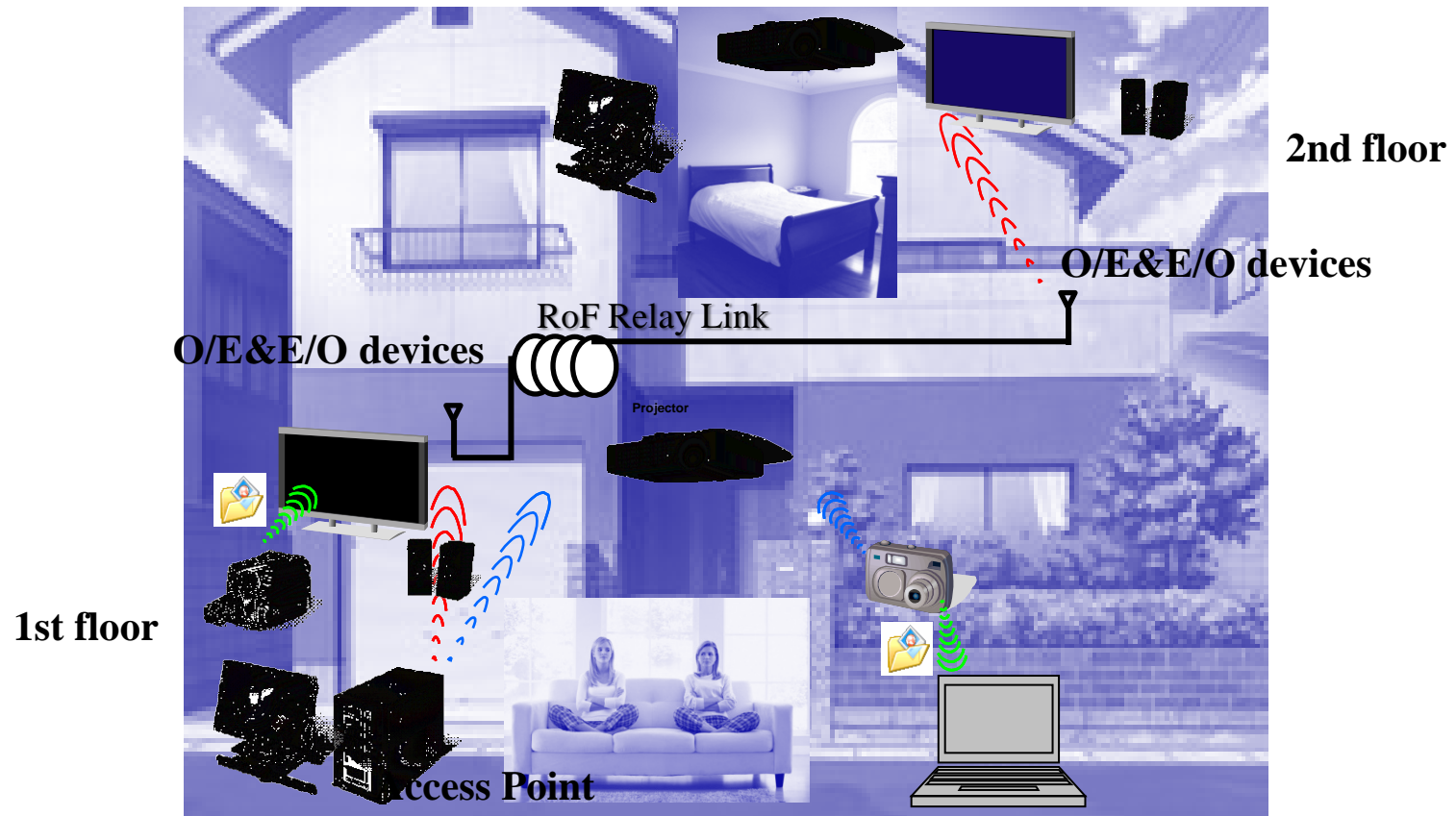
## Category 10: Relay Transmission

### 10a. RoF\* Relay Transmission

\* Radio on Fiber

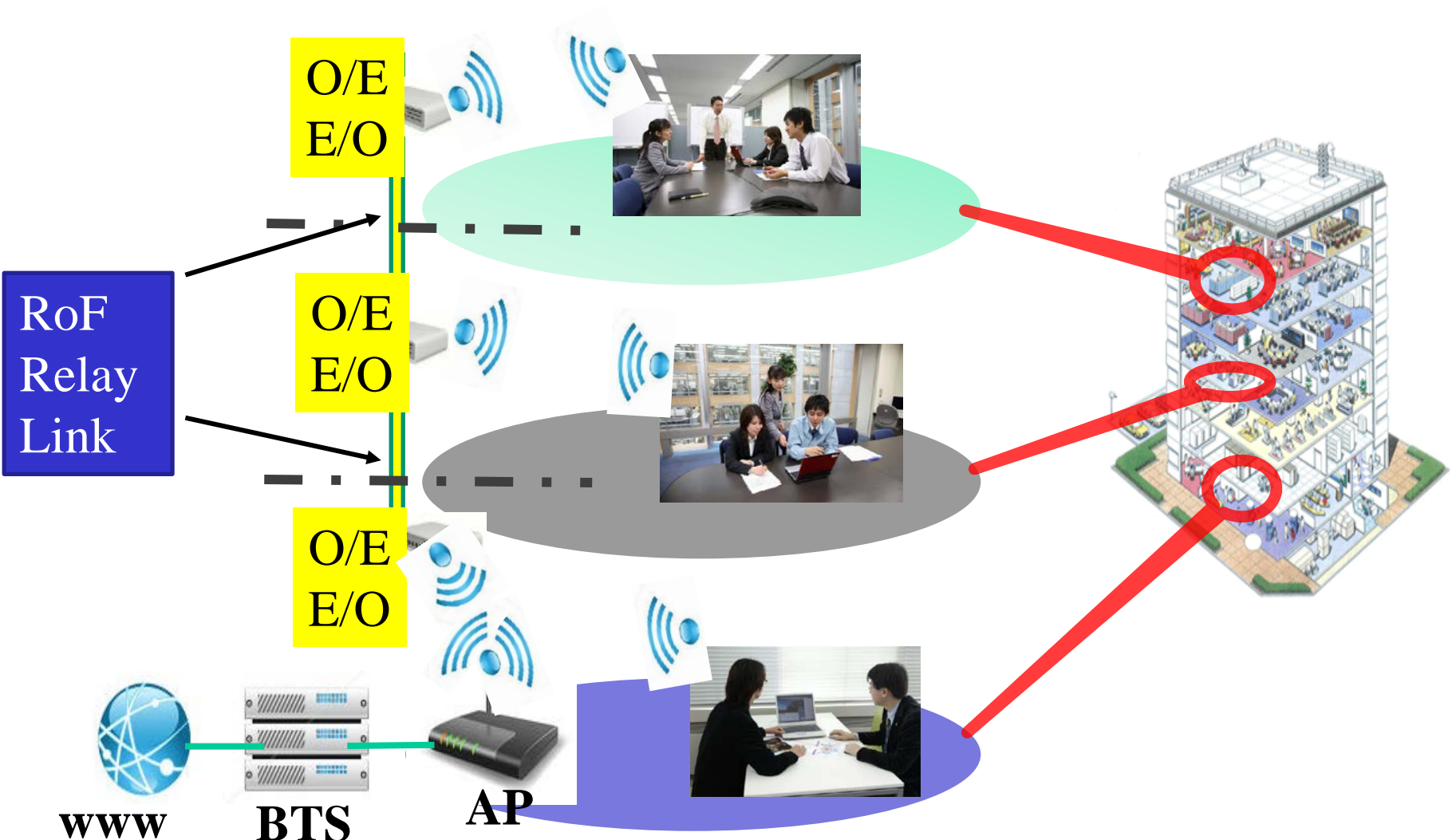
| Category               | #   | Usage Model   |
|------------------------|-----|---|
| 10. Relay Transmission | 10a | Relay Transmission between Electromagnetically Isolated Areas |

# Usage Model 10a: RoF Relay Transmission

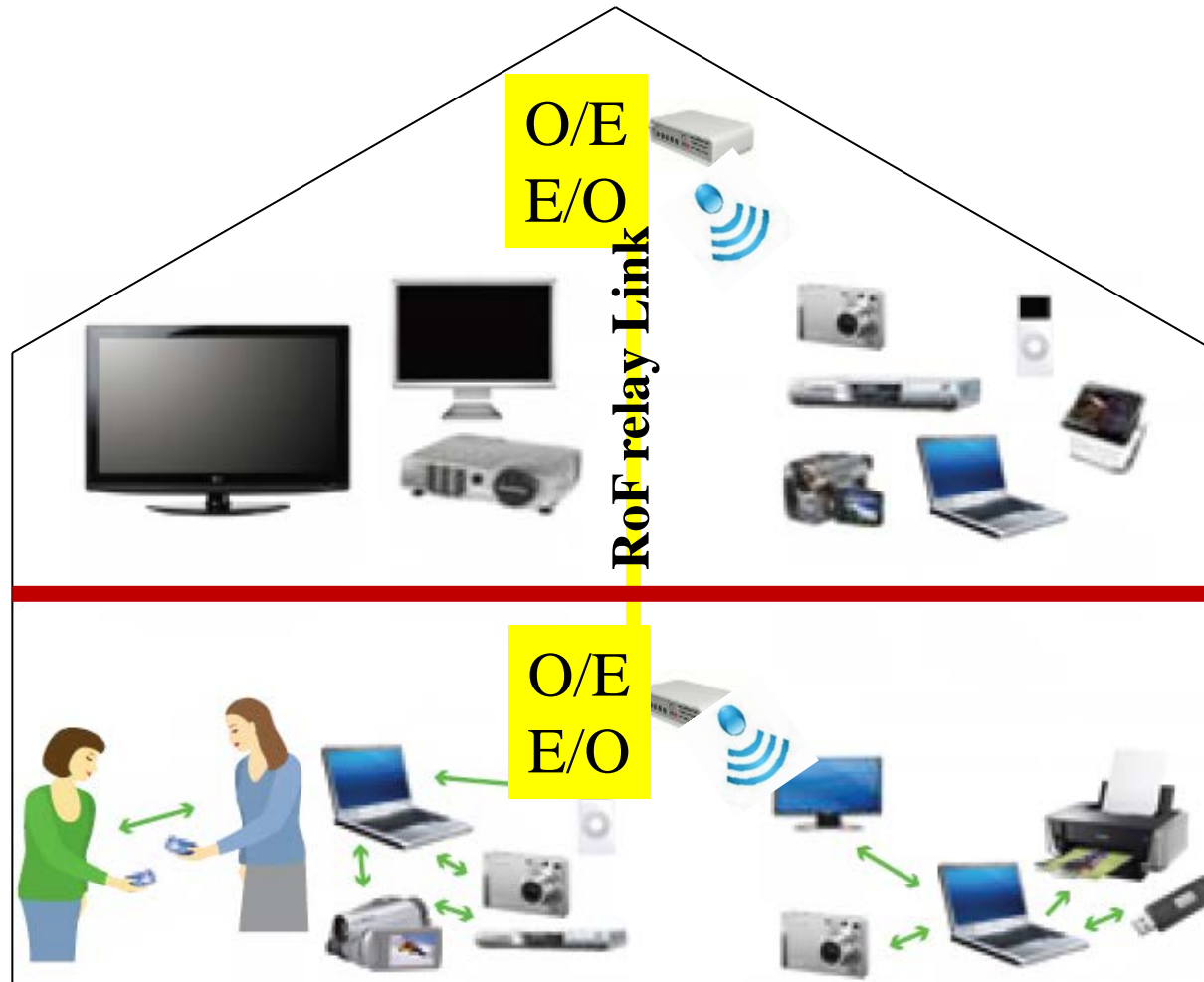


Although this example shows the relay link between the first and the second floors in the house, the idea of the relay link can be extended to connection between rooms in the apartment, hospital, school, factory and etc.

# In-Building RoF Relay Transmission Link for WLAN



# Wi-Fi Miracast™ and Wi-Fi Direct™ connection at home environment using RoF Relay Transmission Link



*45 GHz and 60 GHz frequencies cannot penetrate walls, floors and ceilings in the buildings.*



# Usage Model 10a: RoF Relay Transmission

## Pre-Conditions:

Wireless zones are connected via RoF relay link. The individual wireless zones can support high-speed-data traffic requirements that are limited by the VHT link capabilities.

## Application:

Traffic is bidirectional and is comprised of subcarrier which include data, voice, video, and any kinds of signals. These subcarriers are radio frequencies, i.e. either 45GHz or 60 GHz bands. RoF relay link extends coverage areas without any performance degradation and any changes of traffic requirements.

## Environment:

Environment can be home, office, manufacturing floor, etc. The RoF relay link distance can be extended up to 200 m due to latency of E/O and O/E conversions. Typical areas which are connected via optical fiber cables are electromagnetically isolated. No degradation of system characteristics can be managed by use of RoF relay transmission link.

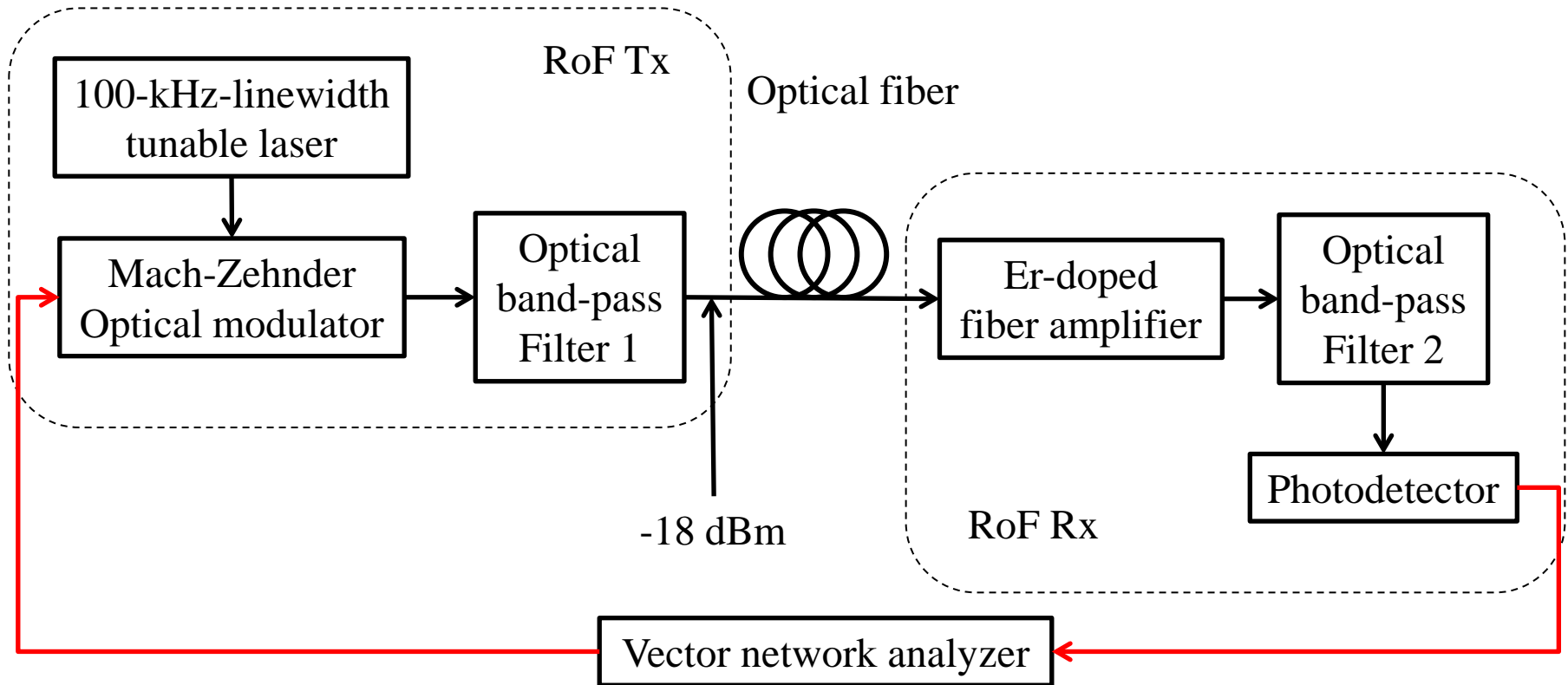
## Traffic Conditions:

RoF relay transmission link can carry any type of traffic due to broadband transmission capability and linear characteristics of E/O and O/E devices. No additional traffic conditions are introduced by RoF relay link.

## Use Case:

1. Electromagnetic isolated spaces such as rooms of houses surrounded by concretes are directly connected through RoF relay link without any digital signal processing units of relay stations.
2. In spite of physical and electromagnetic separation, one wireless zone is extended to another wireless zone through optical cables.
3. Users at different locations can take advantage of broadband multi-media applications.

# Experimental Setup 1 : Frequency Response of RoF Link



Tunable laser: Yenista optics OSICS TLS-AG (Power stability:  $\pm 0.03$  dB)

MZ modulator: GIGOPTIX LX8901 (3-dB BW:  $> 65$  GHz)

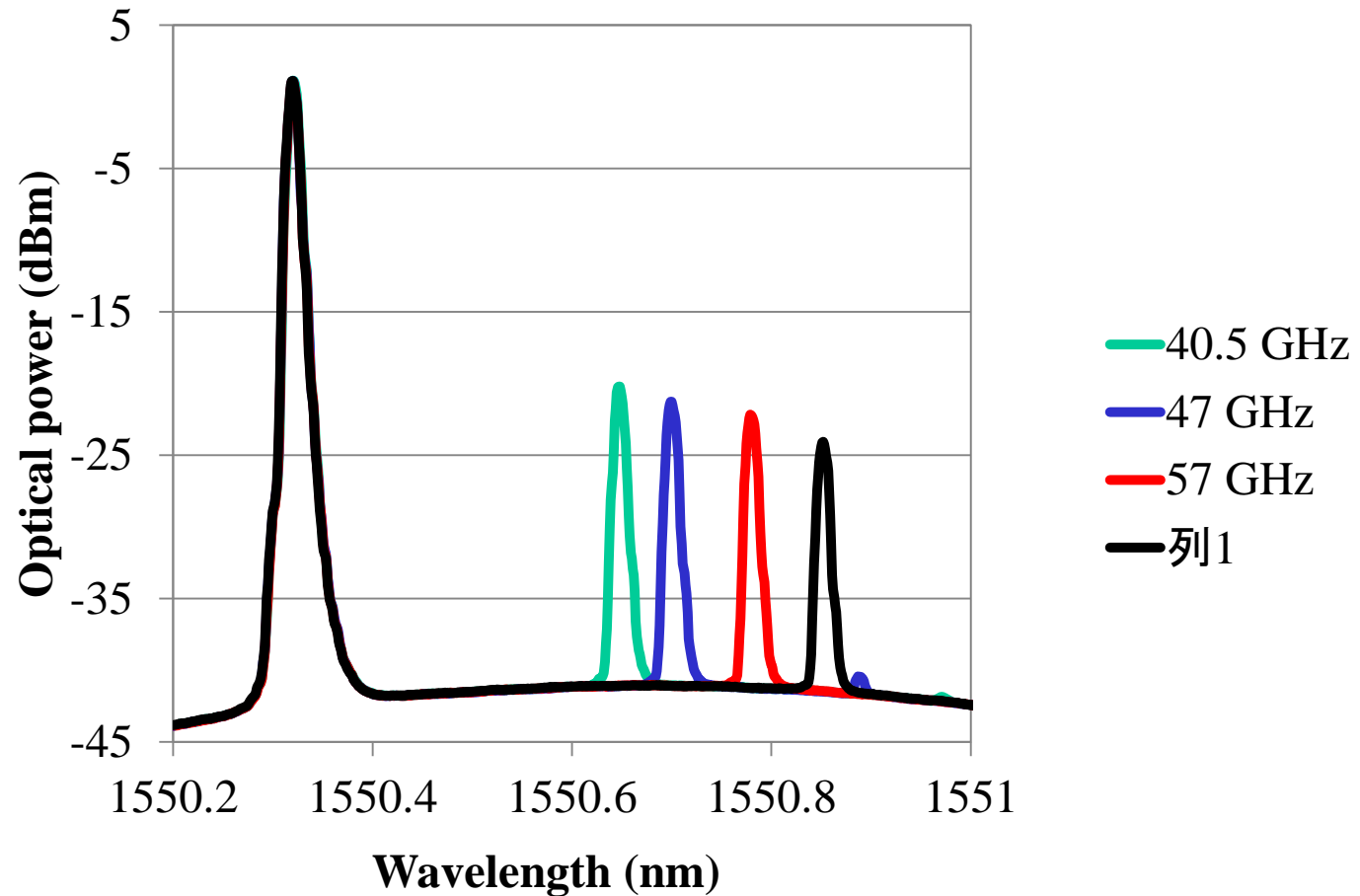
Photodetector: u2t photonics XPDV4120 (3-dB BW: 100 GHz)

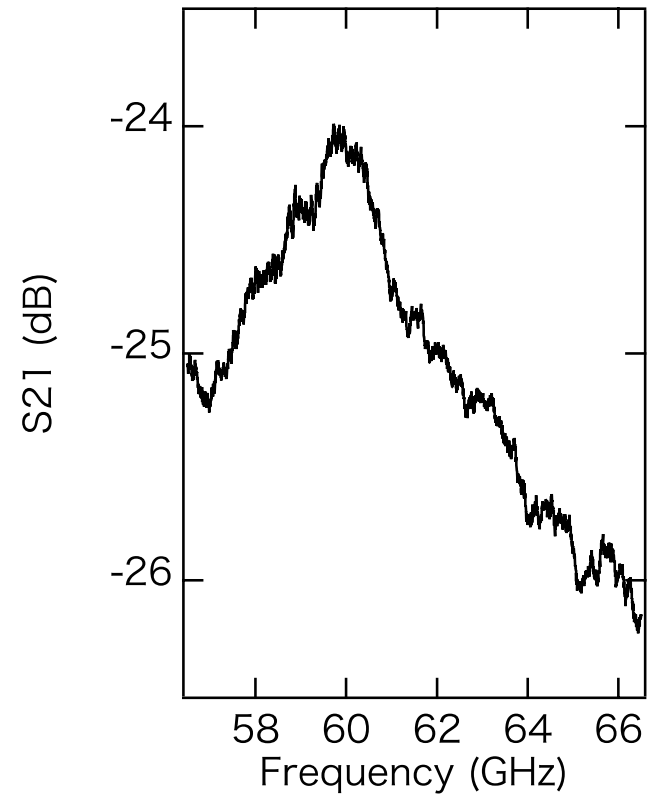
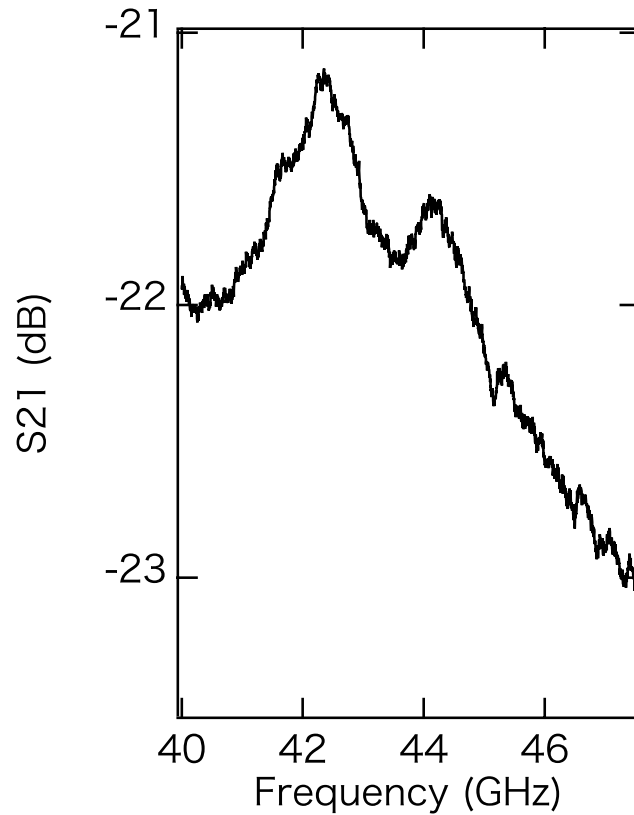
EDFA: Amonics Burst-mode EDFA (Sat. power 20 dBm, NF:  $< 5.5$  dB)

Bandpass filter1: BW  $> 1$  nm for generation of single sideband signal

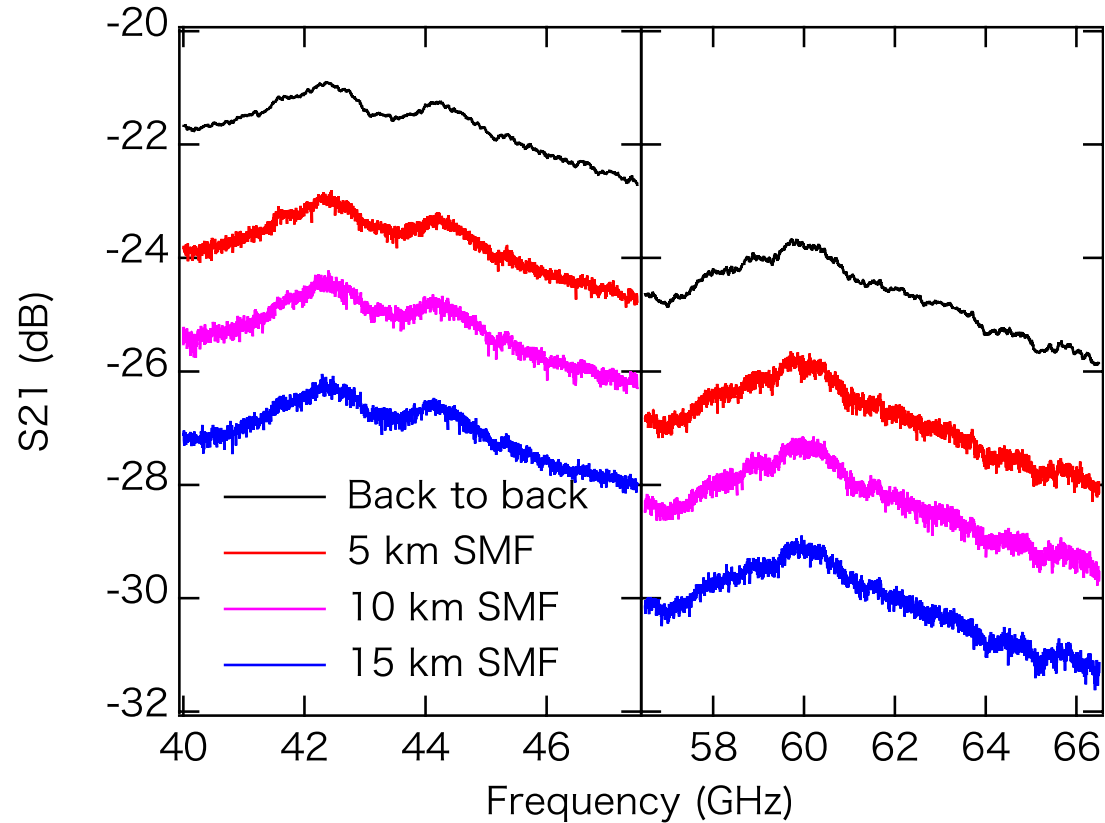
Bandpass filter2: BW  $\sim 1$  nm for suppression of ASE noises from EDFA

# Subcarrier Transmission of RoF Relay Link

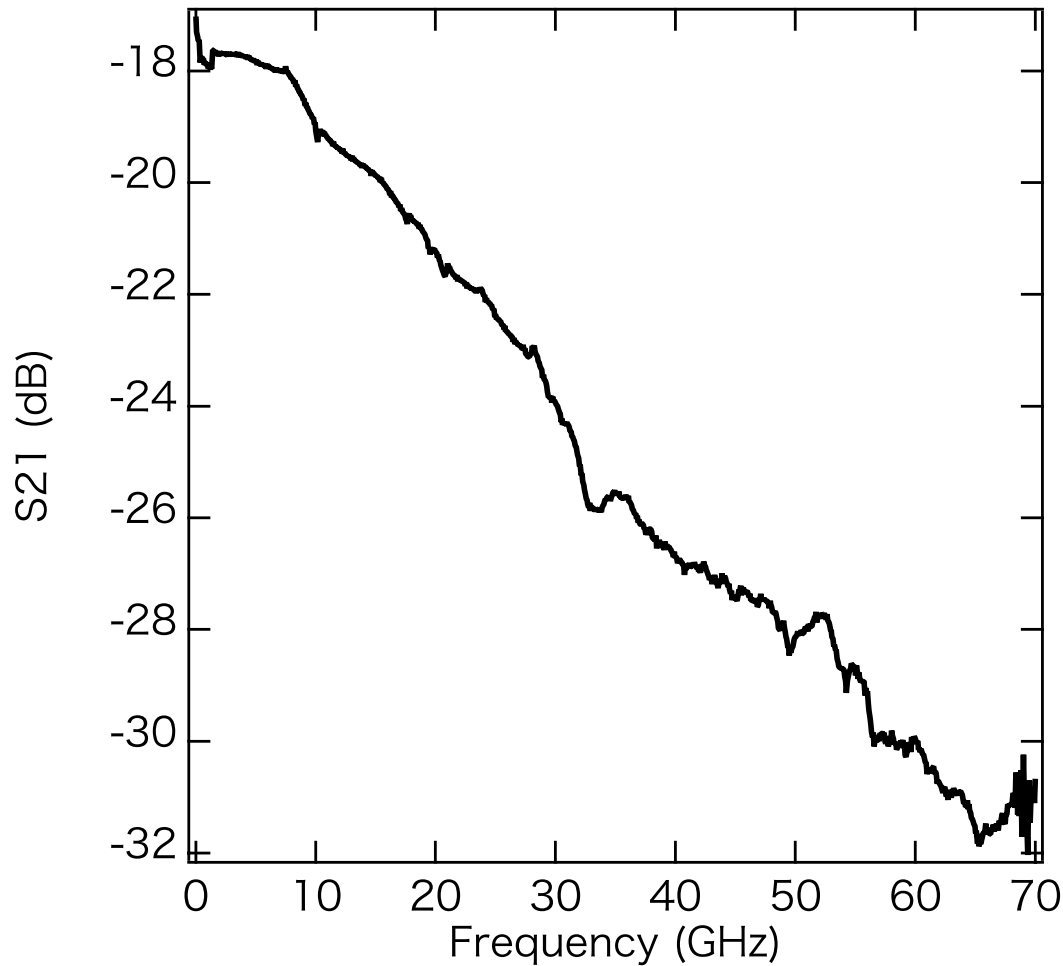




Amplitude Deviation:  $< 2$  dBp-p at 40.5-47 GHz  
 $\sim 2$  dBp-p at 57-66 GHz



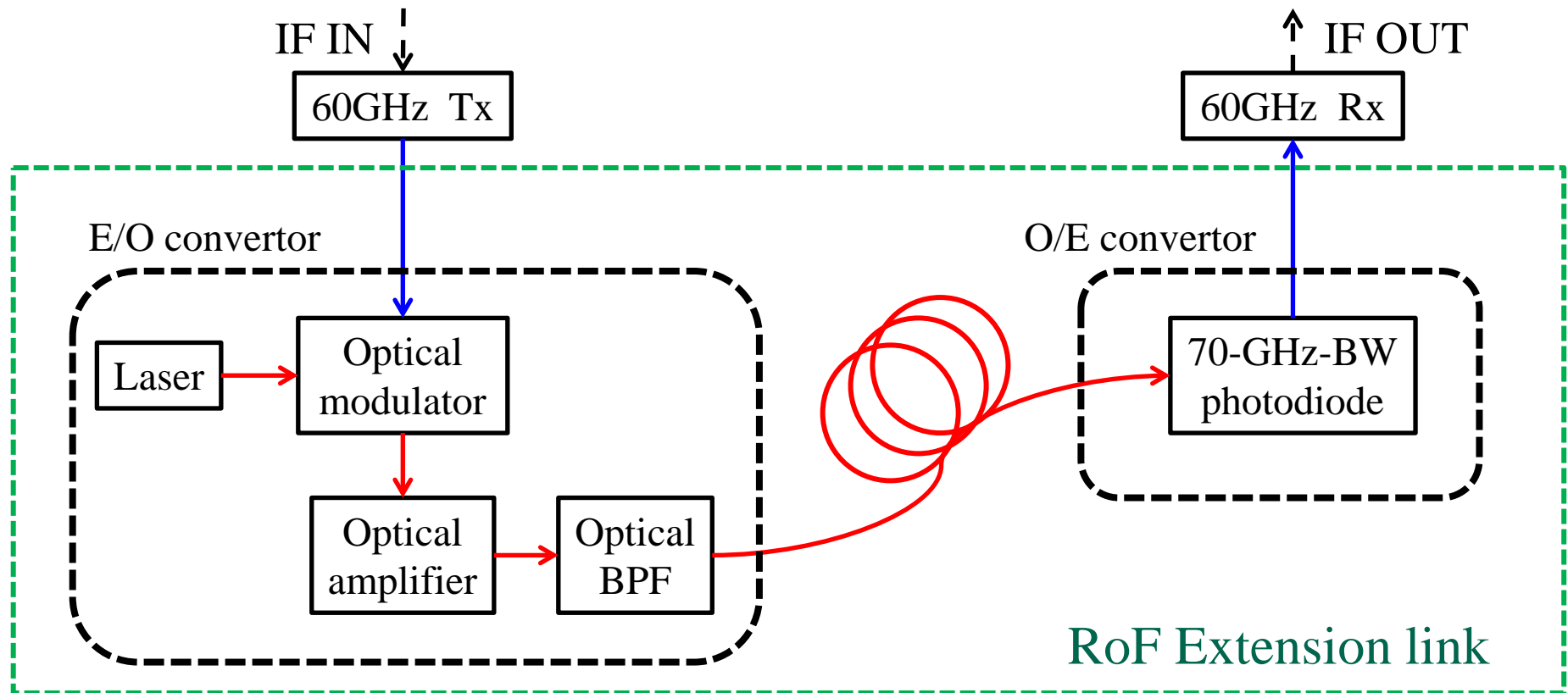
Frequency response of RoF link at 40-48 GHz and 56-67 GHz bands



Measured link loss:  
~ -28 dB @ 40GHz  
~ -31 dB @ 60GHz

## Broadband frequency characteristics of RoF link

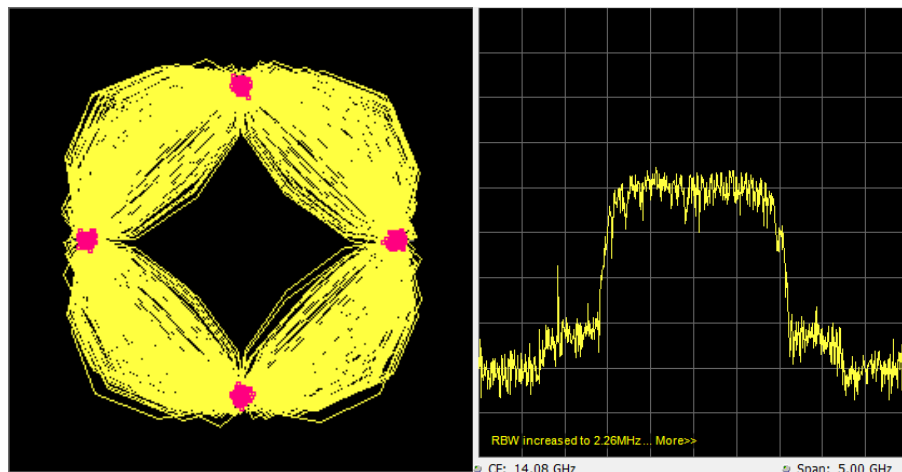
# Experimental Setup 2 : Single-Side-Band Modulated Signal Transmission of RoF Relay Link using IEEE802.11ad Signal



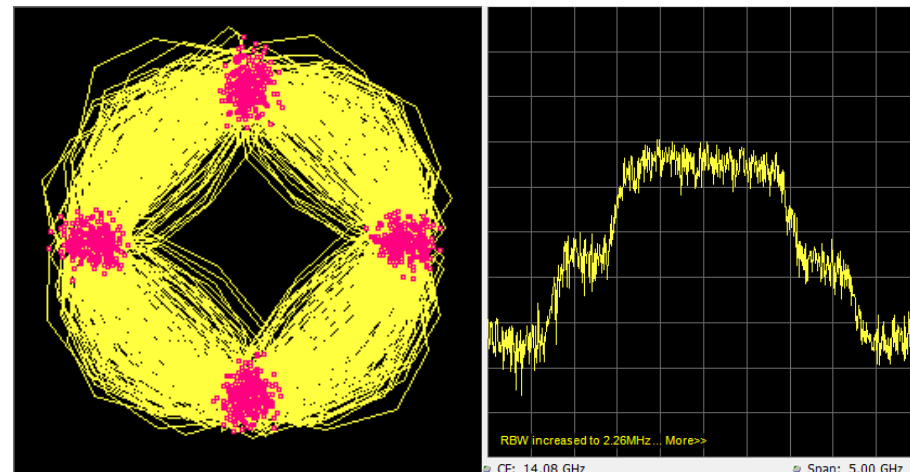
# 60-GHz $\pi/2$ -BPSK Signal Transmission Experimental Results (1)

RF Back to Back

180m RoF Extension link



EVM: 3.3% (-29.6dB)

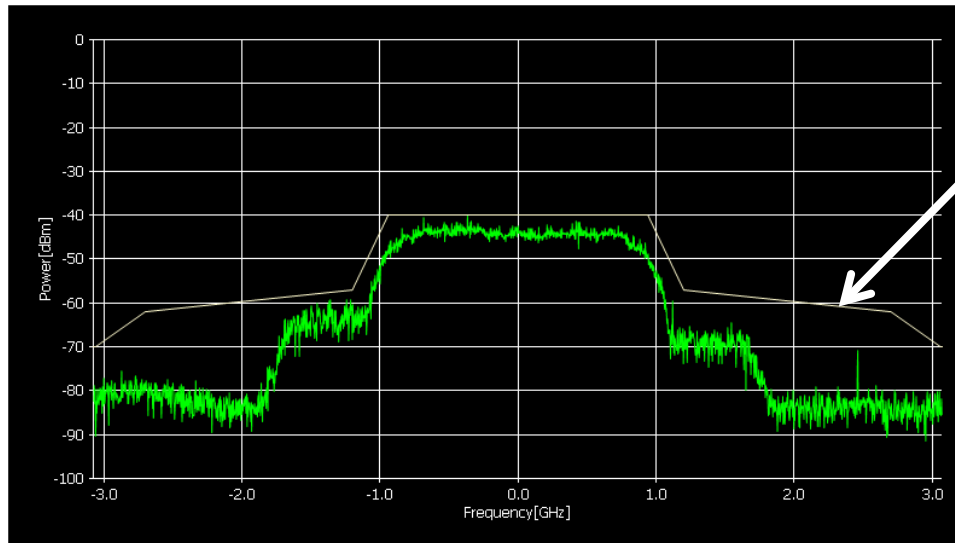


EVM: 12.7% %(-17.9dB)



# 60-GHz $\pi/2$ -BPSK Signal Transmission

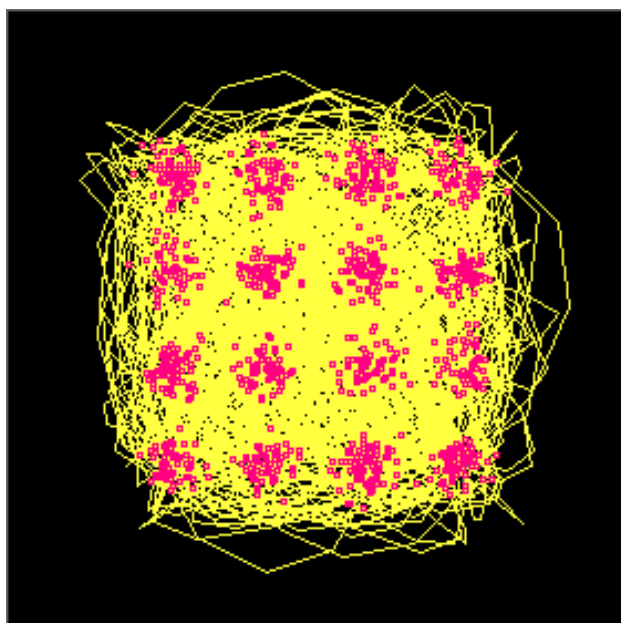
## Experimental Results (2)



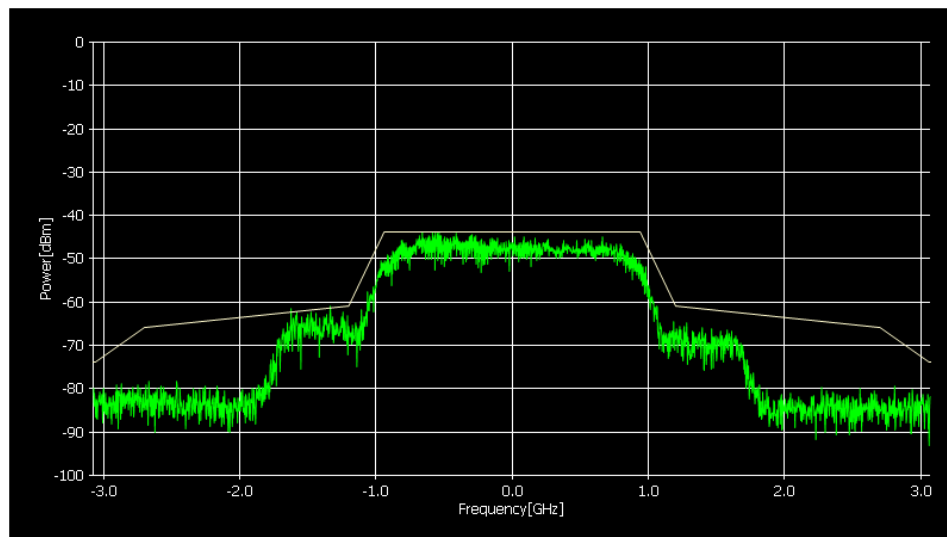
Required spectrum  
mask at channel 4  
of 802.11ad

Ch.4 ( $f_c=64.80$  GHz)

# 60-GHz 16QAM Signal Transmission Experimental Results

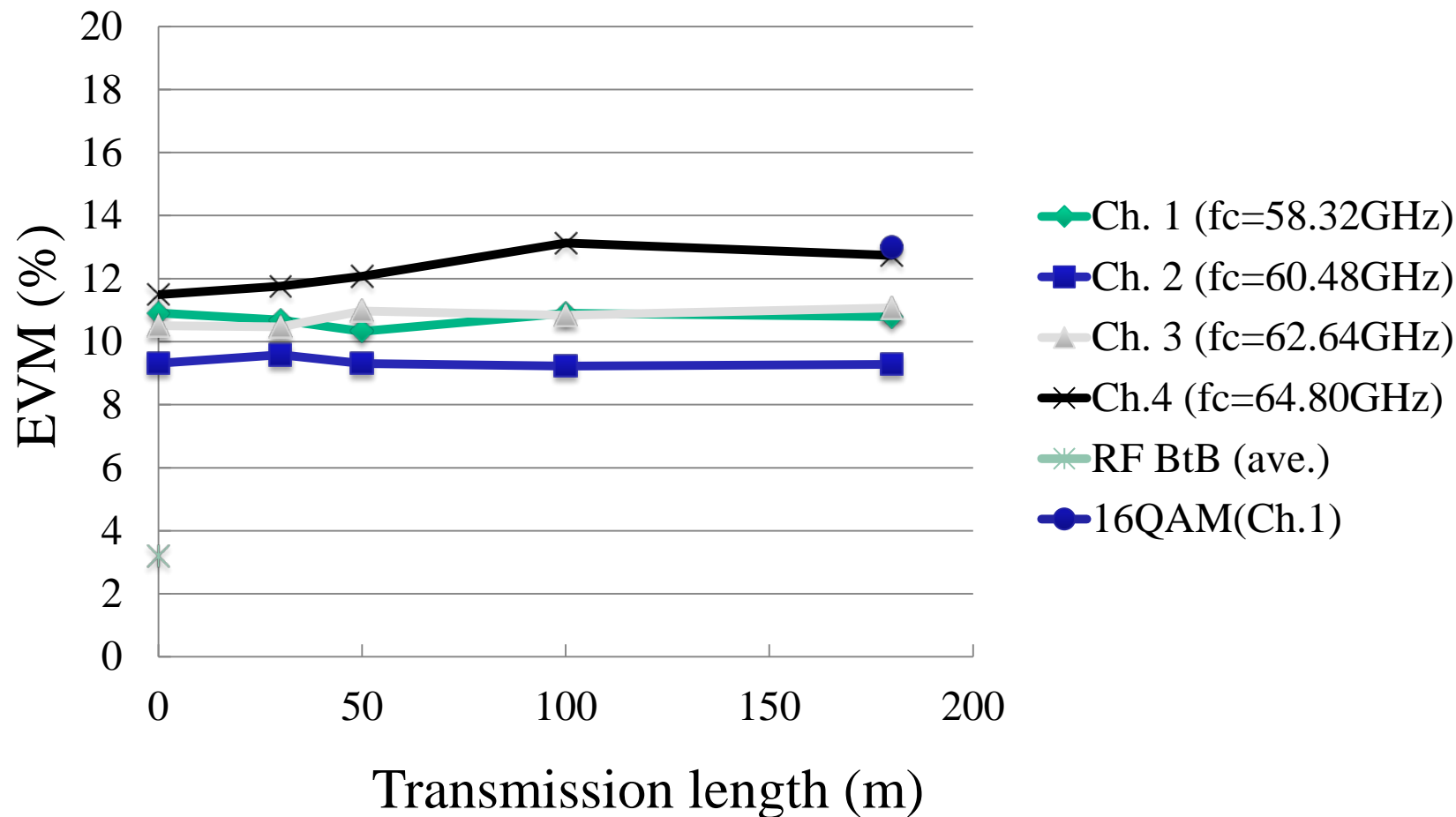


EVM : 14% (-17dB)

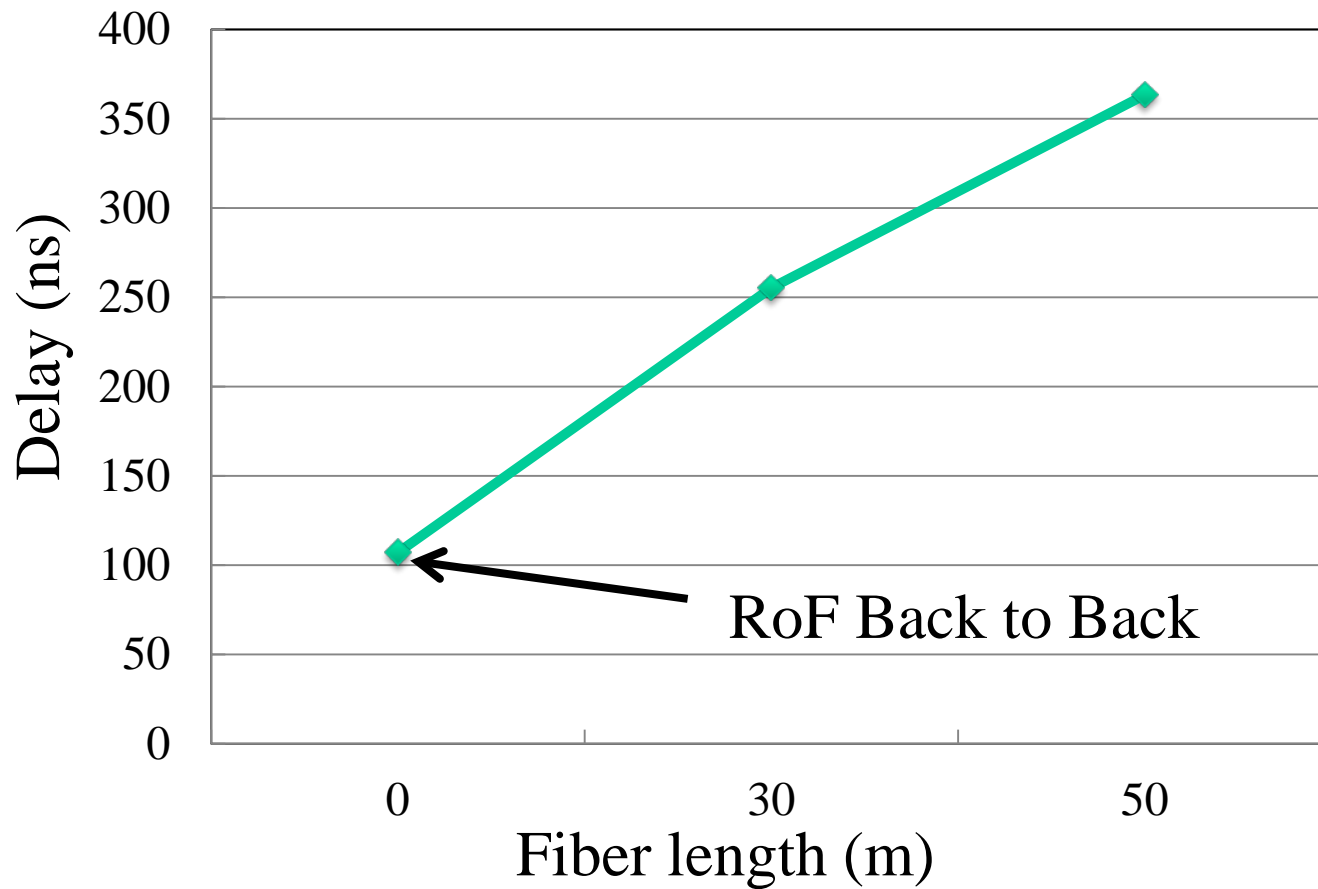


Ch.4 (fc=64.80 GHz)

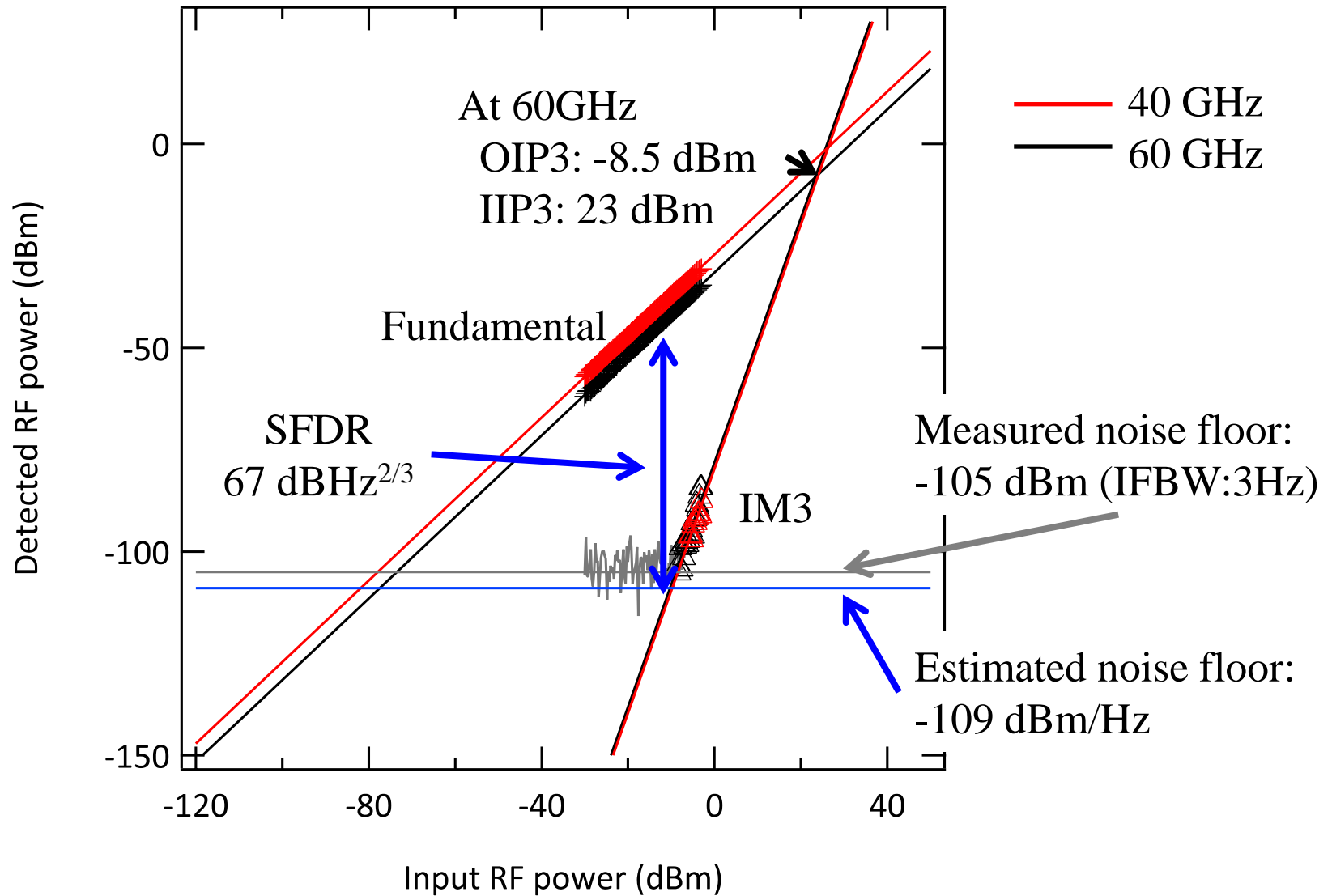
# EVM (Error Vector Magnitude) vs. Fiber Length



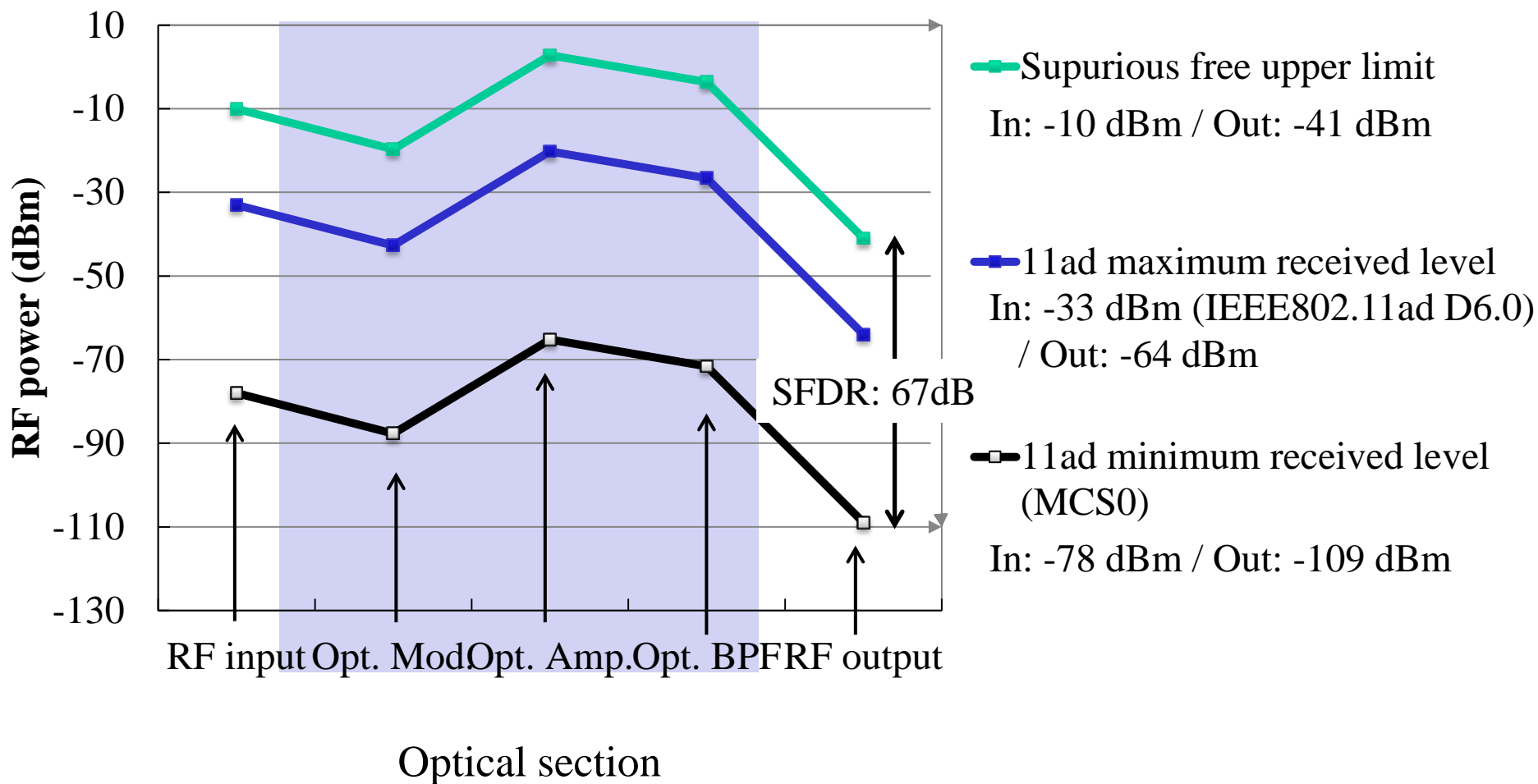
# Delay Time of RoF Relay Link



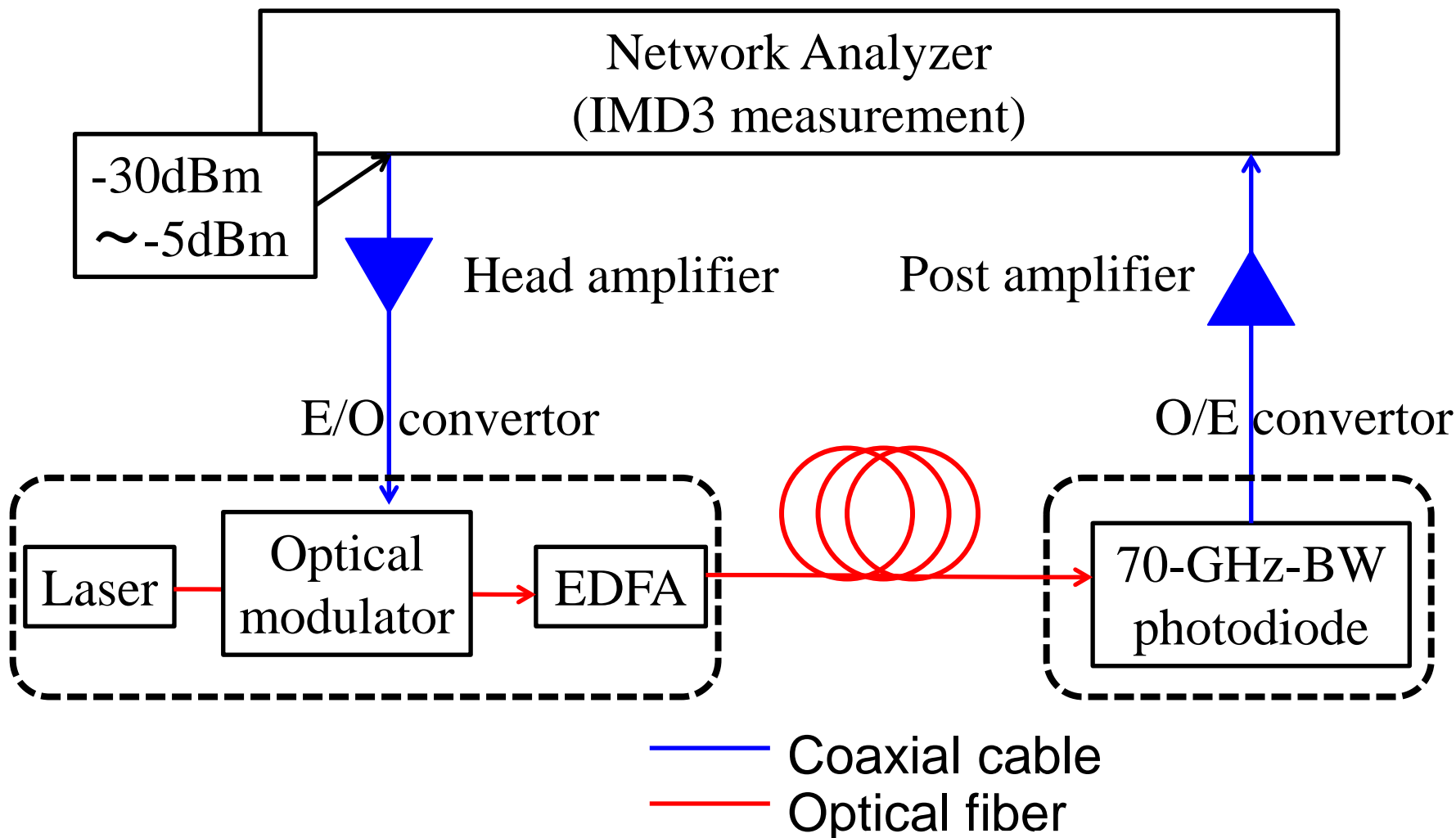
# Spurious Free Dynamic Range of RoF Relay Link



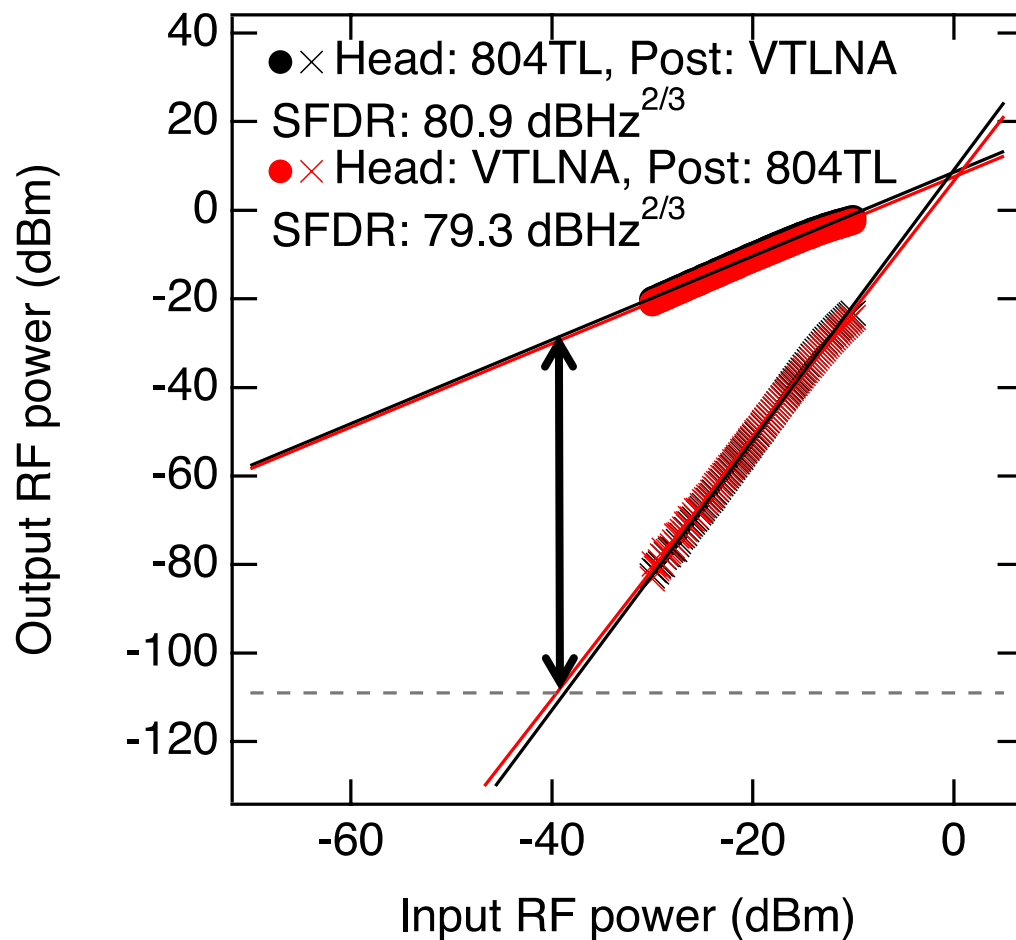
# Level Diagram of RoF Relay Link



# Experimental Setup 3 : SFDR of RoF link with head- and post-amplifier.



# Improved SFDR of RoF Relay Link with Coaxial/WG Amplifiers



SFDR  
~ 80 dBHz<sup>2/3</sup>

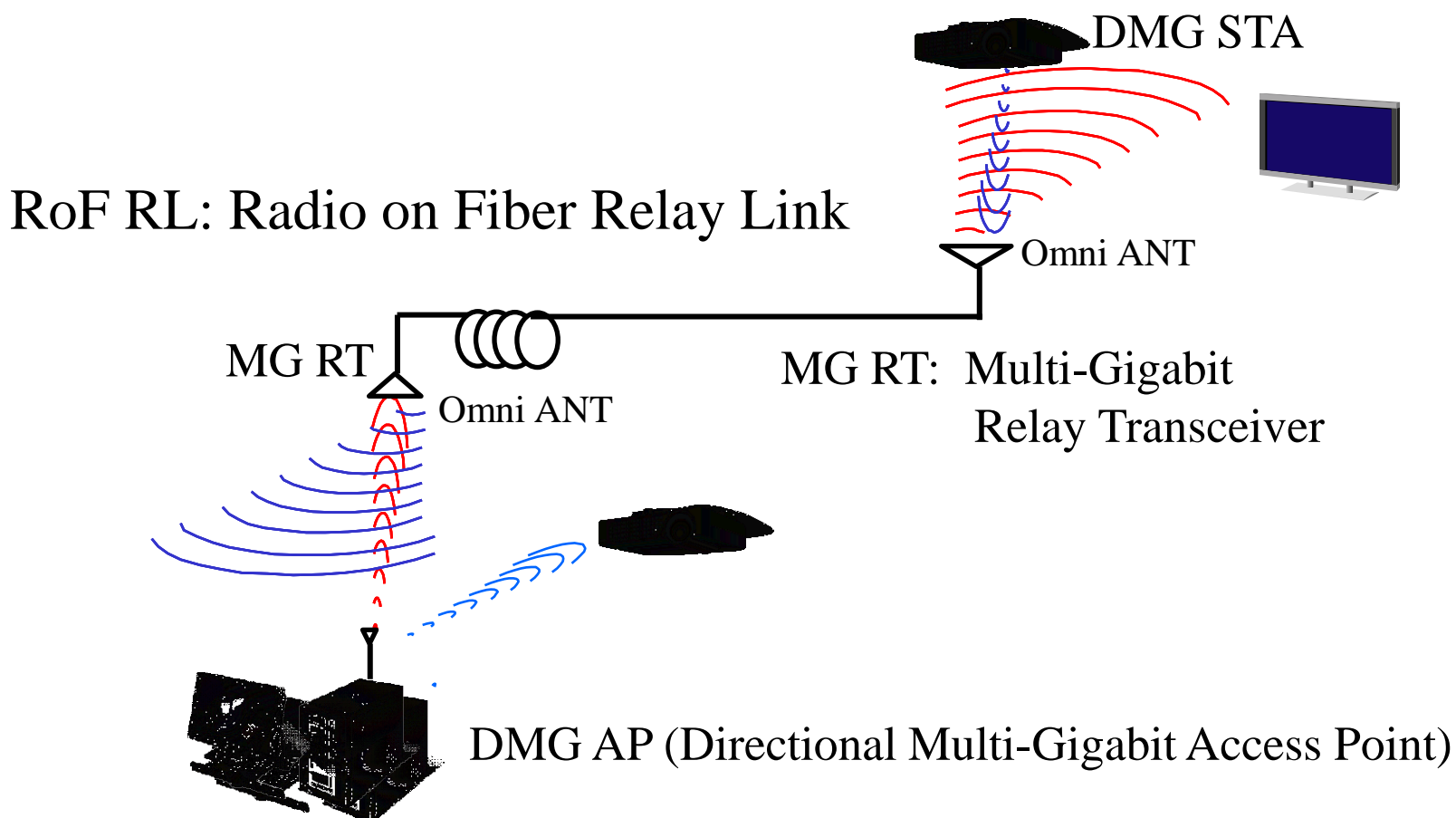


# Specification of MG RT Link

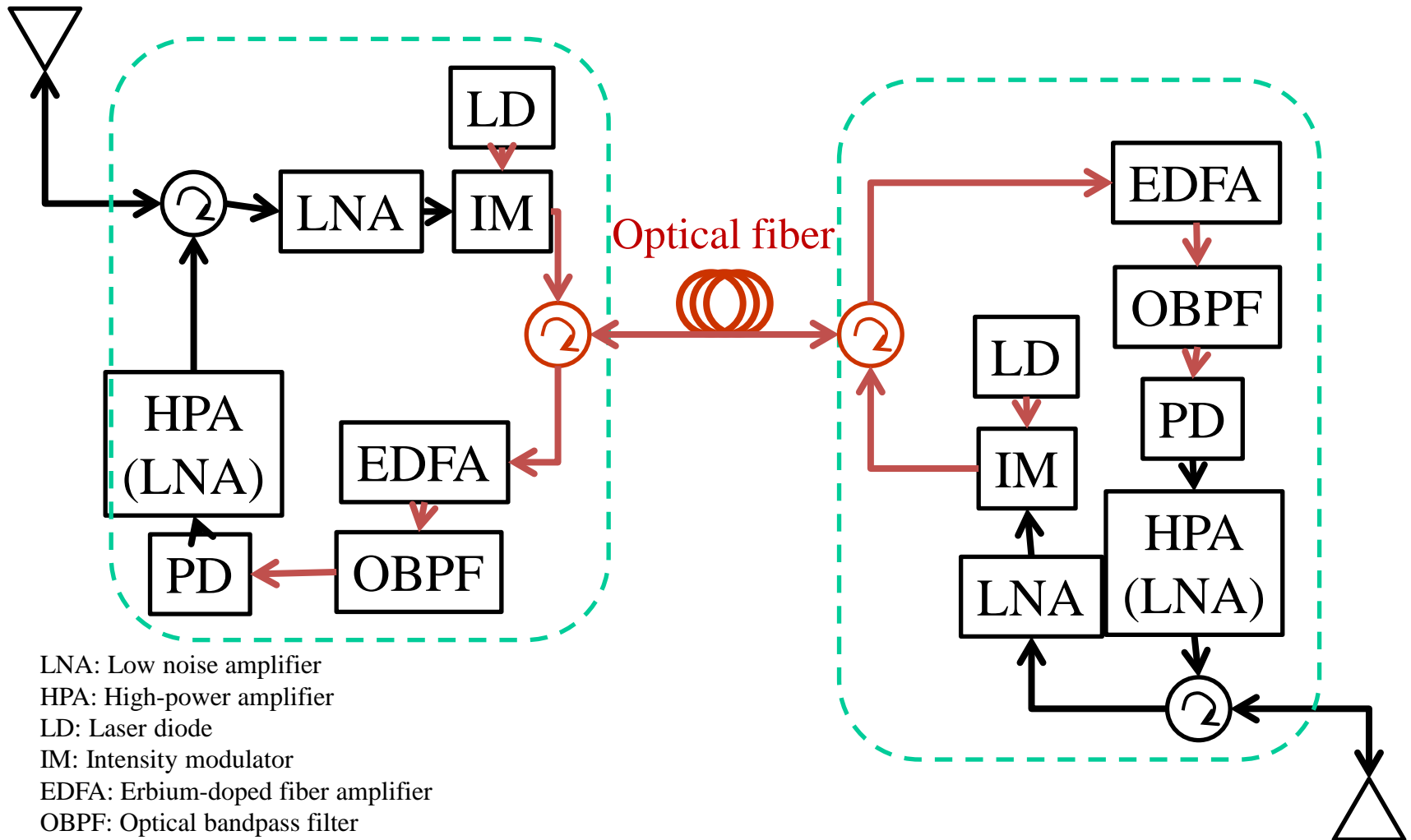
|  |  |
|--|--|
| Bandwidth  | 60 GHz +/- 1GHz                                      |
| Gain<br>(at optical input power of +8 dBm)         | -7 to 8 dB<br>(depends on config.)                   |
| Noise figure<br>(at optical input power of +8 dBm) | ~8 dB  |
| Latency  | <100 ns  |
| Optical wavelength                                 | 1550 nm  |
| Optical output power at E/O                        | +8 dBm   |
| Receivable input power at O/E                      | -20 dBm min. /+8 dBm max.<br>(changes Gain and NF)   |
| SFDR<br>(at optical input power of +8 dBm)         | 84 to 70 dBHz <sup>2/3</sup><br>(depends on config.) |

# AP-MG RT-RoF RL-MG RT-STA Uplink/Downlink

- No additional requirement for Beamforming Training -
- No frequency interference among STAs due to CSAM/TDMA -

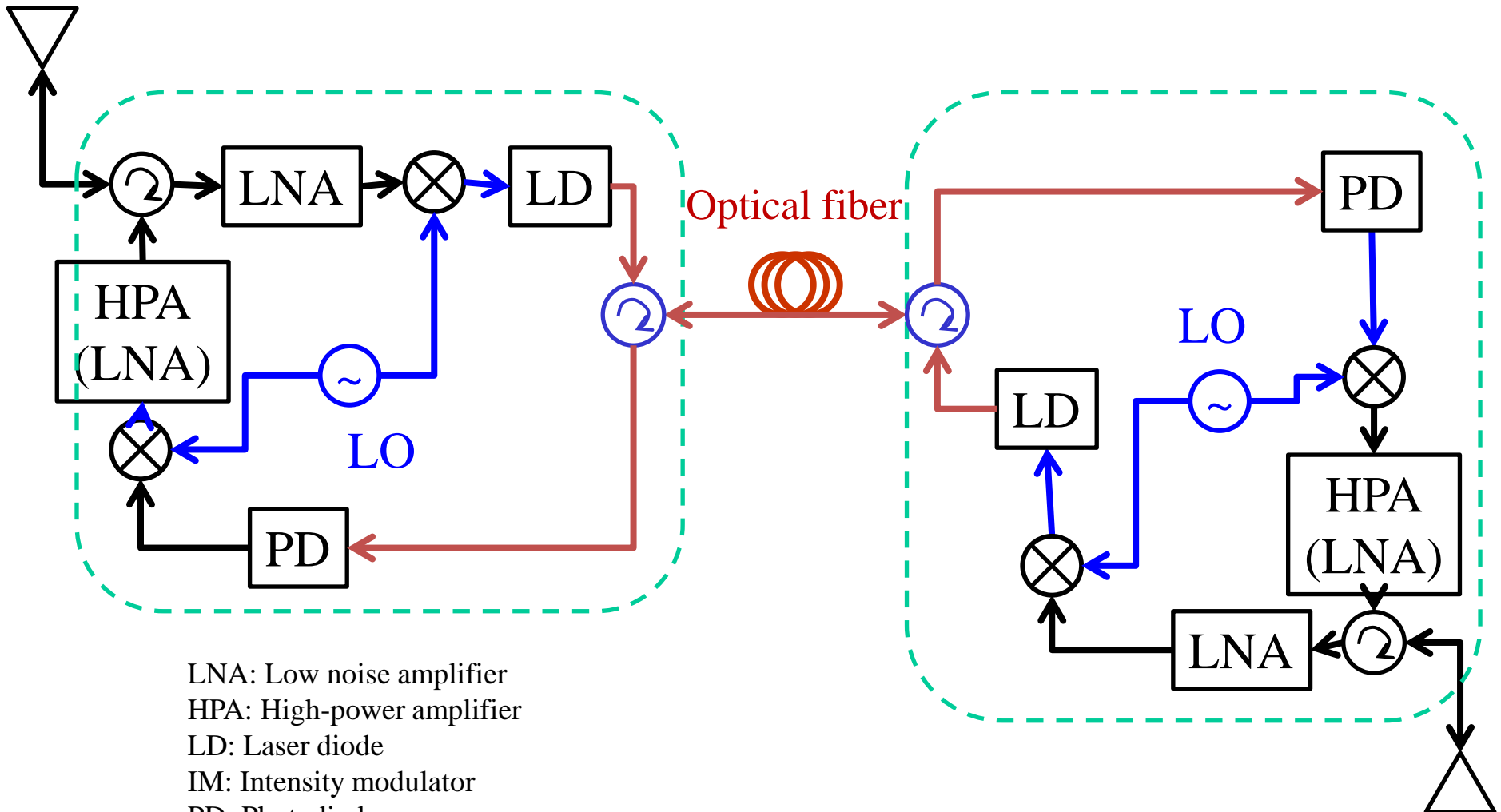


# Block Diagram for RF-over-Fiber based MG RT Link



LNA: Low noise amplifier  
 HPA: High-power amplifier  
 LD: Laser diode  
 IM: Intensity modulator  
 EDFA: Erbium-doped fiber amplifier  
 OBPF: Optical bandpass filter  
 PD: Photodiode

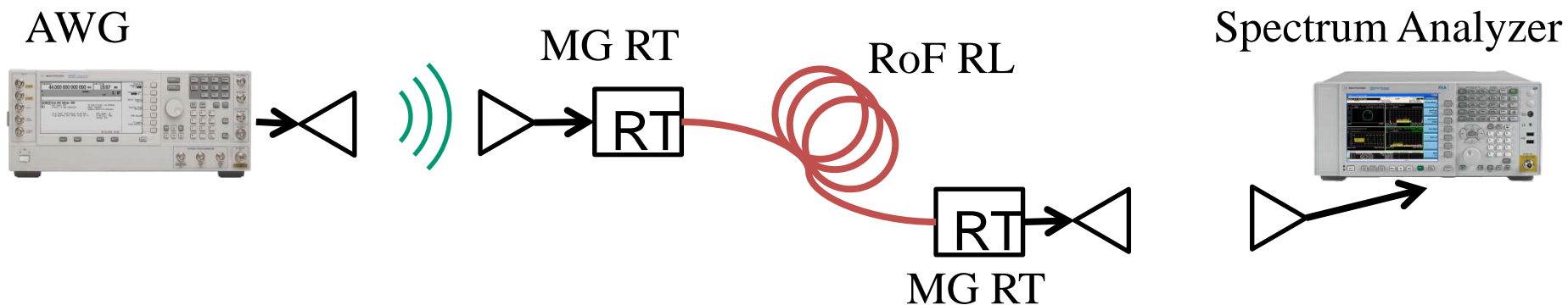
# Block Diagram of IF-over-Fiber-based Simplified MG-RT Link



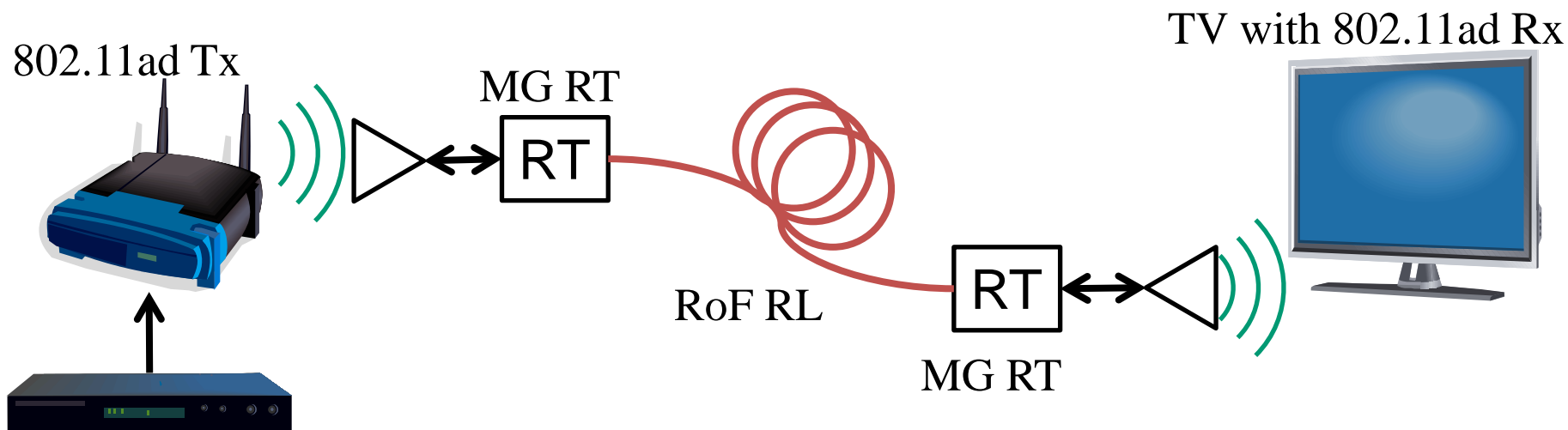
LNA: Low noise amplifier  
 HPA: High-power amplifier  
 LD: Laser diode  
 IM: Intensity modulator  
 PD: Photodiode

# Future Experimental Work

## Step 1:



## Step 2:



# Standards related to Indoor Use of Optical Fiber Cable

- IEC60793-2-40 Ed.4.0 Optical fibers – Part 40: Product specifications – Sectional specification for category A4 multimode fibers

Technical Paper published by Optoelectronic Industry and Technology Development Association (Japan)

- TP02/BW-2011 - Optical fiber distribution system for apartment houses in FTTH
- TP01/BW -2011 - Optical fiber distribution system for detached houses in FTTH
- OITDA/TP03/BW-2012 - Optical fiber distribution system for customer premises

# Summary

- RoF relay transmission link was proposed as a new usage model.
- RoF relay link can extend wireless access area using E/O, O/E and optical fiber without any additional requirements.
- Data transmission experiment of RoF relay link using 802.11ad signal were presented and EVM of transmitted signals are less 14 %.
- Additional delay time caused by RoF relay link is about 350 ns at a fibre cable length of 50 m.
- Maximum length of fibre cable is about 100 m taking into account CCA (Clear Channel Assessment).
- Spurious free dynamic range of RoF relay link is improved up to 80 dBHz<sup>3/2</sup>.
- 802.11ad devices will be used to transmit HD signals through RoF relay link for evaluation and demonstration.

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