Photonic Generation of Millimeter Wave Signals for Wireless Applications

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Outline

- Introduction
- Utilization of Millimeter Waves
- Optical Modulation Scheme
- Harmonic Distortion
- Performance Analysis
- Results
- Conclusion

Millimeter Wave RoF

- Wireless transmission in the lower microwave band is congested by applications such as Wi-Fi, GSM, etc.
- Some other new wireless technologies (e.g. WiMAX) are still handled within the lower microwave regions (2–4 GHz).
- In United States, the 60 GHz band can be used for unlicensed short range (1.7 km) data links with data throughputs up to 2.5 Gb/s.
- Propagation characteristics of the 60 GHz band like oxygen absorption and rain attenuation limits the range of communication systems using this band.
- Geographical consideration is crucial for antenna base stations (BSs) installment.
- Because of large number of required BSs and the high throughput of each BS, deployment of an optical fiber backbone is beneficial.

Why 60 GHz Band?

Bandwidth-traffic (57 GHz – 64 GHz)

License-Free Spectrum

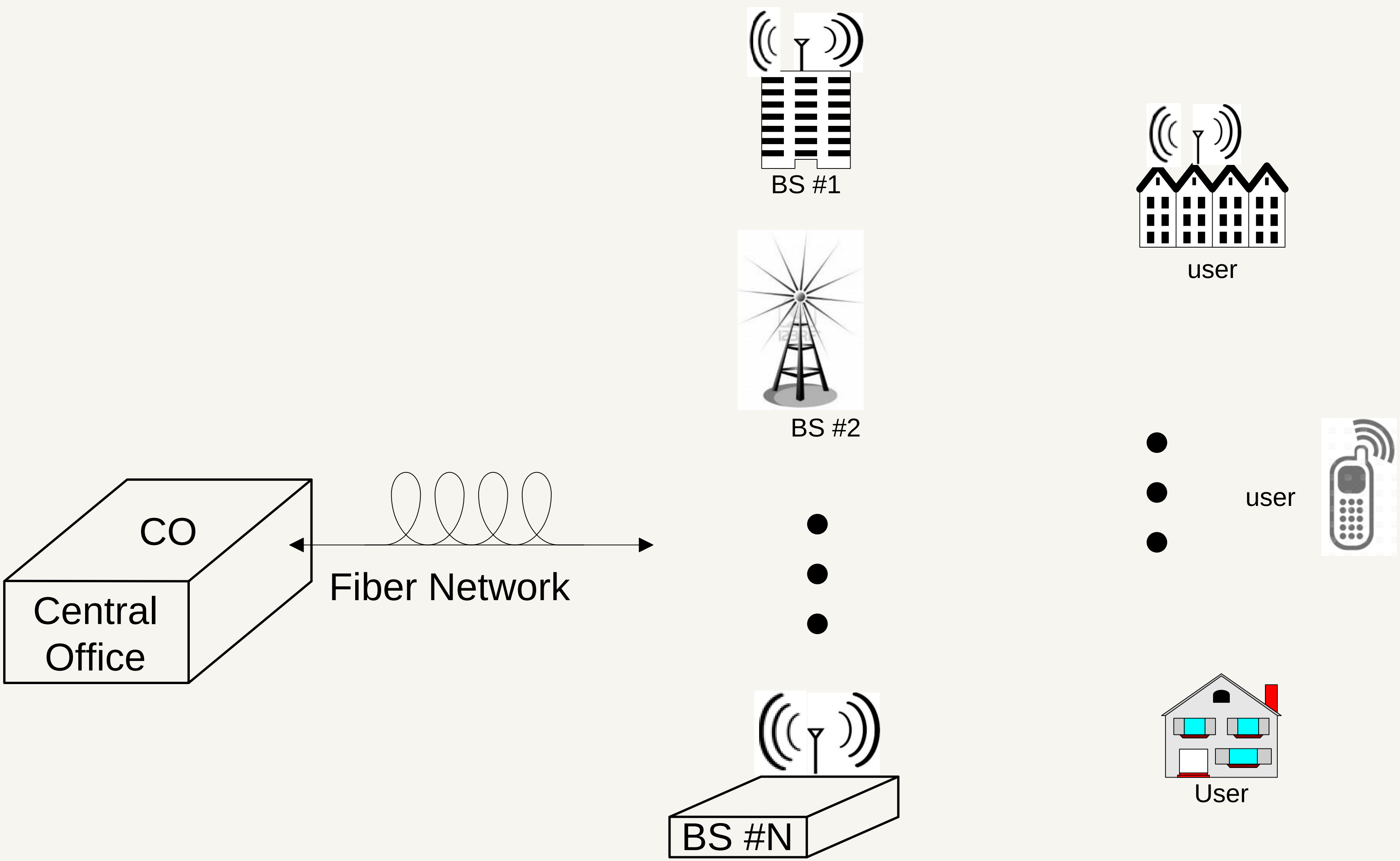
Narrow Beam Antennas (Multiple Antennas)

Highly Directional, "pencil-beam" Signal

Easy to Install and Align

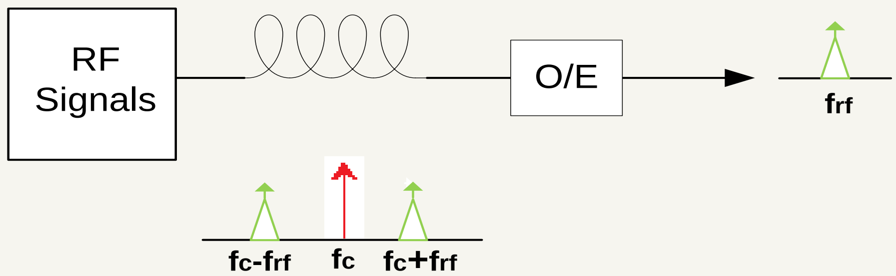
Oxygen Absorption and Security (Reduced Interference)

Optical Network for RoF Transmission

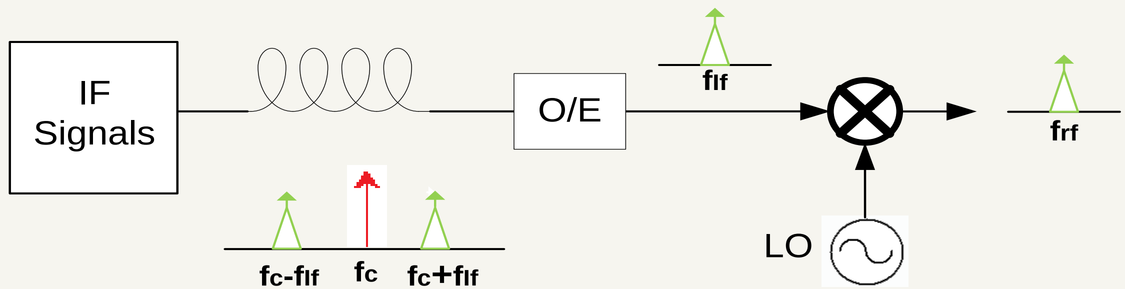


Methods of Transmitting the mm-wave Wireless Signals over the Optical Fiber

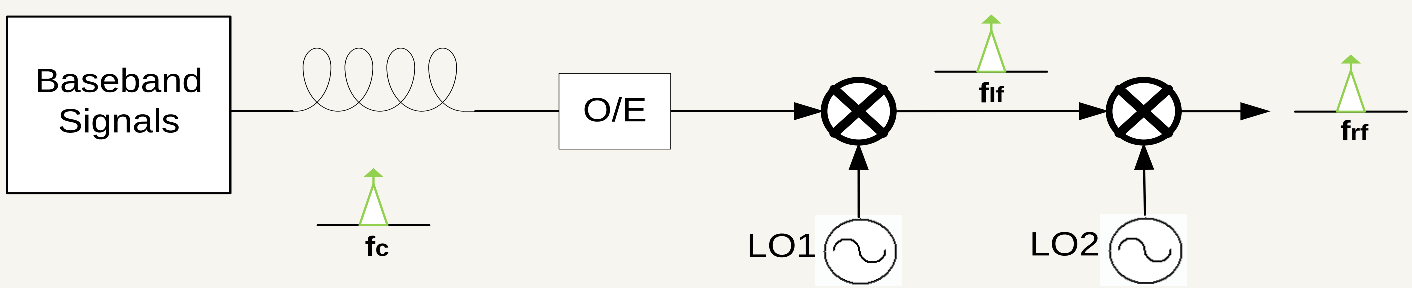
- *RF over Fiber*



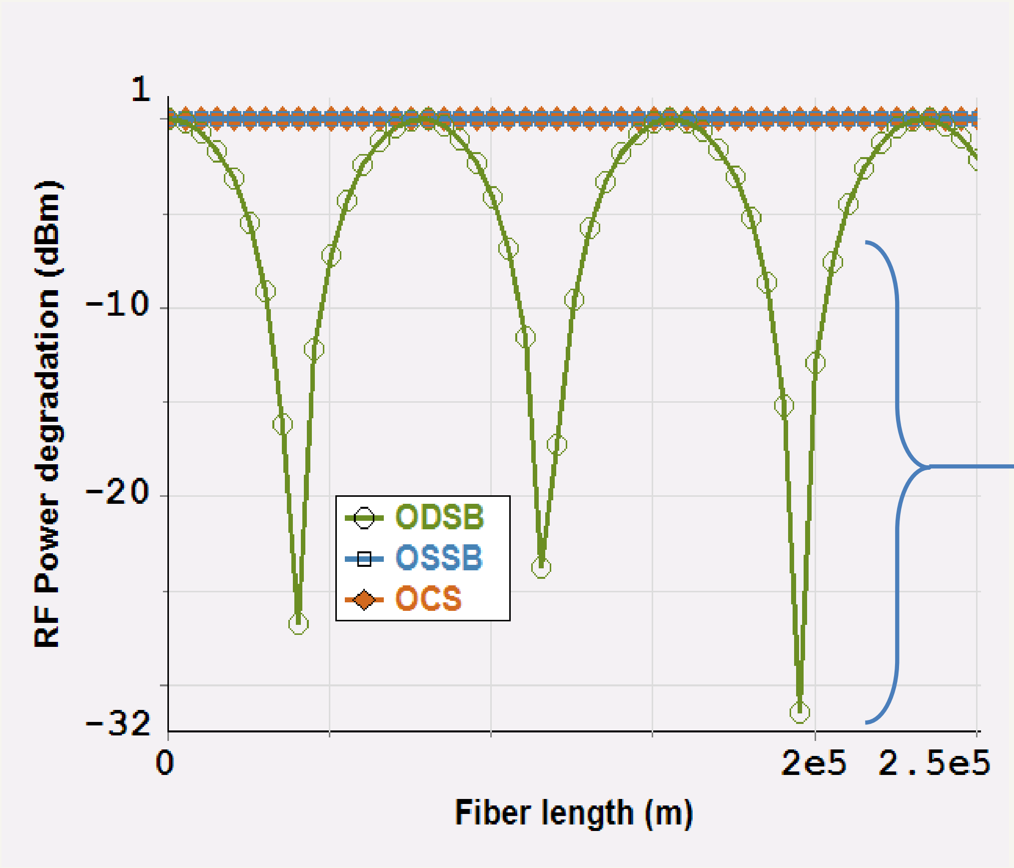
- *IF over Fiber*



- *Baseband over Fiber*



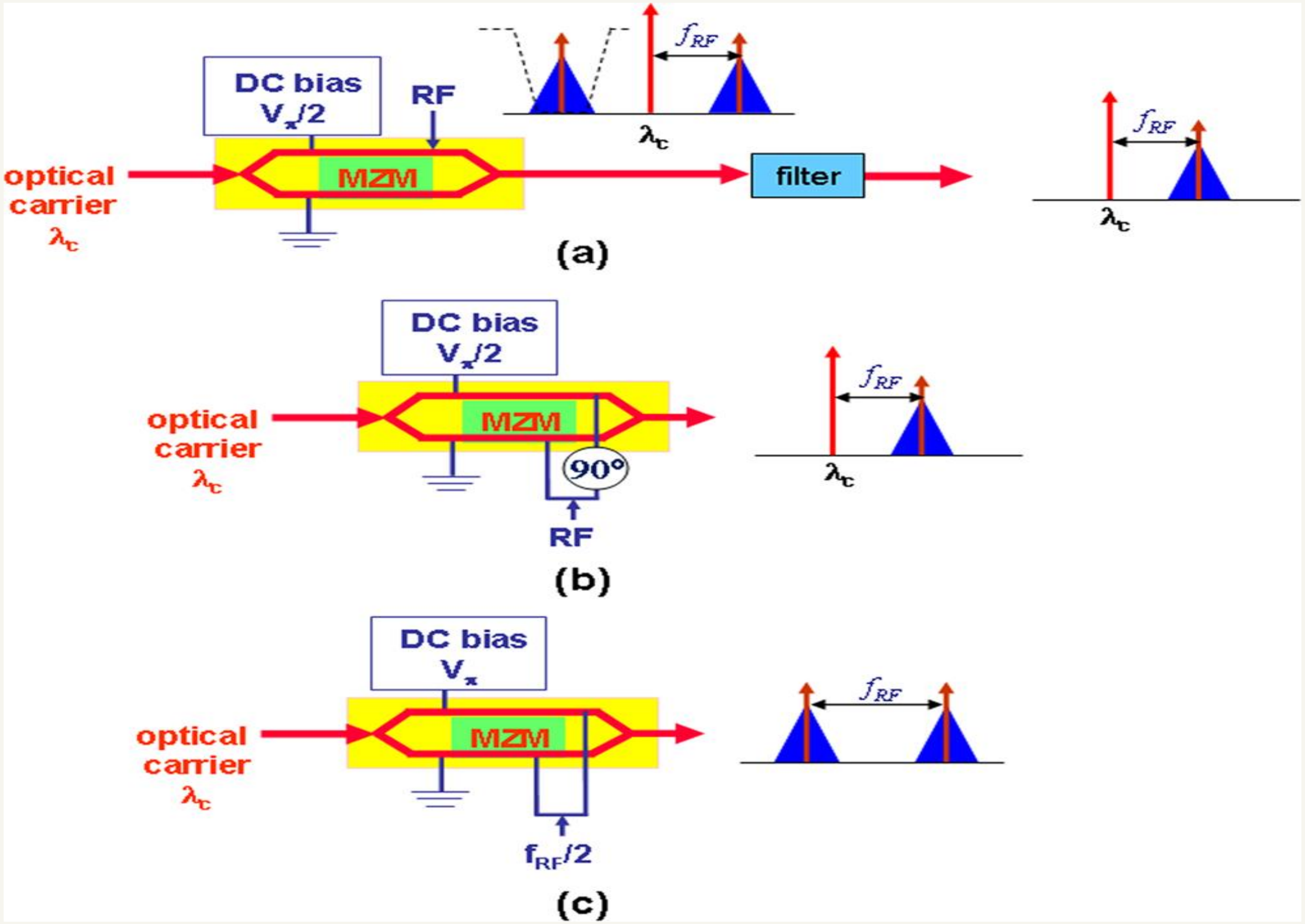
RF Power Degradation Versus Fiber Length for ODSB, OSSB, OCS Modulation Formats



$$\Delta P_{rf} \approx cos^2\left(\pi cLD\left(\frac{f_{rf}}{f_c}\right)^2\right)$$

Power Fluctuation

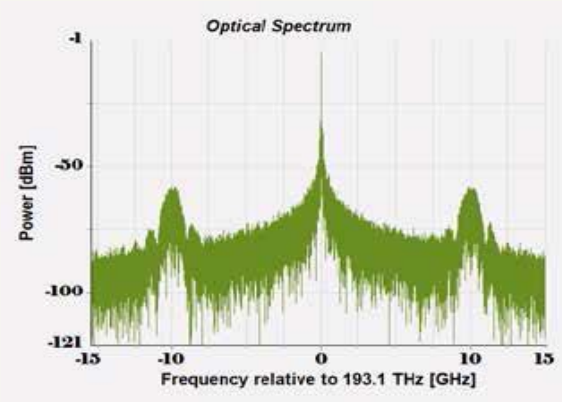
ODSB, OSSB, and OCS



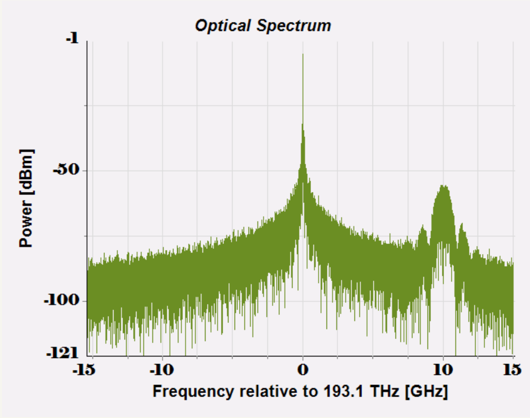
C. Lim, et. al., "Fiber-Wireless Networks and Subsystem Technologies," Light Tech. J., vol. 28, pp. 390–405, Feb. 2010

Overcoming Fiber Chromatic Dispersion

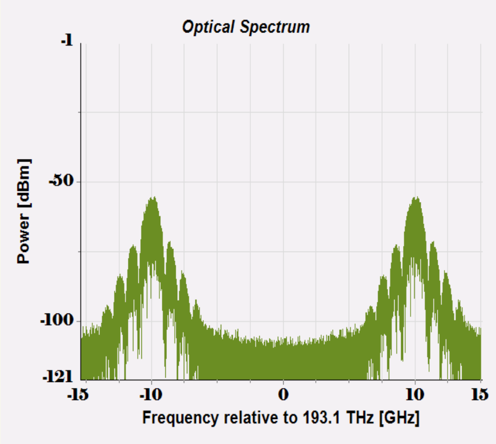
The fiber dispersion effect on optically transmitted signals is critical to be controlled specifically for long fiber link. For eliminating this impairment OCS and OSSB techniques can be used



ODSB: MZM is biased at $\frac{V_\pi}{2}$



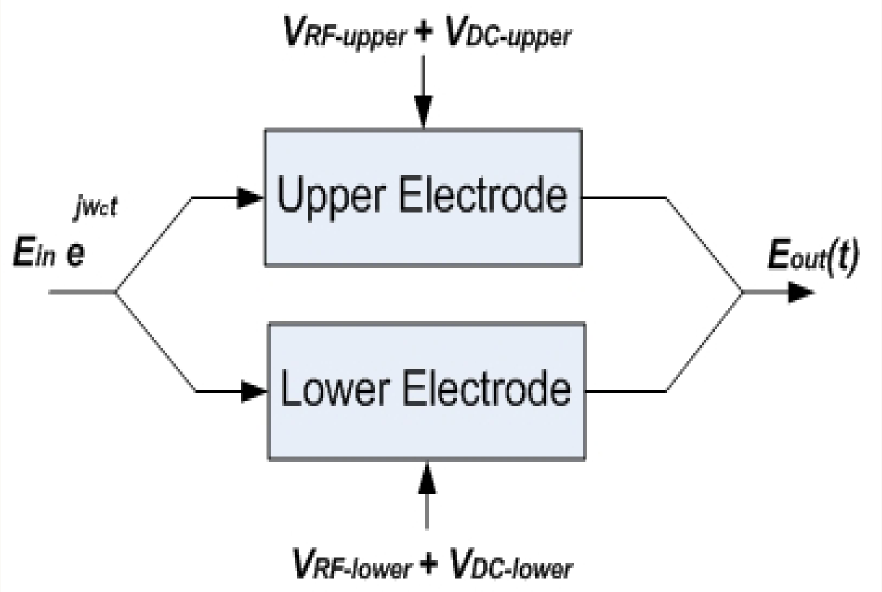
OSSB; MZM is biased at $\frac{V_\pi}{2}$



OCS; MZM is biased at V_π

MZM ER=1000, laser linewidth=2MHz

OSSB Modulation

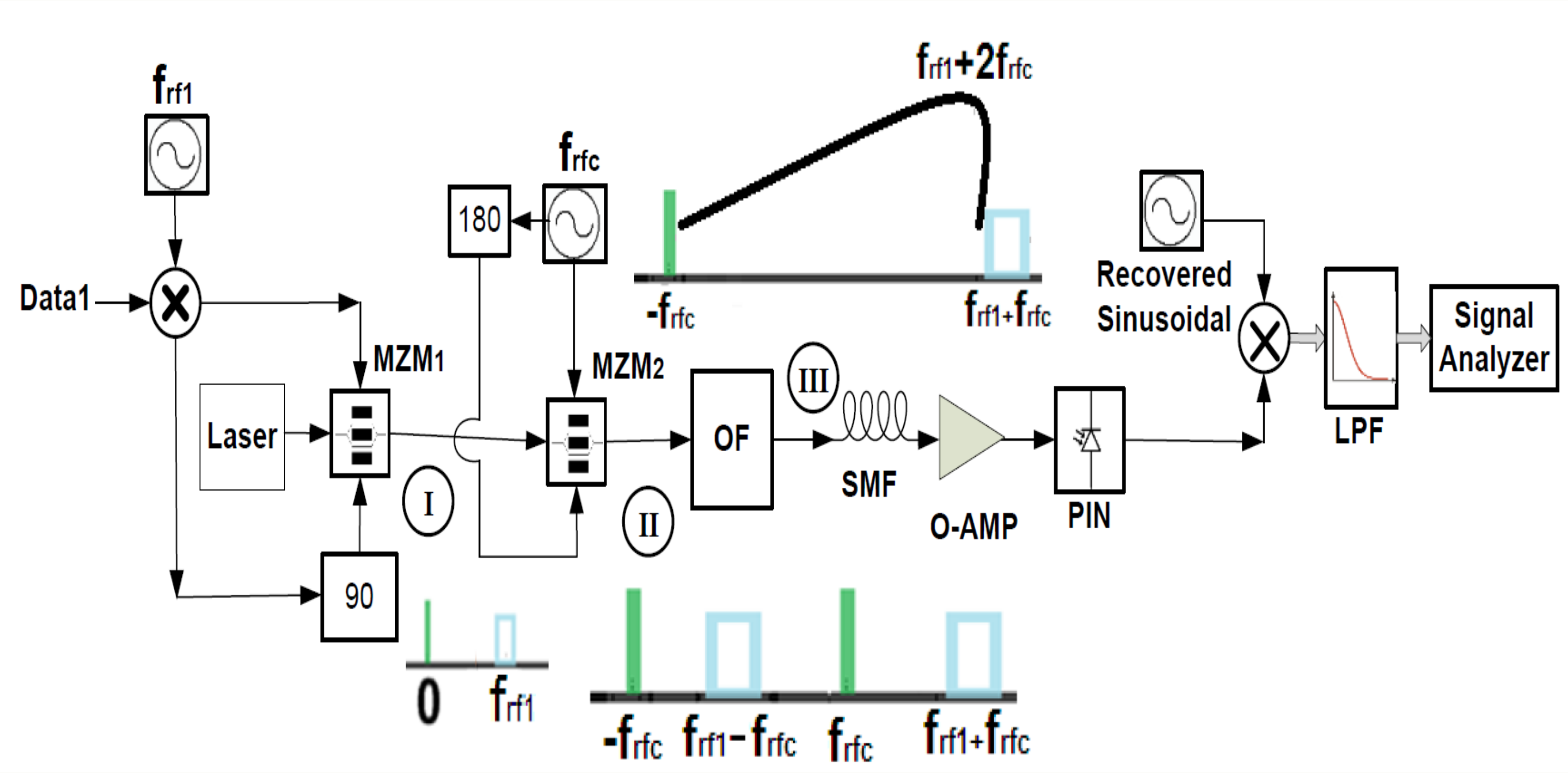


$$V_{upper} = V_{rf}\cos(\omega_{rf} t) + V_{\pi}/2$$

$$V_{lower} = V_{rf}\cos(\omega_{rf} t + \pi/2) + 0$$

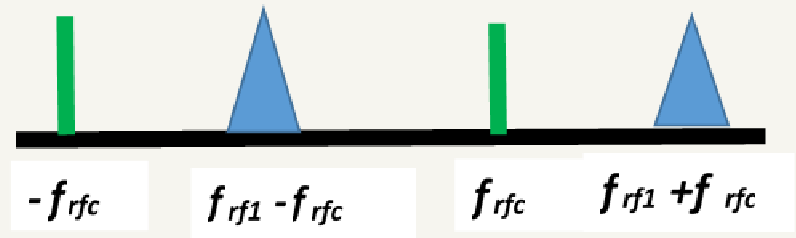
Dual electrode MZM structure

OSSB mm-wave generation system

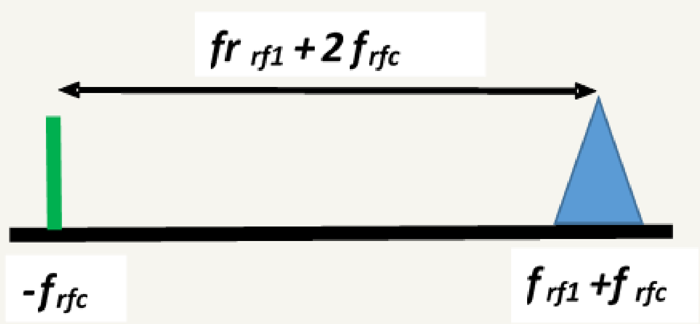


Mm-Wave Generation Procedure

After first MZM



After second MZM



After optical filter: At the photodiode

Second Modulator's Output

$$E_{out2} = E_{in}\{\frac{1}{2} J_0(a\pi) J_1(a\pi) [cos(\omega_c + \omega_{rfc})t + cos(\omega_{rfc} - \omega_c)t - sin(\omega_c + \omega_{rfc})t + sin(\omega_c - \omega_{rfc})t] - J_1^2(a\pi) [cos(\omega_c + \omega_{rf1} + \omega_{rfc})t + cos(\omega_{rfc} - \omega_c - \omega_{rf1}) t] + \frac{1}{2} J_1(a\pi) J_2(a\pi) [cos(\omega_c - 2\omega_{rf1} + \omega_{rfc}) t] + cos(\omega_{rfc} - \omega_c + 2\omega_{rf1})t - sin(\omega_c - 2\omega_{rf1} - \omega_{rfc})t + sin(\omega_c - 2\omega_{rf1} + \omega_{rfc})t + cos(\omega_c + 2\omega_{rf1} + \omega_{rfc})t + cos(\omega_{rfc} - \omega_c - 2\omega_{rf1})t - sin(\omega_c + 2\omega_{rf1} - \omega_{rfc})t - cos(\omega_c + 2\omega_{rf1} + \omega_{rfc})t] + J_3(a\pi) J_1(a\pi) [cos(\omega_c - 3\omega_{rf1} + \omega_{rfc})t + cos(\omega_{rfc} - \omega_c + 3\omega_{rf1})t] + \cdots\}$$

Photodiode's Output

$$PD_{out} = R\,\eta\,|E_{out2}(t)|^2$$

Harmonics after the Photodetection

$$PD_{out} = R\,\eta\,|E_{out2}(t)|^2$$

....

.... $2\omega_{rf1} - 2\omega_{rfc}$

.... $\omega_{rf1} - 2\omega_{rfc}$

....

Shifted Optical Carrier: $2\omega_{rfc}$

Fundamental Frequency: $\omega_{rf1} + 2\omega_{rfc}$

Second Harmonic: $2\omega_{rf1} + 2\omega_{rfc}$

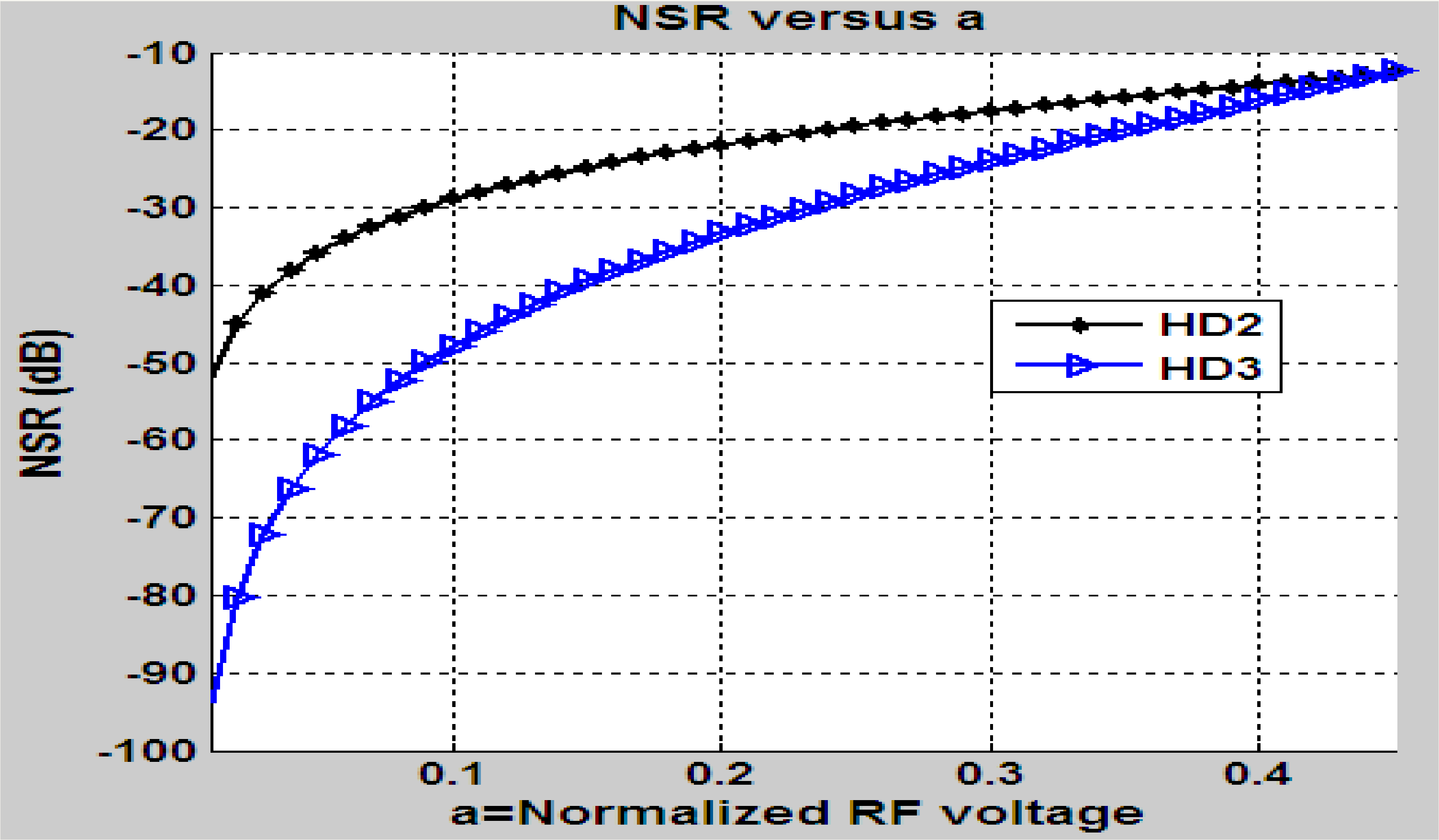
Third Harmonic: $3\omega_{rf1} + 2\omega_{rfc}$

....

....

2nd and 3rd Order Harmonic Distortions due to Nonlinearities in MZMs

Distortion order	Distortion frequency	Noise/signal approximation
Two, HD2	$\boldsymbol{\omega} = 2\,\omega_{rf1} + 2\,\omega_{rfc}$	$\left\lvert \dfrac{[-J_0(a\pi)\,J_2(a\pi)]}{\sqrt{2}\,[J_3\,(a\pi)\,J_2(a\pi) - J_0(a\pi)\,J_1(a\pi)\,]} \right\rvert$
Three, HD3	$\boldsymbol{\omega} = 3\,\omega_{rf1} + 2\,\omega_{rfc}$	$\left\lvert \dfrac{[J_0^2(a\pi)\ J_3\,(a\pi) - J_2(a\pi)\ J_1(a\pi)\,]}{[J_3\,(a\pi)\ J_2(a\pi) - J_0(a\pi)\ J_1(a\pi)\,]} \right\rvert$



Fundamental Frequency: $\omega rf_1 + 2\,\omega_{rfc}$

HD2: $2\omega_{rf1} + 2\,\omega_{rfc}$

HD3: $3\,\omega_{rf1} + 2\,\omega_{rfc}$

Second and Third order harmonic distortions due to fiber dispersion

$$\beta_\omega \approx \beta_0 + \beta_1(\omega - \omega_0) + 0.5\beta_2(\omega - \omega_0)^2$$

$$\beta_1 = \frac{d\beta_\omega}{d_\omega} = \frac{1}{v_g}$$

$$\beta_2 = \frac{d^2\beta_\omega}{d\omega^2} = \frac{-D\lambda^2}{2\pi c}$$

The propagation constant for each optical subcarrier is different

Source: W.H. Chen, et al, J. LWT, Vol. 22, No. 7, July 2004

Second and Third order harmonic distortions due to fiber dispersion

Distortion order	Distortion frequency	Noise/signal approximation
Two, HD2	$\omega = 2\,\omega_{rf1} + 2\,\omega_{rfc}$	$\left\lvert \frac{D_3 + D_4}{D_1 + D_2} \right\rvert$
Three, HD3	$\omega = 3\,\omega_{rf1} + 2\,\omega_{rfc}$	$\left\lvert \frac{D_5 + D_6}{D_1 + D_2} \right\rvert$

$$D_1 = -J_0(a\pi)\, J_1^3(a\pi)\ \cos(B_2\,(-\frac{\omega_{rf1}^2}{2} - \omega_{rf1}\,\omega_{rfc})\,L)$$

$$D_2 = J_0(a\pi)\, J_1^3(a\pi)\, \sin(B_2\,(-\frac{\omega_{rf1}^2}{2} - \omega_{rf1}\omega_{rfc})\,L)$$

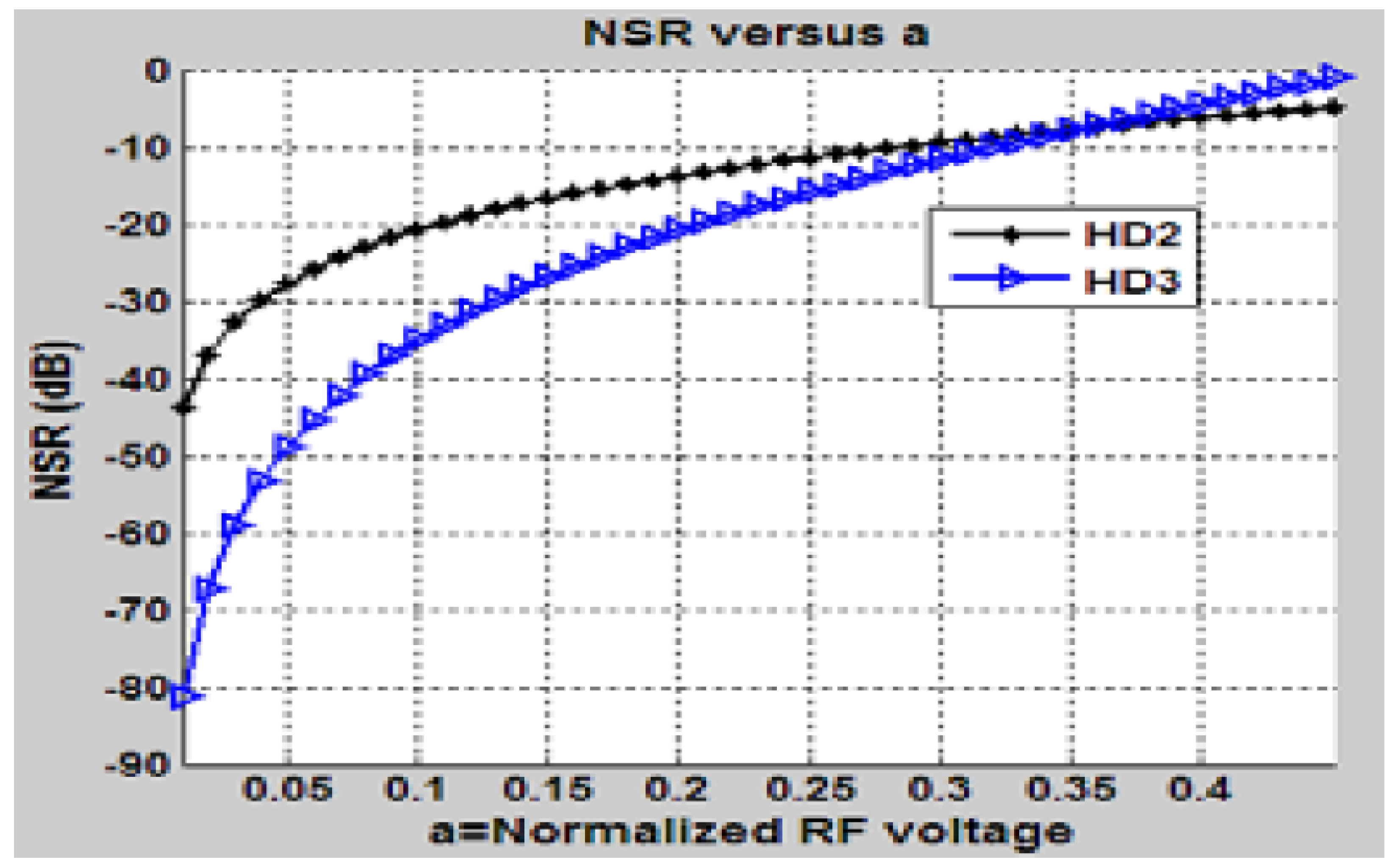
$$D_3 = -\frac{1}{\sqrt{2}}\, J_0(a\pi)\, J_1^2(a\pi)\, J_2(a\pi)\, \cos(B_2(2\,\omega_{rf1}^2 + 2\,\omega_{rf1}\,\omega_{rfc})\,L)$$

$$D_4 = \frac{1}{\sqrt{2}}\, J_0(a\pi)\, J_1^2(a\pi) J_2(a\pi)\ \sin(B_2\,(2\,\omega_{rf1}^2 + 2\,\omega_{rf1}\,\omega_{rfc})\,L)$$

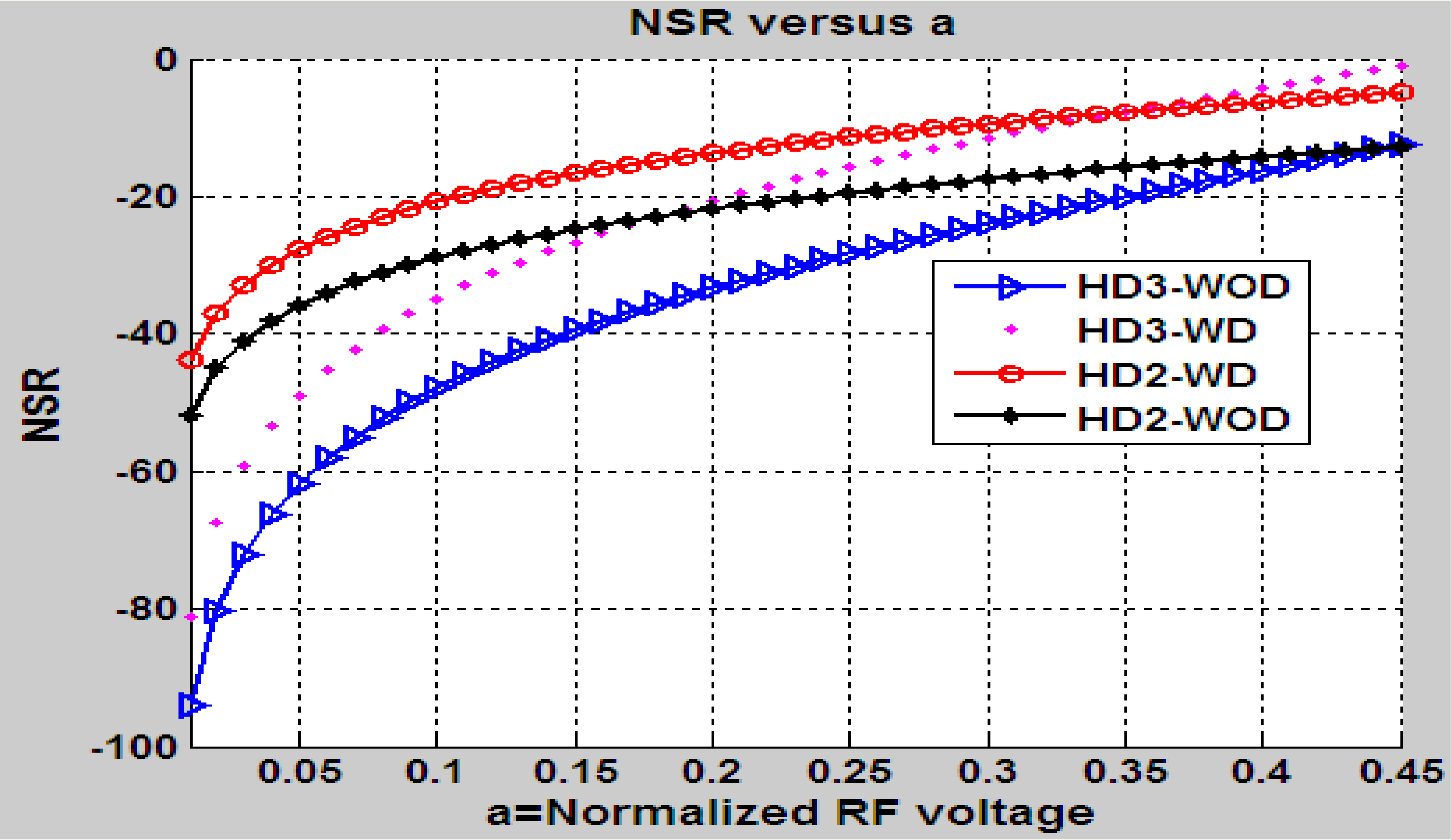
$$D_5 = J_1^3(a\pi)\, J_2(a\pi)\ \cos(\,B_2\,(\frac{3\,\omega_{rf1}^2}{2} + \omega_{rf1}\,\omega_{rfc})\,L\,)$$

$$D_6 = -\,J_1^3(a\pi)\, J_2(a\pi)\, \sin(\,B_2\,(\frac{3\,\omega_{rf1}^2}{2} + \omega_{rf1}\omega_{rfc})\,L\,)$$

Second and Third Harmonic Distortion due to Fiber Chromatic Dispersion

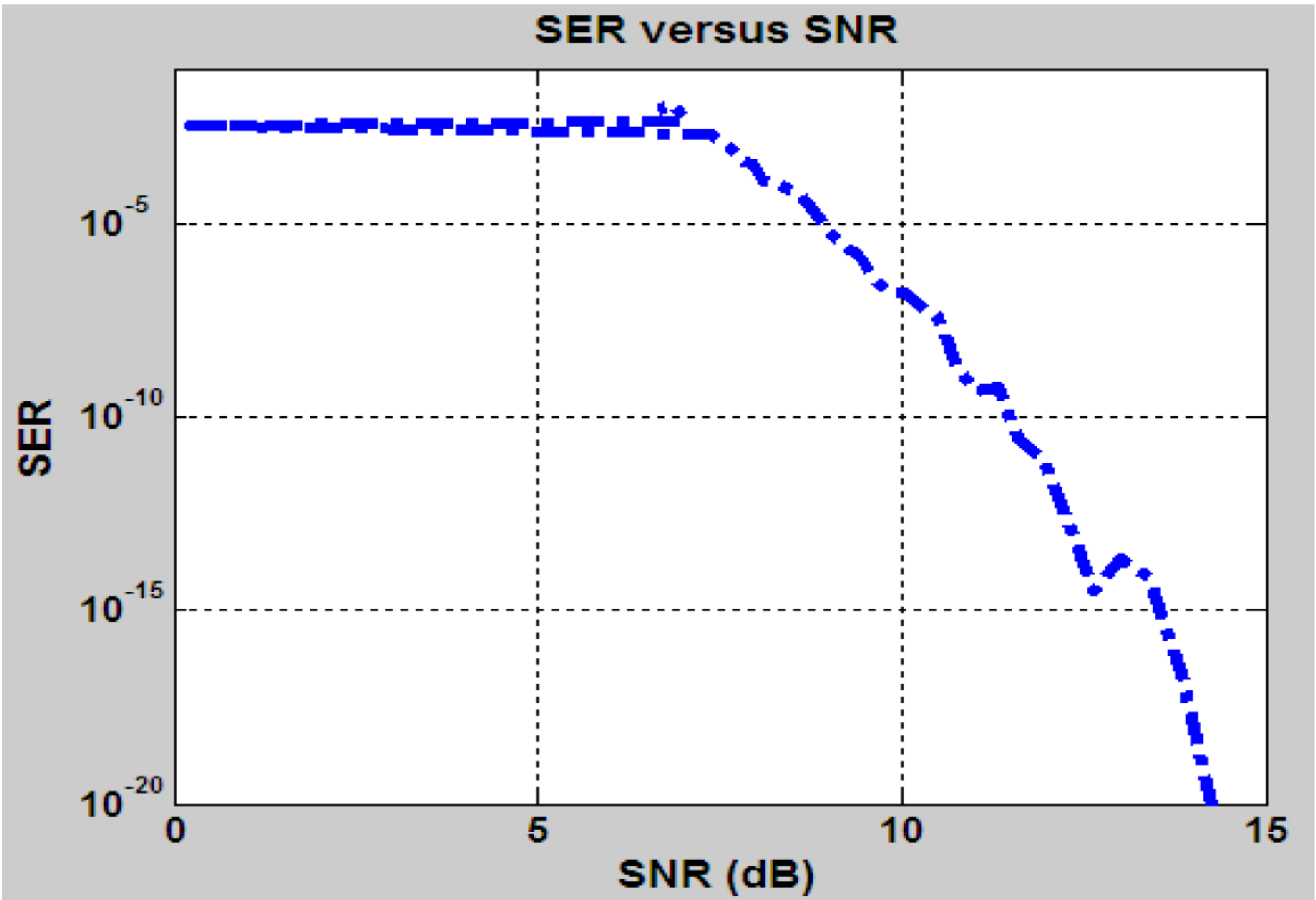


Harmonic Distortions with and without Fiber Dispersion

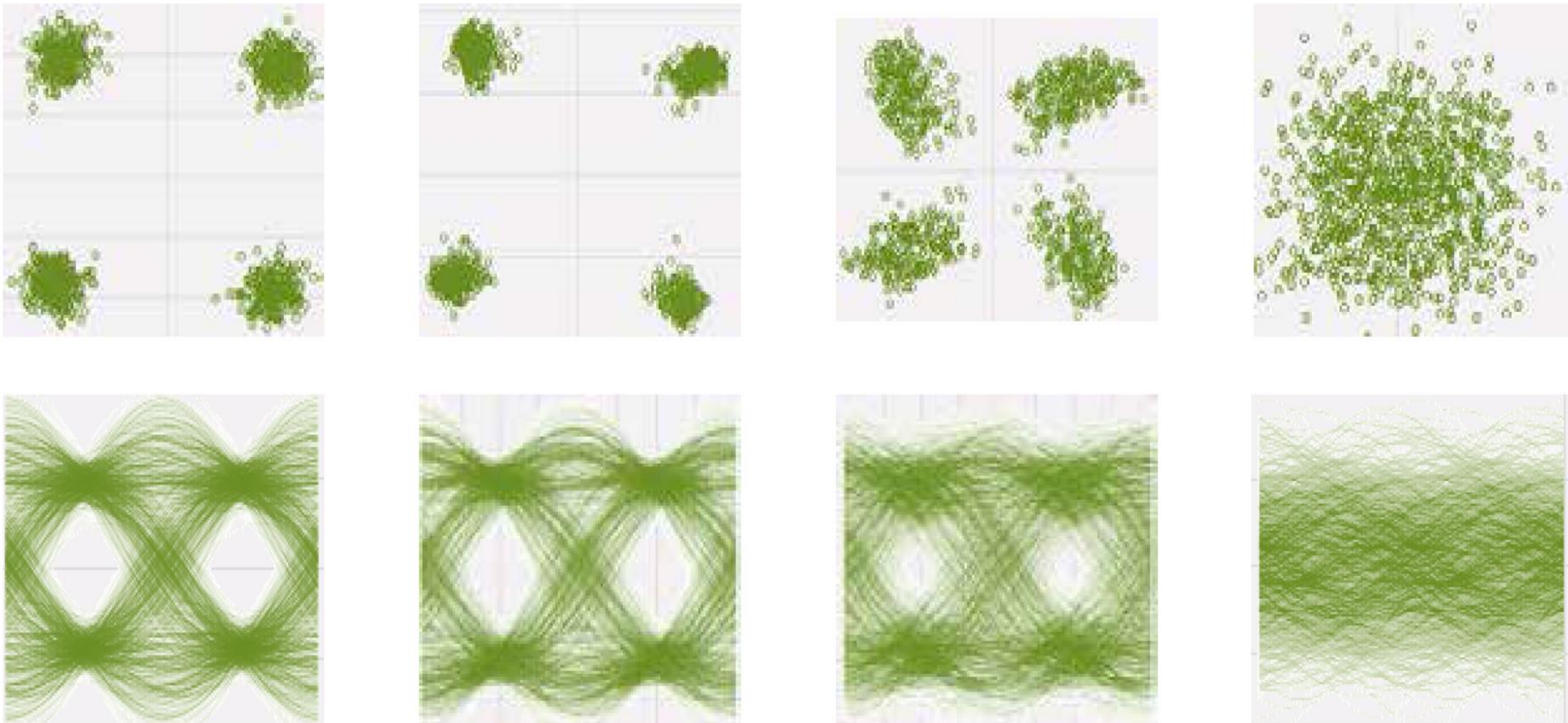


SER for the 4-QAM vs. SNR

L=80km; D=17 ps/(nm.km); Attn: 0.2dB/km; RF=62 GHz, Bit Rate=1 Gb/s

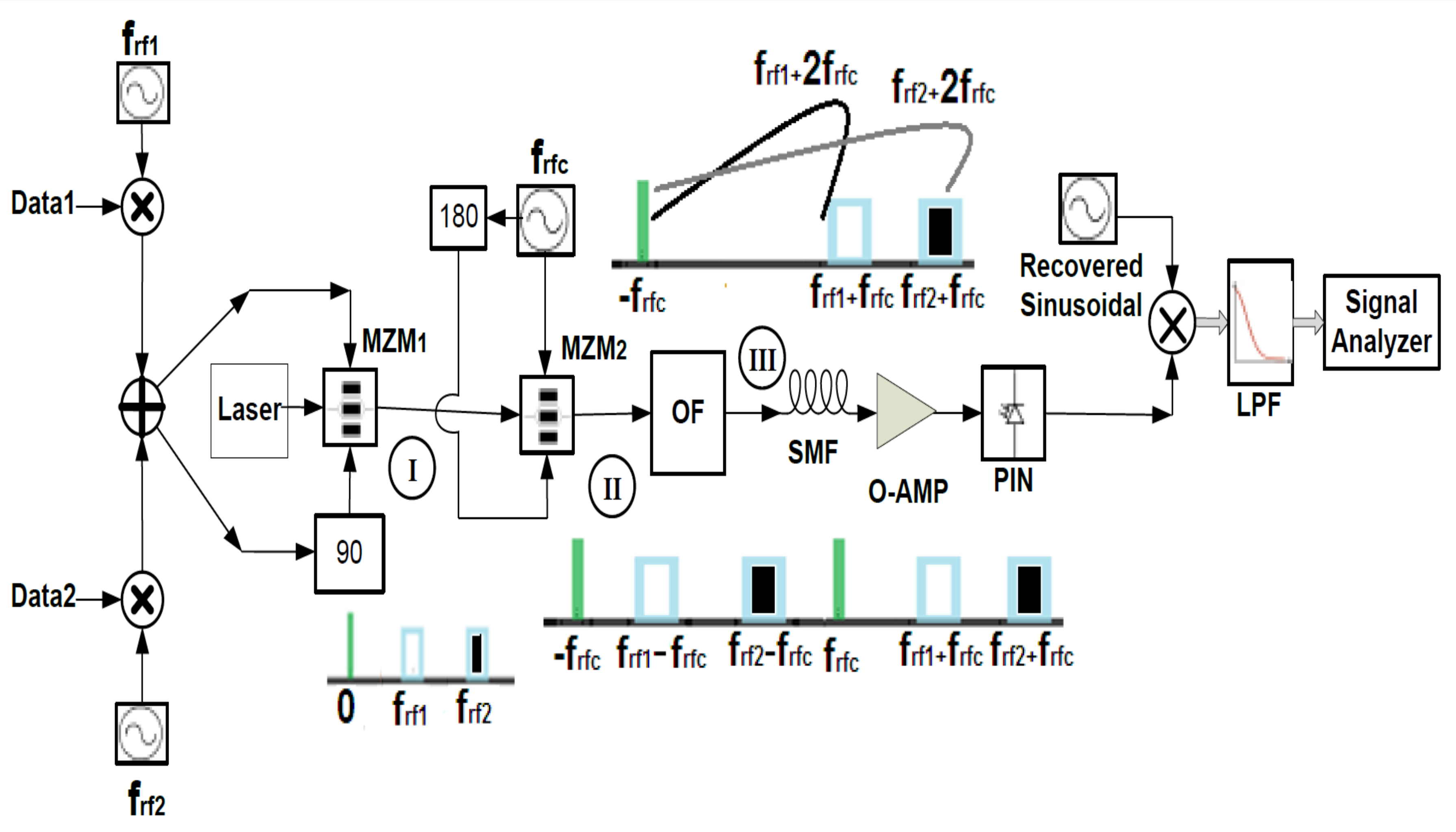


Received Eye Diagrams and Signal Constellations



a=0.04	a=0.26	a=0.45	a=0.02
NSR=-12.3065 dB	NSR= -11.0246 dB	NSR= -7.5331 dB	NSR=-0.9234 dB
SER=2.65e-^{10}	SER= 4.55e-^{10}	SER= 0.0011	SER= 0.2855

Generation of Multi Single Side-Band Sub Carriers



Conclusion

- RF multiplexed OSSB mm-wave signals generated using cascaded MZMs
- Harmonic distortions caused by the MZM and chromatic dispersion are discussed
- In order to optimize the suggested system performance, it is required to adjust the RF amplitude properly.
- A compromise between high SNR and low nonlinearity effects should be considered to guarantee the system performance.

THANK YOU

Questions?