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REVIEW OF IMPROVEMENTS IN RADIO FREQUENCY PHOTONICS

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14. ABSTRACT

Radio Frequency (RF) photonics can be used for multiple applications. One of these is as an RF link. The various components that make up the link influence the overall performance. A review of the performance of the different photonic components is described, along with methods for optimizing their performance.

15. SUBJECT TERMS

radio frequency, photonics, gain, intensity modulated direct detection

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1. INTRODUCTION

For an intensity modulated direct detection (IMDD) link there are three ways to improve the performance: increase the optical power, decrease the Vpi, or reduce the optical noise. All require individual photonic component improvements.

Other means to improve the radio frequency (RF) performance of the photonic links exist, focusing on operating components in unique configurations.

Figure 1 shows an example of an IMDD link, along with the electrical to optical transfer of the Mach Zehnder modulator (MZM), the dual sideband modulation, an erbium doped fiber amplifier (EDFA) and the photodiode (PD) response back to RF.

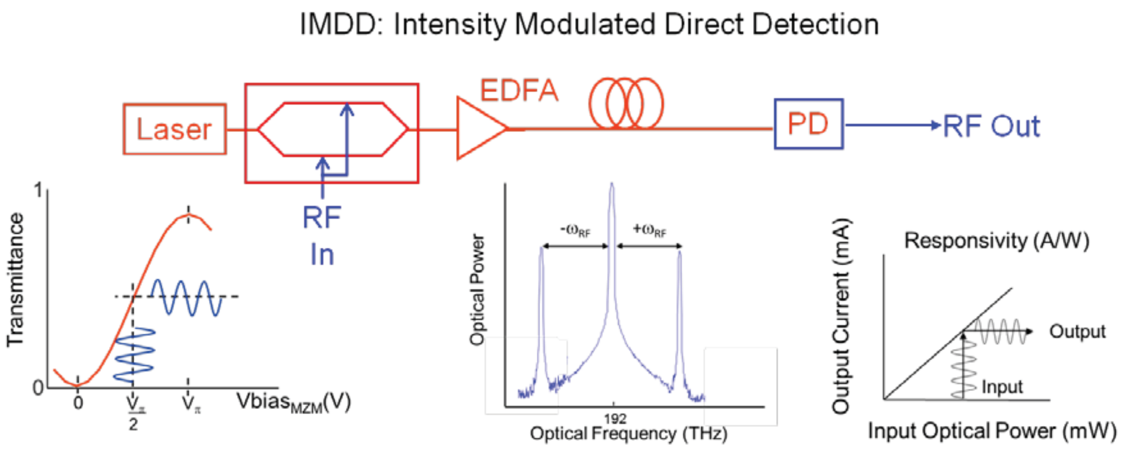

Figure 1: Example of an RF Photonic Link

2. RF PHOTONIC COMPONENTS

The RF photonic link is comprised of some basic components: the laser, MZM, EDFA, fiber optic cable, and the photodiode. Each of these components has been previously investigated for their application to RF systems.

In this section, the impact of these components on the RF performance will be measured and methods for optimizing their performance will be covered.

2.1 Mach Zehnder Modulator Operation

Different configurations of MZMs exist, including single arm drive, dual arm drive and push-pull. In all cases the RF electrodes imparts the RF signal onto the light. In an MZM, the power of the light will be modulated by the RF signal. Figure 2 shows an MZM along with the transfer function of the MZM, which is sinusoidal in shape. The electro-optic efficiency is measured by the Vpi. Common direct current (DC) bias point for an MZM is the quadrature (Vpi/2) point. The quadrature point adds no additional even-order distortion to the RF signal.

Bias control boards keep the MZM biased at quadrature. A couple of methods exist for bias control: optical power monitoring or second harmonic power monitoring. The optical power monitoring requires a dual output MZM. The ratio between the two output powers is kept at a constant ratio. This is referred to as ditherless control. Second harmonic power monitoring introduces a known RF frequency into the MZM. The board seeks to minimize the second harmonic power. This is referred to as dither control.

With an MZM followed by optical amplification, the highest RF gain occurs at below the quadrature bias, referred to as low-biasing. The increased RF gain for operating at the low bias point comes from the improved optical gain of the sidebands. Figure 3 shows the MZM operating at quadrature and low bias. The strong optical carrier saturates the EDFA, taking the majority of the optical gain. When the MZM is at the low bias, the optical carrier is suppressed, the carrier as well as the sidebands sees more gain, increasing the RF gain of the link. An example of the increased RF gain versus bias point appears in Figure 4.

The MZM no longer operating at the quadrature bias point does not cancel the even order distortion at the photodiode. Also, the EDFA is no longer operating in the saturation regime. An advanced system to address these deficiencies appears above. The technique uses a dual-output MZM with two wavelength inputs. By using a dual-output MZM, each wavelength can then be low-biased at their respective output. The system is shown in Figure 5.

Figure 6 shows the first transfer curve is for one wavelength while the other transfer curve is for a second wavelength. Combining the low-bias outputs through an optical amplifier can simultaneously improve the various RF metrics as compared to a quadrature-biased MZM through the same optical amplifier. The dual laser system with a single output can compensate the second harmonic distortion introduced by fiber dispersion. This system appears in Figure 7. The architecture is similar to the one in Figure 5 with two exceptions: no EDFA and the wavelengths are set for quadrature bias.

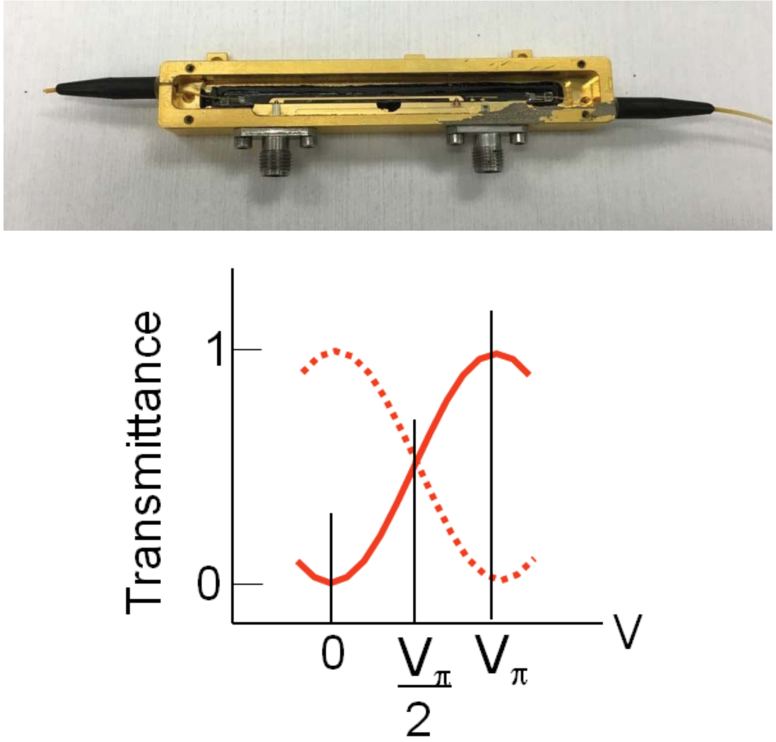

Figure 2: Practical MZM along with its Transfer Curve

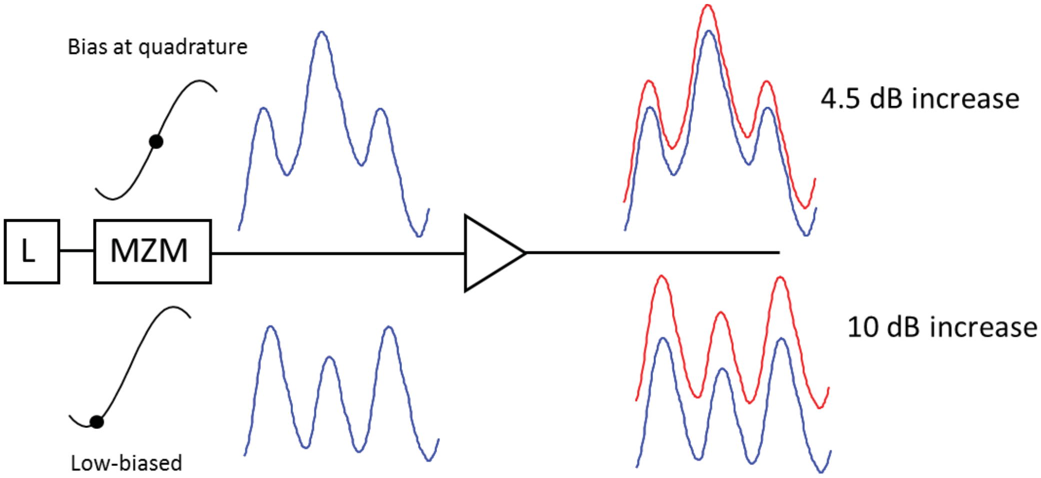

Figure 3: Optical Gain for an MZM at Quadrature and Low Bias Operation

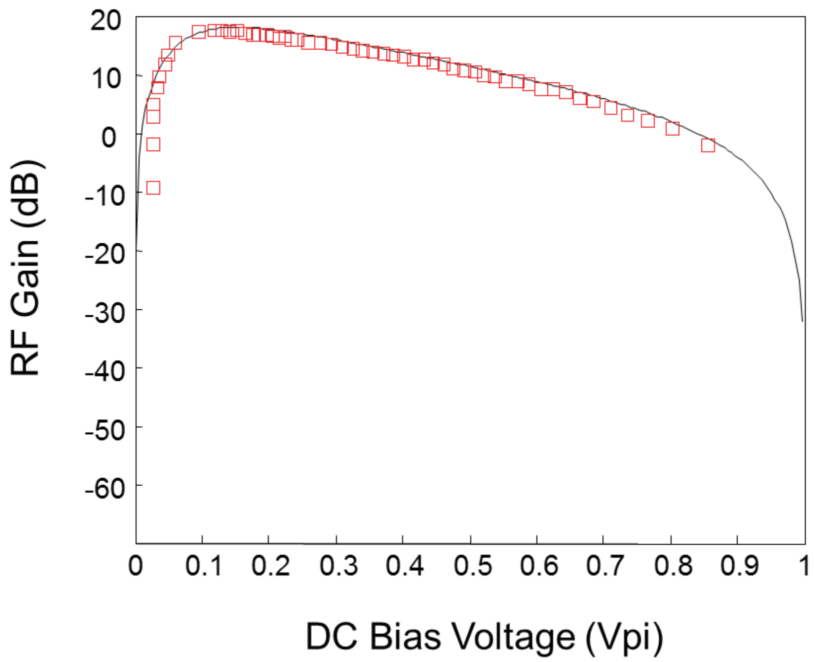

Figure 4: RF Gain for an MZM at Different Biases

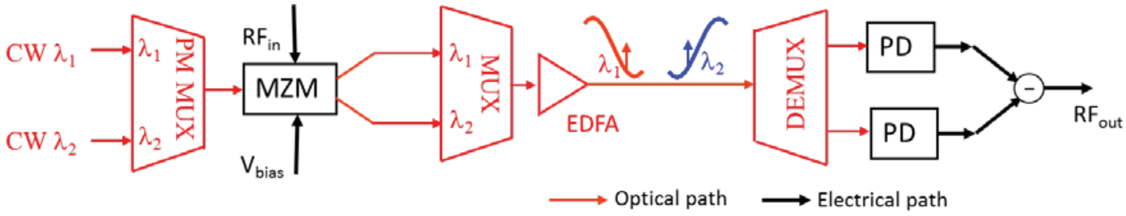

Figure 5: System using Two Lasers for Higher Performance

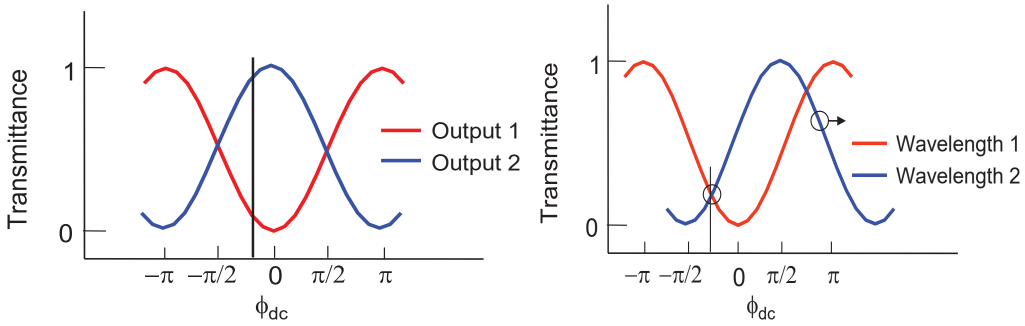

Figure 6: Transfer Curves for One Wavelength and Two Wavelengths

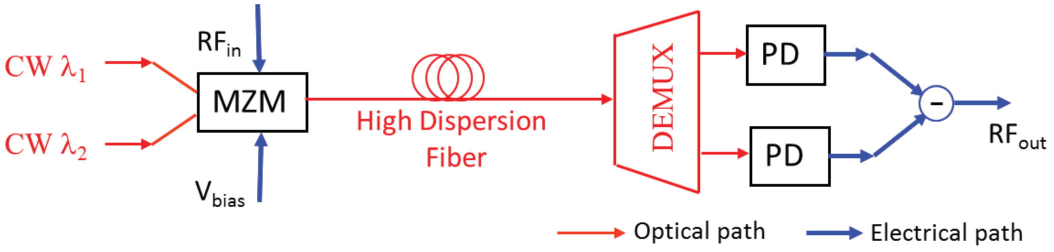

Figure 7: System with Two Lasers for Dispersion Compensation

2.2 Photodiode Operation

Increased optical power to the photodiode will improve the RF metrics. Limitations exist on the improvement. Photodiodes with high frequency response operate safely when the input optical power is below 10 milliwatts. Otherwise the photodiode will be destroyed. Some photodiodes use a gradient index (GRIN) lens to handle more optical power. Figure 8 shows an unpackaged photodiode component.

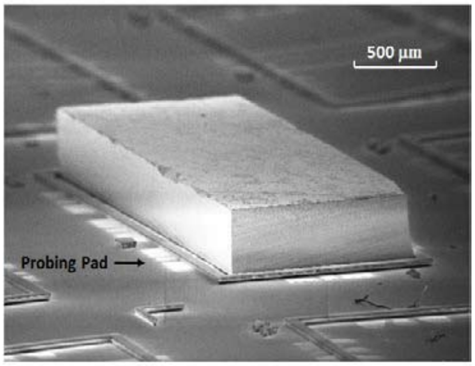

Figure 8: Unpackaged Photodiode

Photodiodes are nonlinear devices and can affect the RF metrics. Phase noise is one way the performance can be affected due to intensity-to-phase noise conversion in the photodiode. Compressing the photodiode can limit the intensity-to-phase conversion. Figure 9 shows the improvement in the phase noise when compared to an unsaturated photodiode.

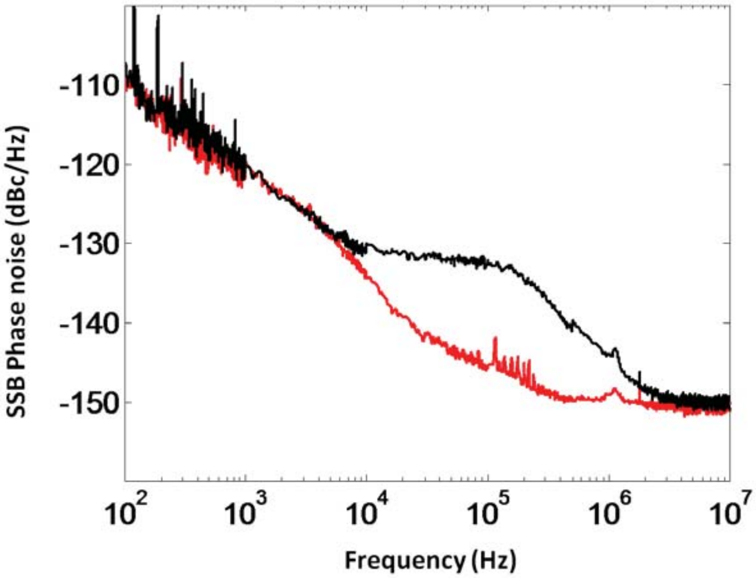

Figure 9: Improvement in Phase Noise of a Photodiode

Balanced photodetection can also be used to provide benefits. The balanced photodiode can be used for both intensity and phase modulated links. Two photodiodes can handle twice as much power. This leads to an increase in RF gain. Balanced photodetection also reduces laser relative intensity noise (RIN) impact on the RF metrics. So the RF gain increases and the noise is simultaneously suppressed. Balanced photodiodes can cancel even-order distortion. This is accomplished by optimizing each photodiode's bias. A microcontroller used to optimize the bias voltages showed an improvement of 8.3 dB in the second harmonic distortion. Figure 10 shows the power of the second harmonic as the bias changes.

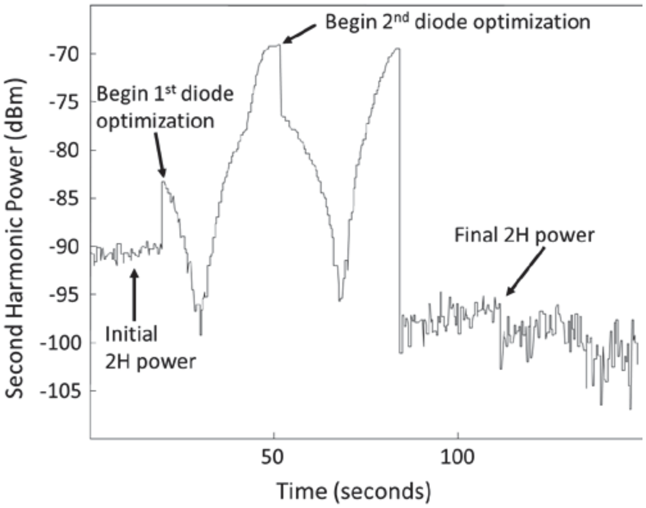

Figure 10: Second Harmonic Power after Optimization

2.3 Optical Fiber Operation

The stimulated Brillouin scattering (SBS) effect limits the incoming light into a fiber to the SBS threshold. Powers above the SBS threshold will generate an acoustic travelling wave that will reflect the light like a mirror. To bypass the SBS effect, multiple approaches have been attempted, including changing the temperature and strain of the fiber. Another method to address both SBS and dispersion is the use of alternating pairs of fiber spans. Optical isolators can be placed between each alternating pair. The overall fiber will have dispersion close to zero. The combination also increases the SBS threshold. Figure 11 shows the alternating fiber with isolators. The SBS threshold is increased by 6 dB when compared to a single fiber as seen in the Figure 12. Thus the alternating fiber span addresses both the dispersion and the SBS issues.

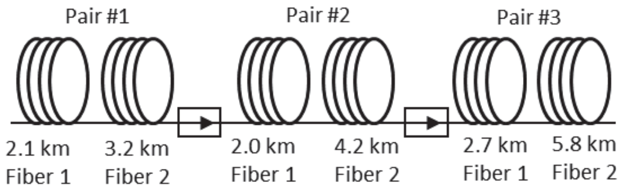

Figure 11: Example of Alternating Fibers with Isolators to Increase SBS Threshold

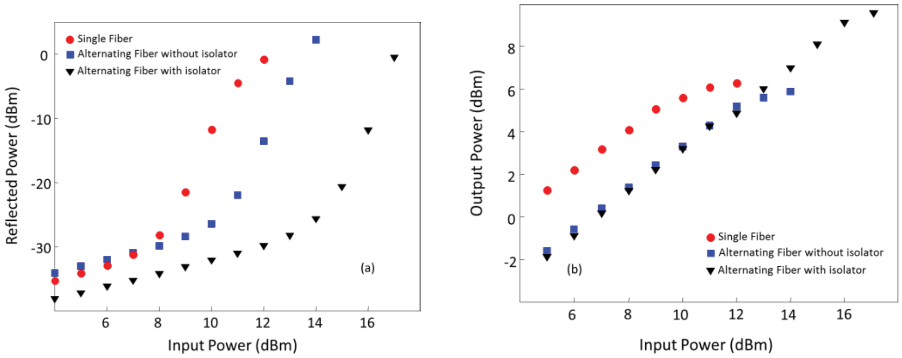

Figure 12: Measurements of Reflected and Transmitted Power for Different Fiber Spools

2.4 Optical Amplifier Operation

The EDFA is the preferred optical amplifier for RF photonic applications. The cost of using an optical amplifier is the added noise. The added noise from the EDFA degrades the RF metrics of the photonic link. The noise penalty of the EDFA is measured using a similar method to measuring RIN of a laser. A measurement of the noise penalty appears in the Figure 13. An example of multiple EDFAs used in a long photonic link is shown in Figure 14. The noise penalty changes versus input power. This relation is shown in Figure 15.

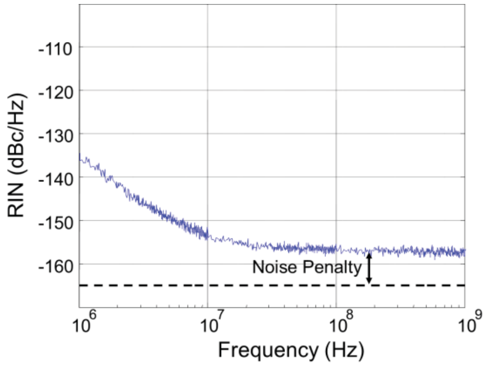

Figure 13: Measurements of Noise Penalty of an EDFA

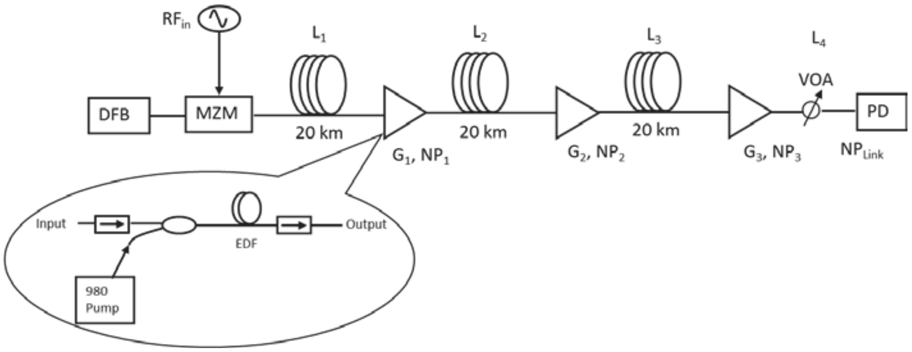

Figure 14: Example of Multiple EDFAs used in a Long Photonic Link

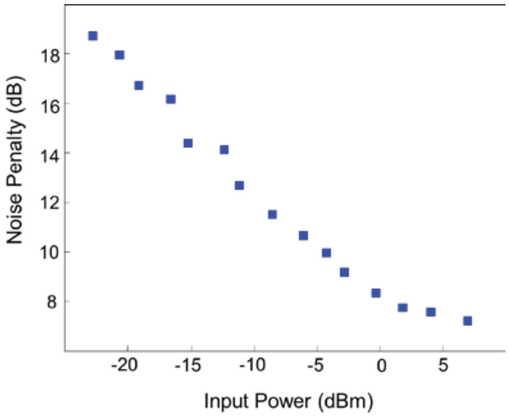

Figure 15: Noise Penalty versus Input Power

3. CONCLUSIONS

Various advanced techniques have been demonstrated to improve the performance of the photonic links. Nonlinearities can be overcome by using different modulation formats. Optical fiber limits can also be overcome by using different fiber types and isolators. The noise of the EDFA can be characterized and controlled by proper design to reduce the added noise. Finally the MZM can be used at different biases to improve the RF performance.

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ACRONYM	DESCRIPTION
DC	direct current
EDFA	erbium-doped fiber amplifier
GRIN	gradient index
IMDD	intensity modulated direct detection
MZM	Mach Zehnder modulator
PD	photodiode
RF	radio frequency
RIN	relative intensity noise
SBS	stimulated Brillouin scattering