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14. ABSTRACT
In the first quarter we have focused primarily on the amplitude-encoded link, distortion correction, and RIN transfer. We have experimentally analyzed the amplitude encoded link for gain and 3rd order distortion and are identifying the proper conditions for maximizing the overall spurious-free dynamic range (SFDR) of the link. In addition, we have investigated new methods for cascaded four-wave mixing (FWM) through a multi-stage nonlinear interaction. Finally, we are performing numerical simulations of the transfer of laser relative intensity noise (RIN) and quantum noise through the cascaded FWM process.

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Title:
Critical Performance Enhancement of Ultrahigh-Bandwidth Microwave Photonic Links through Nonlinear Photonic Signal Processing

Program Manager: Dr. Stephen A. Pappert

I. Executive Summary

The research program is proceeding as scheduled other than a slight delay in the experimental work due to arrival of the funds for capital equipment purchases. In the first quarter we have focused primarily on the amplitude-encoded link, distortion correction, and RIN transfer. We have experimentally analyzed the amplitude encoded link for gain and 3rd order distortion and are identifying the proper conditions for maximizing the overall spurious-free dynamic range (SFDR) of the link. In addition, we have investigated new methods for cascaded four-wave mixing (FWM) through a multi-stage nonlinear interaction. Finally, we are performing numerical simulations of the transfer of laser relative intensity noise (RIN) and quantum noise through the cascaded FWM process.

This research program currently supports two graduate students pursuing their doctoral degree. One student is fully supported through this program and the other student is partially supported. In addition, two undergraduate students are currently participating in the research program and they are receiving a small amount of support from this grant.

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II. Research Summary

We have focused our research efforts in the first quarter of this program on the amplitude-encoded link. We have experimentally characterized the link gain and 3rd order distortion as a function of the power of the FWM pump laser sources for a nonlinear fiber with an anomalous group-velocity dispersion (GVD) value of 2 ps/nm/km. The results of this experiment are displayed in Fig. 1. As is shown, we observe a improvement in link transmission of over 10 dB and also observe an improvement in third-order intercept (OIP3) of 10 dB. As seen in the plot, the improvement in third-order distortion is highly dependent on the pump laser operating power since the third-order distortion compensation of the FWM process can be tuned through this parameter. Importantly this provides a route to compensation of additional sources of distortion through fine adjustment of the pump laser power. For these measurements the received optical power at the photodetector is fixed at 0 dBm to eliminate the impact of photodetector effects from this measurement.

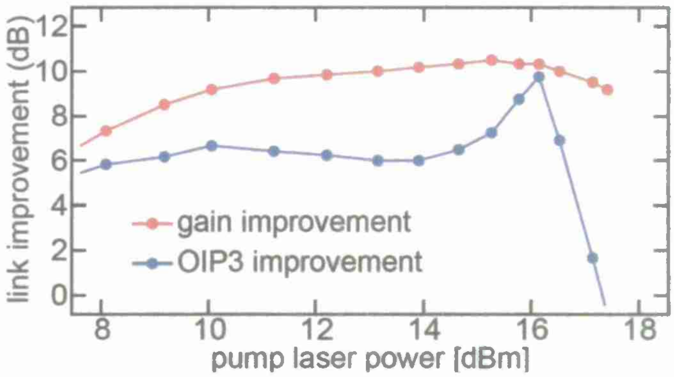

Figure 1. Improvement in link gain and third-order intercept point (OIP3) as a function of the pump laser power for the FWM interaction. For these measurements the highly nonlinear fiber has an anomalous GVD value of 2 ps/nm/km and the received optical power at the photodetector is held constant (0 dBm).

These two curves are shaped by the GVD of the nonlinear medium. Through a different choice of GVD we can expect a different amount of gain and third-order distortion correction. Additionally, the laser separation and the choice of FWM sideband number will also impact these performance metrics. We are currently implementing numerical simulation of the interaction to first verify our current measurements and subsequently determine the optimal operating conditions for maximum SFDR improvement. Additionally, we are developing a numerical model of the noise transfer (both RIN and quantum noise) resulting from these cascaded FWM interactions. An example of the numerically calculated RIN transfer resulting from the cascaded FWM interaction is shown in Fig. 2. Since the signal is encoded on both laser sources and the RIN of each laser source is uncorrelated the SNR of the FWM sideband is generally better than the SNR of each individual pump laser. Our goal through this modeling is to identify a nonlinear regime to maximize this SNR improvement.

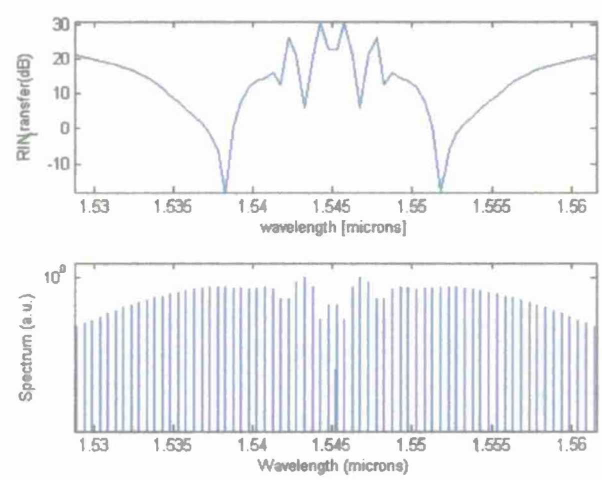

Figure 2. Numerically modeled RIN transfer (top) for a multi-stage cascaded FWM interaction producing the optical spectrum shown (bottom).

We are also investigating multiple approaches to implementing the FWM interaction. The primary concern is minimizing the impact of stimulated Brillouin scattering (SBS) from the interaction. It is crucial to limit SBS as it acts to saturate the FWM process and prohibits the efficient generation of FWM sidebands. We currently implement phase modulation to broaden the laser linewidth and reduce the impact of SBS. Unfortunately, we have found that the noise floor of the system is dominated by phase to amplitude conversion of this broadband phase noise. For this reason it is necessary to implement alternative approaches to SBS suppression to maximize the noise figure of the demonstrated links. We have successfully developed an approach using a multistage process incorporating fiber isolators and periodic nonlinearity and dispersive compression to eliminate SBS. The experimental diagram of this approach and the resulting cascaded FWM spectrum are shown in Fig. 3. Unfortunately, the overall loss of this approach is undesireable for analog applications such as those investigated here. We are currently purchasing a fiber spooling apparatus that will allow for SBS suppression through fiber tensioning to overcome the limitations of the two approaches described above.

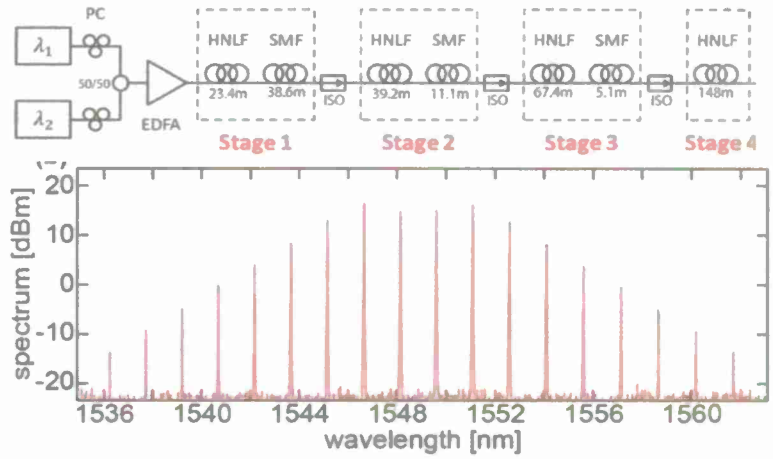

Figure 3. Cascaded FWM generation through a multistage nonlinear interaction involving periodic nonlinearity and dispersive compression. Brillouin scattering is mitigated through fiber isolators positioned between the stages. The scheme is depicted on the top and an example experimentally generated spectrum is shown on the bottom.

III. Management Summary

Two graduate students, Hong-Fu Ting and Walter Wall, are currently employed to carry out this research program. Hong-Fu Ting is currently supported full time on the project while Walter Wall is currently supported part time on the project. In addition, two undergraduate students, Jasper Stroud and Mitchell Sacks, are currently assisting with the research program and their work is supported by the funding. All of the student's progress and research directions are overseen by Prof. Mark Foster through weekly research meetings and hands-on experimental assistance. The research team has made very good progress towards the completion of the tasks as depicted graphically in Fig. 4. However, the progress of the experimental work has been delayed slightly relative to the anticipated schedule due to delays in receiving the funds for the capital equipment purchases. However, we anticipate that we will be able to make up for this delay in the future quarters. The tasks descriptions are detailed below the figure for reference.

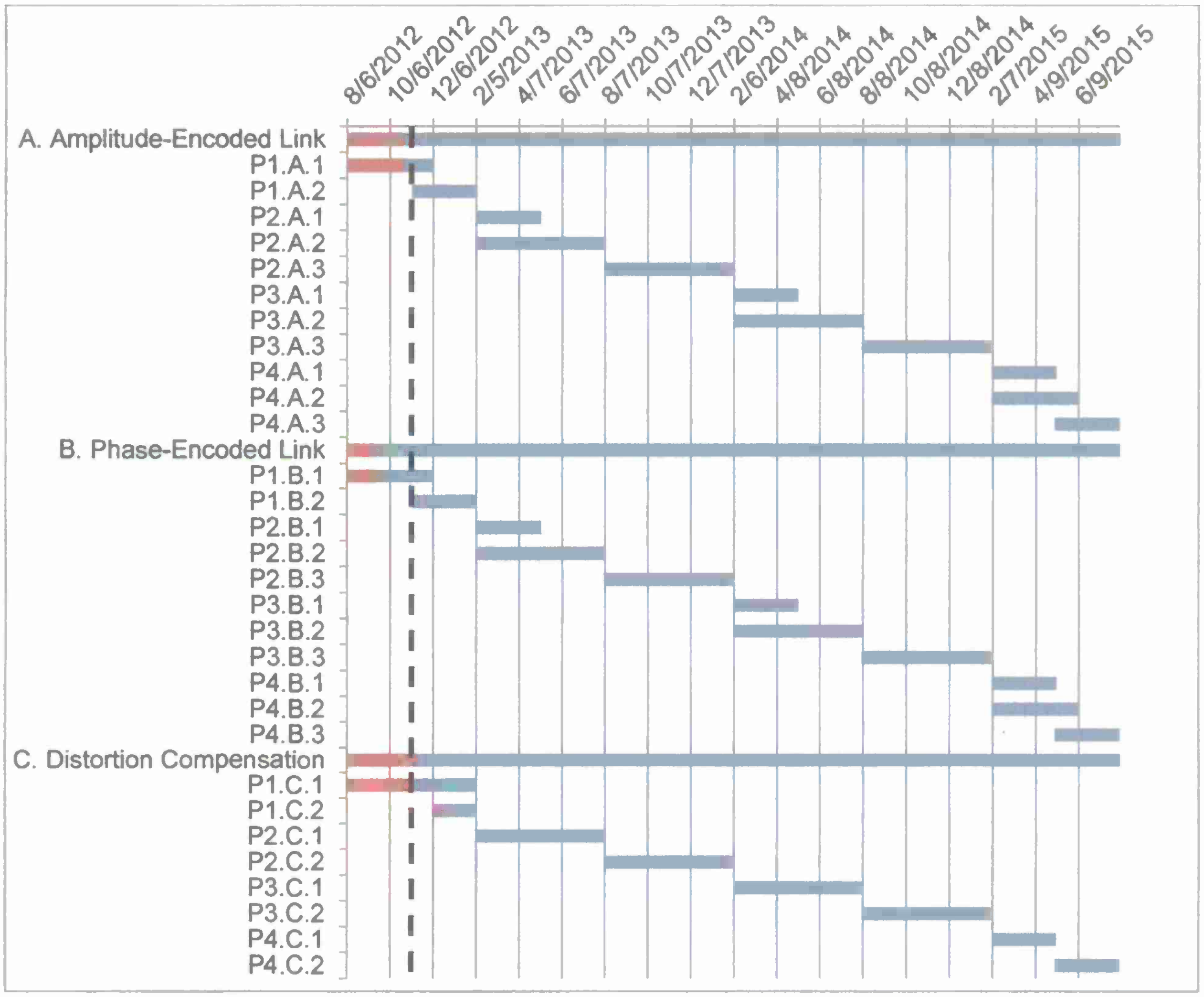

Figure 4. Anticipated task schedule and current progress towards task completion. The black dotted line indicates the current date.

Project Schedule and Milestones

The anticipated schedule of the events, milestones, and deliverables are detailed below by period.

Period 1 (months 1-6)

Milestones:

1) Fully characterized 14-GHz bandwidth amplitude-encoded link and with 9-dB FWM gain enhancement.
2) Phase-encoded link with 10-GHz bandwidth and 6-dB FWM gain enhancement.

Task A. Amplitude-Encoded Link

P1.A.1. Generate a pair of cascaded FWM spectra using the two output of the MZM.

P1.A.2. Characterize the noise figure of the amplitude encoded link with 9-dB gain enhancement.

Task B. Phase-Encoded Link

P1.B.1. Implement local oscillator generation and FWM phase multiplication.

P1.B.2. Demonstrate 6-dB of FWM gain enhancement in the phase-encoded link.

Task C. Distortion Compensation

P1.C.1. Characterize the SFDR of the amplitude encoded link with 9-dB gain enhancement.

P1.C.2. Characterize the power transfer characteristics for the generated wavelength channels in the cascaded FWM interaction.

Period 2 (months 7-18)

Milestones:

1) Amplitude-encoded link with 20-GHz bandwidth, >16 dB FWM gain enhancement, and <10 dB noise figure.
2) Phase-encoded link with 20-GHz bandwidth, >10 dB FWM gain enhancement, and <10 dB noise figure.
3) Distortion compensation capable of 10-dB improvement in SFDR.

Task A. Amplitude-Encoded Link

P2.A.1. Demonstrate a 20-GHz amplitude-encoded link with FWM gain enhancement.

P2.A.2. Demonstrate > 16 dB of FWM gain enhancement in the amplitude-encoded link.

P2.A.3. Demonstrate < 10 dB noise figure in the amplitude-encoded link.

Task B. Phase-Encoded Link

P2.B.1. Demonstrate a 20-GHz phase-encoded link with FWM gain enhancement.

P2.B.2. Demonstrate >10 dB FWM gain enhancement in phase-encoded link.

P2.B.3. Demonstrate < 10 dB noise figure in the phase-encoded link.

Task C. Distortion Compensation

P2.C.1. Characterize the SFDR of the demonstrated links.

P2.C.2. Demonstrate 10-dB SFDR improvement using transfer function synthesis.

Period 3 (months 19-30)

Milestones:

1) Amplitude-encoded link with 30-GHz bandwidth, >23 dB FWM gain enhancement, and <8 dB noise figure.
2) Phase-encoded link with 30-GHz bandwidth, >16 dB FWM gain enhancement, and <8 dB noise figure.
3) Distortion compensation capable of 20-dB improvement in SFDR.

Task A. Amplitude-Encoded Link

P3.A.1. Demonstrate a 30-GHz amplitude-encoded link with FWM gain enhancement.

P3.A.2. Demonstrate > 23 dB of FWM gain enhancement in the amplitude-encoded link.

P3.A.3. Demonstrate < 8 dB noise figure in the amplitude-encoded link.

Task B. Phase-Encoded Link

P3.B.1. Demonstrate a 30-GHz phase-encoded link with FWM gain enhancement.

P3.B.2. Demonstrate >16 dB FWM gain enhancement in phase-encoded link.

P3.B.2. Demonstrate < 8 dB noise figure in the phase-encoded link.

Task C. Distortion Compensation

P3.C.1. Characterize the SFDR of the demonstrated links.

P3.C.2. Demonstrate 20-dB SFDR improvement using transfer function synthesis.

Period 4 (months 31-36)

Milestones:

1) Amplitude-encoded link with 40-GHz bandwidth, >30 dB FWM gain enhancement, and <6 dB noise figure.
2) Phase-encoded link with 40-GHz bandwidth, >23 dB FWM gain enhancement, and <6 dB noise figure.
3) Distortion compensation capable of 30-dB improvement in SFDR.

Task A. Amplitude-Encoded Link

P4.A.1. Demonstrate a 40-GHz amplitude-encoded link with FWM gain enhancement.

P4.A.2. Demonstrate > 30 dB of FWM gain enhancement in the amplitude-encoded link.

P4.A.3. Demonstrate < 6 dB noise figure in the amplitude-encoded link.

Task B. Phase-Encoded Link

P4.B.1. Demonstrate a 40-GHz phase-encoded link with FWM gain enhancement.

P4.B.2. Demonstrate >23 dB FWM gain enhancement in phase-encoded link.

P4.B.3. Demonstrate < 6 dB noise figure in the phase-encoded link.

Task C. Distortion Compensation

P4.C.1. Characterize the SFDR of the demonstrated links.

P4.C.2. Demonstrate 30-dB SFDR improvement using transfer function synthesis.

IV. Financial Status Report

We are currently spending below the anticipated rate as depicted in Fig. 5. We are spending at the planned monthly rate other than the initial capital equipment purchases which will be made in the next quarter due to the delay in fund availability.

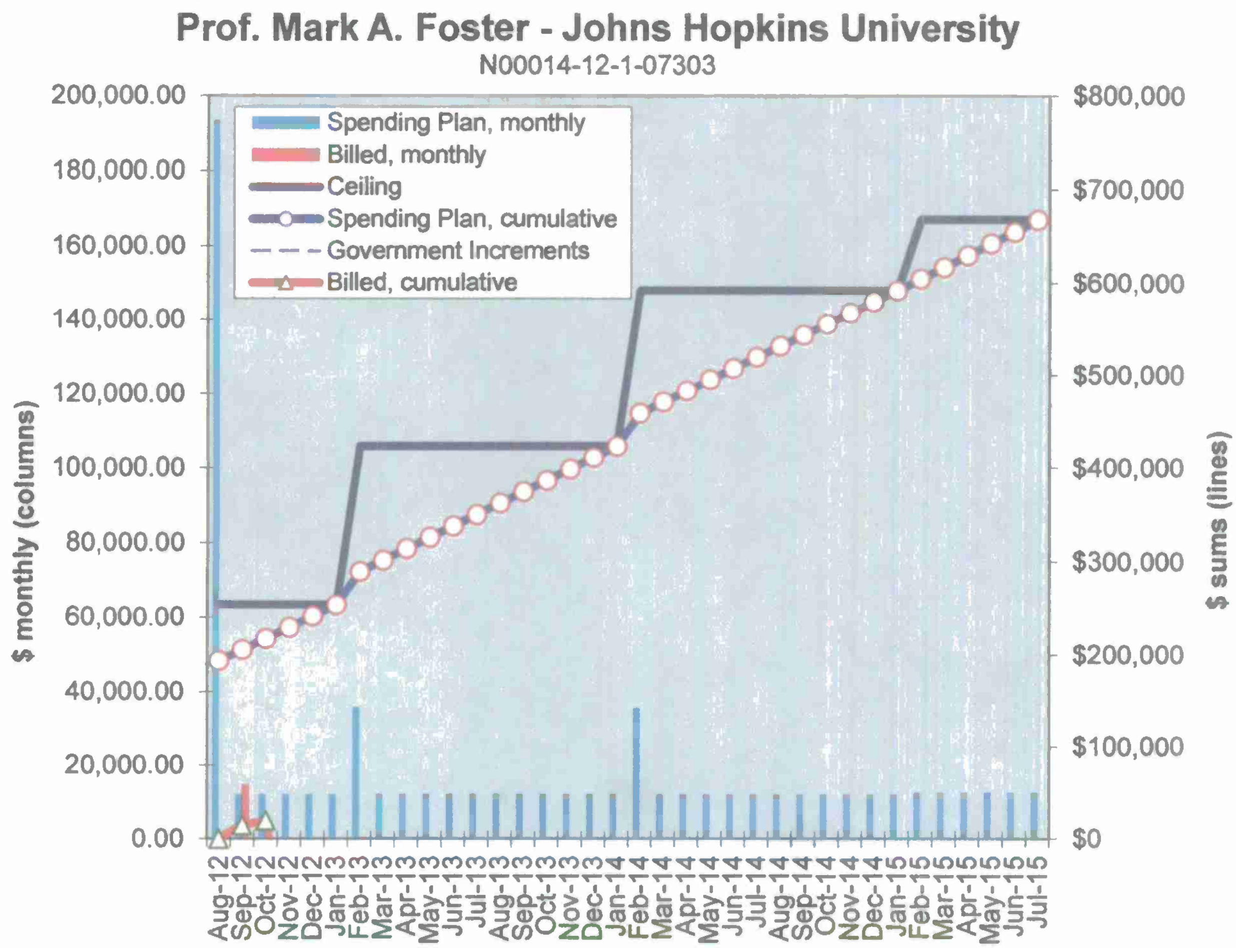

Figure 5. Graphical depiction of planned spending and current financial status.