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TuM3 High-frequency optical FM noise reduction employing a fiber-insertable feedforward technique

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Optical frequency modulation (FM) or phase modulation (PM) noise determines performance limitations in coherent and incoherent optical communication systems. To date techniques for FM noise reduction have been limited to electronic and optical feedback. However, with electronic feedback, the maximum FM suppression frequency (~200 MHz,[1]) is limited by the feedback loop delay time. In the case of optical feedback, the laser linewidth and oscillation mode stability are very sensitive to the feedback phase. Both feedback techniques require access to the source laser and usually enhance FM noise at high frequencies, which can deteriorate the transmission performance in coherent systems.

Here we propose a new feedforward compensation (FFC) technique for reducing optical FM noise to microwave frequencies. As shown in Fig. 1, first the input optical signal is split into two paths by a 50:50 optical coupler. On one path the FM noise is measured using an optical frequency discriminator (OFD). For our experiments, the OFD was a waveguide Mach-Zehnder[2] interferometer with an optical path imbalance of 2 cm, yielding an optical 3-dB bandwidth of 5 GHz. The FM noise is integrated to PM noise at the balanced receiver by a high-impedance preamplifier having a transimpedance gain of ~90 dB and a 500-ns RC time constant. This PM noise is amplified and fedforward to a $LiNbO_3$ phase modulator[3] (LNPM) located on the other through path. Between the coupler and LNPM, a ~7 m length of optical fiber was inserted to equalize the delay of the feedforward signal. When the PM noise to the LNPM is out of phase relative to the optical PM noise, the PM noise is canceled. tHus, the PM (or FM) noise of the input optical signal is reduced independent of the source.

A multielectrode DFB laser was used as the optical source in the following experiments. For FM and PM measurements, the fiber output was connected to a second Mach-Zehnder OFD with an APD balanced receiver. To demonstrate FM reduction, a network analyzer (NA) was used; rf output from port 1 FM modulated the DFB laser and the balanced receiver output was amplified and directed to port 2 of the NA, see inset to Fig. 2. Before connecting the FFC loop, the S_{21} throughput is measured for normalization. The normalized S_{21} characteristic with FFC in Fig. 2 shows >20-dB FM reduction over a narrow (15–40 MHz) bandwidth and >10 dB from 5 MHz to ~1 GHz. The reduction was limited mainly by the LNPM V_π together with output voltage saturation (~15 $V_{p\text{-}p}$) of the driving amplifier and at low frequencies by the integrating time constant. By using a narrower bandwidth, higher output voltage amplifier, we observed an FM reduction of 20 dB from 2 to 200 MHz. Limitations to FM noise reduction, including gain and time-delay flatness and OFD bandwidth, are presented.

Figure 3 shows the effect of FFC on the input optical linewidth. For this measurement the fiber output is connected to a conventional delayed self heterodyne linewidth measurement system. The input 19-MHz linewidth is reduced to 8 MHz. The limited linewidth reduction may be due to the low frequency limit or nonlinearities of the FFC circuit.

Summarizing: We have proposed and demonstrated a new insertable fiber-optic device that reduces optical FM noise and linewidth. Experimental results reveal FM modulation reduction to 1 GHz, which we believe is the widest reported bandwidth for FM suppression. This technique should be especially useful in conjunction with feedback, where FM noise at low frequencies is reduced by feedback and at high frequencies (including feedback-induced FM noise enhancement) by feedforward.

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2. A. Sugita *et al.*, J. Sel. Areas Commun. **SAC-8**, 1128–1131 (1990).
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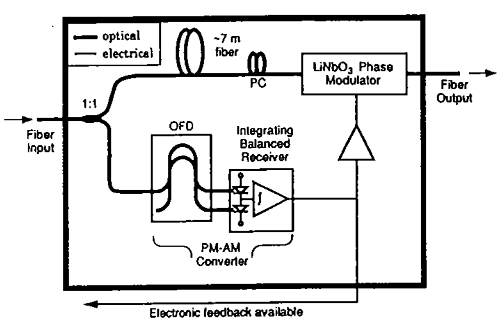
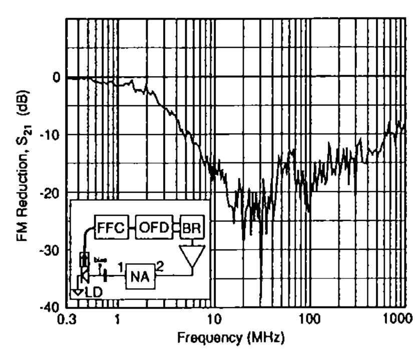
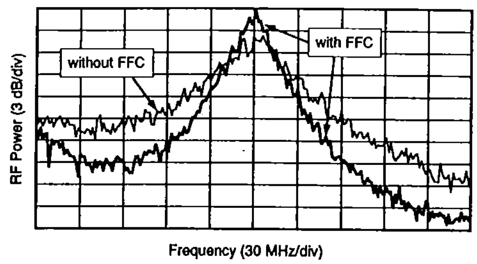


TuM3 Fig. 1. Experimental setup. The optical frequency discriminator (OFD) is a temperature-controlled polarization-insensitive fiber-pigtailed silica waveguide Mach-Zehnder interferometer. The feedforward signal path includes amplitude and phase adjustments not shown. The phase modulator 3-dB bandwidth, π voltage, and insertion loss are 4 GHz, 5.8 V, and 6.5 dB, respectively. Total optical insertion loss is ~10 dB. PC stands for polarization controller.



TuM3 Fig. 2. Optical FM reduction—S_{21} normalized to S_{21} without FFC. Effective (≳10 dB) reduction is observed from 5 MHz to ~1 GHz. Inset: measurement setup using a laser diode, network analyzer (NA), a second OFD, and a balanced receiver (BR).



TuM3 Fig. 3. Measured laser linewidth with and without feedforward compensation. The optical linewidth is taken as half the measured delayed self-heterodyne linewidth.