

# Upstream OOK Remodulation Scheme Using Injection-Locked FP Laser with Downstream Inverse-RZ Data in WDM Passive Optical Network

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## ABSTRACT

We propose and demonstrate the use of 10-Gb/s inverse-RZ data as downstream signal in WDM-PON to injection-lock a directly modulated Fabry-Perot laser used for the upstream signal at 1Gb/s.

**Keywords:** Injection-locking, Fabry-Perot Laser, Inverse-RZ

## 1. INTRODUCTION

The wavelength-division multiplexing passive optical network (WDM-PON) provides a simple and effective solution to meet the increasing demand of bandwidth for last-mile solution. For each light-path from the Optical Line Terminal (OLT) from and to its associated Optical Network Units (ONU), WDM-PON uses light sources of different wavelength to achieve the circuit routing function. Therefore, a challenge of building WDM-PON is to select a suitable light source which can accommodate the large number of wavelengths used. On the central office (CO) side, where a large number of wavelengths should be generated, laser array and tunable laser can be used. Spectral slicing techniques which use broadband light source and optical filters are also commonly used to further simply the network architecture.

A WDM-PON that uses centralized light sources (CLS) from the central office (CO) with different wavelength to reach different ONUs, has become an attractive solution for cost-effective implementation for distribution network. For the light-path from the ONUs to the CO, it is relatively expensive to have tunable light sources or tunable filter in the design. In addition, from the manufacturing and management point of view, it is still better to keep the ONU wavelength independent (or “colorless”), in which the design of ONU does not have registered wavelength or wavelength tunable component such as tunable laser or filter [1]. Data re-modulating schemes [2-4] have been proposed to achieve colorless operation of ONUs, where the light from the CO is reused for the upstream signal. Modulation format such as Inverse-return-to-zero (IRZ) [2, 3] and Manchester coding [4] were studied and were used for the downstream data. Unlike non-return-to-zero (NRZ) and return-to-zero(RZ) format, both the zero and one bits in IRZ and Manchester coding carry power, therefore the downstream data can be re-

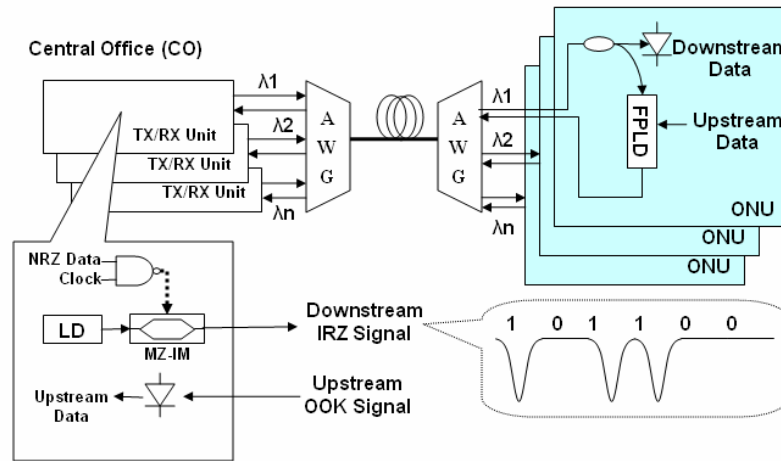
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modulated using an intensity modulator to produce NRZ upstream data in the ONU. However, the use of expensive intensity modulator in ONU is not preferred. Another approach is to inject the downstream signal into a low-cost Fabry-Perot (FP) laser in the ONU and lock the upstream wavelength using the downstream signal. In [6], DPSK was used for this purpose and it was reported that the large phase modulation depth in downstream injection signal will create noise in the output of the FP laser diode. Prior to this, using on-off-keying (OOK) data for injection locking was also demonstrated in [5] but this scheme required high injection power and sacrificed the extinction ratio of the downstream data to reduce the crosstalk to the upstream signal.

In this paper, we propose and demonstrate a colorless and cost-effective solution, which uses the 10-Gb/s downstream IRZ data to injection-lock a low-cost FP-laser with direct modulation of 1-Gb/s for upstream transmission at the ONU. We showed that a side mode suppression ratio (SMSR) of over 28 dB in the output of the FP-laser was obtained by injection locking using the downstream IRZ signal with high extinction ratio of over 16 dB and low injection power of -17.7 dBm.



**Figure 1.** System Architecture of WDM PON with injection locking using downstream IRZ signals. The inset shows typical waveform of the downstream optical IRZ signal.

## 2. SYSTEM ARCHITECTURE

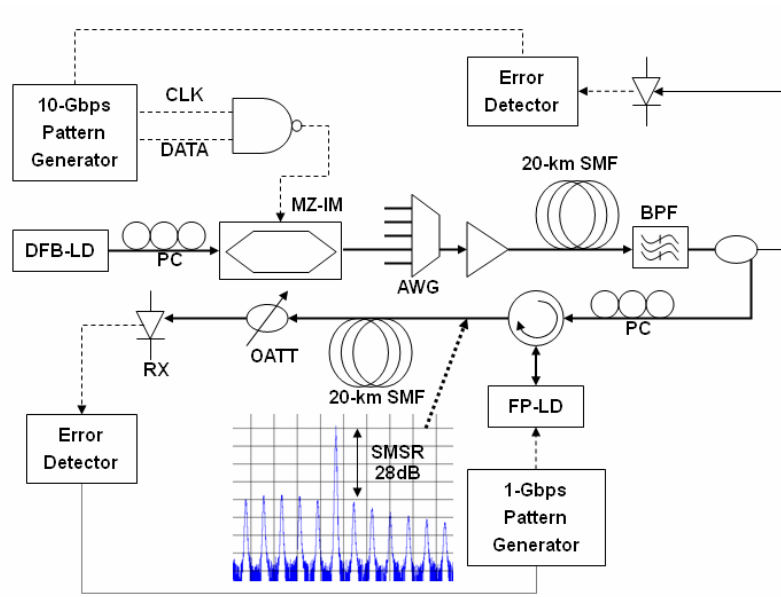
Figure 1 shows the architecture of a typical WDM-PON with our proposed FP-Laser injection locking with downstream IRZ signal scheme. Inverse return-to-zero data is formed by inverting the intensity level of a conventional RZ signal, thus it carries more optical power in both zero and one bits than the ordinary return-to-zero and NRZ data format, as shown in inset of Figure 1. IRZ downstream data is then modulated onto a specific wavelength channel through an optical intensity modulator and is transmitted from the CO to the ONUs through an

array waveguide grating (AWG) at the remote node (RN). Each ONU is receiving the downstream optical signal on a distinct wavelength.

A proportion of received power at the ONU is then fed into an optical receiver to recover the downstream signal, whereas the remaining power is injected into an FP laser for injection locking such that the SMSR of the FP-laser can be greatly enhanced. By directly modulating the FP-laser, the upstream optical signal with the same wavelength carrier as the downstream signal is generated. If we can further remove the cost constraint, it is also possible to use an intensity modulator right after the FP laser. In this scheme, both the upstream and downstream wavelength are selected by the CO, thus the ONUs are operating in colorless manner.

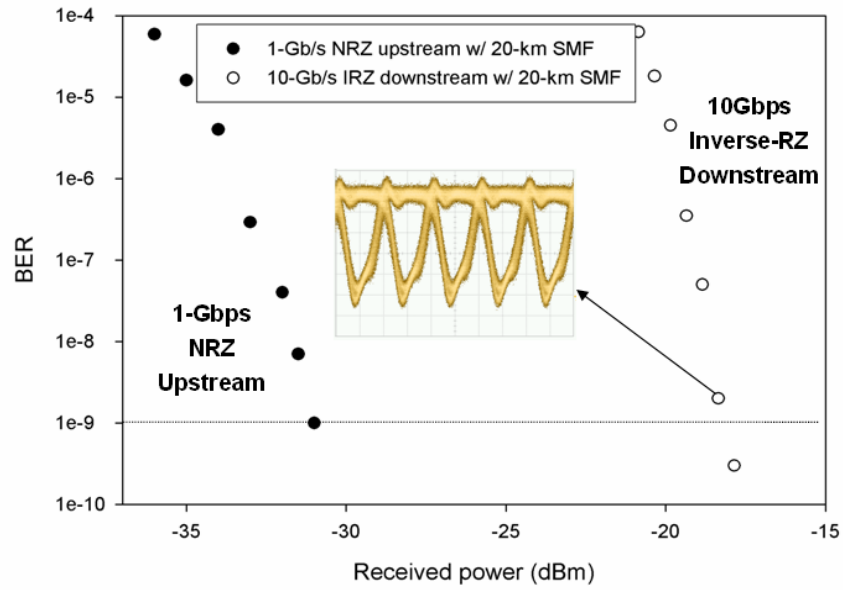
### 3. EXPERIMENTAL SETUP AND RESULTS

Figure 2 shows the experimental setup to demonstrate and evaluate our proposed upstream data remodulation and SMSR enhancement scheme. Downstream traffic was generated from a DFB laser at 1550.78 nm was externally modulated by a Mach-Zehnder intensity modulator (MZ-IM) at the CO. The electrical driving signal for the modulator was generated by a logic NAND operation between a clock signal and an NRZ RF data which was a 10-Gb/s NRZ  $2^{31}-1$  pseudorandom binary sequence (PRBS). By biasing the resultant signal at the quadrature point of the positive slope of the MZ-IM, the optical IRZ signal was generated for transmission with an extinction ratio of 16 dB, as shown in inset of Figure 3. The signal was then passed through an AWG and an optical amplifier before transmission in a 20-km single mode fiber (SMF) with transmission power of 1.3 dBm. An optical band-pass filter with a 3-dB bandwidth of  $\sim 0.8$  nm was used at the ONU to emulate one channel of a 100-GHz AWG and to suppress the amplified spontaneous emission (ASE) noise. A portion of the downstream received power was tapped off by a 50/50 coupler and fed into a PIN-typed photo-detector. The bit-error-rate (BER) curve of the received IRZ signal at the ONU was recorded, as shown in Figure 3. The receiver sensitivity for the downstream was -17.9 dBm at BER of  $10^{-9}$ .



**Figure 2.** Experimental setup, DFB-LD – distributed feedback laser diode, PC – polarization controller, FP-LD – Fabry-Perot laser diode, OATT – optical attenuator, APD – avalanche photo diode, MZ-IM – Mach-Zehnder intensity modulator, BPF – optical band-pass filter, AWG – array waveguide grating.

The remaining received optical power was injected into a Fabry-Perot laser through a polarization controller and an optical circulator with injection power of -17.7 dBm. The output of FP laser was then monitored by an optical spectrum analyser (OSA) through the port 3 of the optical circulator to ensure the locking condition. The inset of Figure 2 shows that the improved SMSR obtained in the experiment was around 28 dB and the total output power of the FP-laser was about -10.15dBm. At the same time, the FP-laser was directly modulated by a 1-Gb/s NRZ  $2^{31}-1$  PRBS. The output from the ONU was then transmitted in a 20-km SMF to emulate the upstream transmission. The upstream signal was received by an APD-typed photo-detector diode at the central office. The BER measurement of the upstream data was plotted in Figure 3. The receiver sensitivity was around -31 dBm, which should provide enough power budget over upstream transmission with AWG.



**Figure 3.** Bit-Error-Rate Measurement of Upstream and Downstream Data

## 4. CONCLUSIONS

We have proposed a cost-effective solution for the WDM-PON which uses the IRZ downstream data to injection lock the FP-laser in the ONU without any sacrifice in extinction ratio of the downstream signal and at low injection power. The upstream transmission is initiated by directly modulated the injection locked FP-laser. Small power penalties for both the downstream and the upstream 20-km transmission were achieved without dispersion compensation.

## ACKNOWLEDGMENTS

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