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Radio over Fiber Access for Integrated Broadband Wireless Systems using OptiSystem

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Abstract—Radio over Fiber (RoF) is an integration of wireless and fiber optics networks. In RoF, radio frequencies are transmitted over the optical fiber links for various wireless applications. The proposed RoF system consists of externally injected gain-switched DFB laser as optical source. This optical source has better tolerance to the time delay in comparison to the pre-compensation technique. The noise due to optical phase decorrelation is reduced, without using pre-compensation techniques; laser is externally injected to generate a low line-width comb source. Line-width and noise is directly proportional. In this technique, External Cavity Laser (ECL) is used as master laser and it has low line-width. ECL tunes the line-width of the externally injected DFB laser (Slave Laser) to its line-width. As the line width is low, noise is reduced.

Keywords— Radio over Fiber (RoF), External Cavity Laser (ECL), Distributed Feedback Laser (DFB laser)

I. Introduction

Radio over fiber (RoF) refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to distribute radio signals from central location to base station and facilitate wireless access, such as 3G and WiFi simultaneous from the same antenna. Thus, a single antenna can receive all radio signals (3G, Wifi, etc..) carried over a single-fiber cable to a central location where equipment then converts the signals; this is not possible with the traditional way where each protocol type (3G, WiFi, cell) requires separate equipment at the location of the antenna [1]. The minimum bit rate that 4G would provide for broadband services is 20 Mb/s for indoor and 2Mb/s for outdoor application even with high relative mobility. Nowadays, 4G-cellular and Intelligent Transport System (ITSs) have been attracting much interest in the mobile communication field. Both of these technologies take advantage of ROF technique. Cell optimization is the concept in 4G cellular system. In ITS system, the key technology in road vehicle communication system is again ROF, in which many base stations are placed along the trunk road in order to communicate with vehicles, and several control base stations manage these bases.

RoF transmission systems are usually classified into two main categories: (i) In RF-over-fiber architecture, a data-carrying RF (radio frequency) signal with a high frequency is imposed on a light wave signal before being transported over the optical link. Therefore, wireless signals are distributed optically to base stations directly at high frequencies and converted from the optical to electrical domain at the base stations before being amplified and radiated by an antenna [2]. As a result, no frequency up–down conversion is required at the various base stations, thereby resulting in simple and rather cost-effective implementation is enabled at the base stations. (ii) In IF-over-fiber architecture, an IF (intermediate frequency) radio signal with lower frequency is used for modulating light before being transported over the optical link [3]. Hence the signal must be up-converted before it radiates through the air.

II. Methodology

A. *Utilizing a gain switched DFB laser*

The DFB laser is gain switched using a sinusoidal RF signal, which results in an OFC [4]. A wavelength selective switch (WSS) is used to filter off two tones separated. The two tones are amplified by an Erbium doped fiber amplifier (EDFA) before being split using a DEMUX. Due to the large bandwidth of the DEMUX (>80 GHz), the required channels cannot be selected with perfect rejection of the neighboring channels. Therefore, tunable optical band pass filters (OBPF) are used, in both arms, to further suppress the unwanted channels.

In channel 1 (Ch. 1), OFDM signal is generated using an arbitrary waveform generator and amplified before being applied to the individual arms of the dual drive Mach-Zehnder modulator (DD-MZM) [6]. In channel 2 (Ch. 2), a tunable delay line is employed to compensate for the time delay induced by the splitting of the optical tones as well as the time delay induced by the SSMF. As the time delay is compensated before the signal is transmitted through the fiber, hence this technique is called pre-compensation.

A variable optical attenuator (VOA) is used to vary the optical power in order to achieve the most efficient beating of the modulated and un-modulated signals at the photodetector. A polarization controller optimizes and rematches the polarization of the two split channels. Excellent rejection of the unwanted channels is achieved with the tunable OPBFs. The two channels are recombined and amplified by another EDFA and an OBPF is subsequently used to reject the out of band amplified spontaneous emission (ASE). ASE is the light produced by spontaneous emission; this light is captured by fiber core and propagates together with signal along with the fiber (in both directions). Importantly, it can then experience a similar gain as any signal. As fiber amplifiers often reach a high gain, the guided part of the light from spontaneous emission is strongly amplified. Therefore, it is called as amplified spontaneous emission (ASE).

The system is analyzed for back to back (BTB) transmission and transmission over 50 km of SSMF (equivalent to a 400 ps delay between the two optical channels). After transmission through fiber, the optical signal is sent to an EDFA via a VOA which is employed to vary the input optical power for bit-error rate (BER) measurements. An OBPF is again used to reject the out of band ASE. The amplified optical signal is then sent to the photodetector via a VOA. After photodetection, the electrical signal contains the desired OFDM signal and an undesired component. The electrical signal is passed through an electrical band pass filter (EBPF) before being amplified.

The filtered signal is subsequently down-converted with a sinusoidal RF signal using an external mixer. The data signal is filtered with a electrical low pass filter (ELPF) before being sent to the real time scope (RTS) [9]. Below layout represents the RoF system utilizing gain switched DFB laser and phase noise pre-compensation technique designed and simulated using OptiSystem software [7]. In which BER and SNR are calculated.

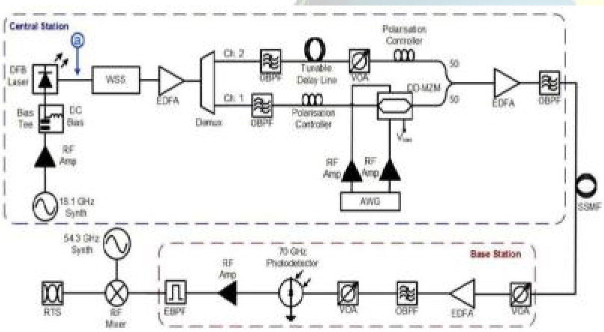

Fig 1: Schematic of the experimental setup utilizing a gain switched DFB laser.

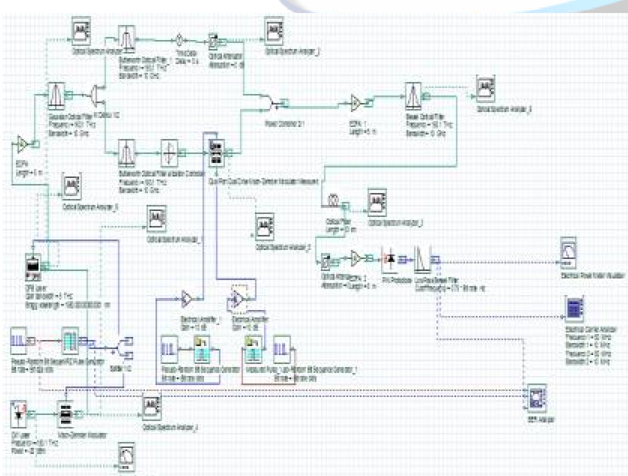

Fig 2: OptiSystem Layout of RoF system using gain switched DFB laser.

B. RoF system using a externally injected gain switched DFB laser.

Main components in this technique is similar to pre-compensation except tunable delay line is not used and External Cavity Laser (ECL) is used here. ECL is a non-monolithic diode laser where the laser cavity (resonator) is completed with external optical elements. ECL is a tunable laser. A tunable laser is a laser whose wavelength of operation can be altered in a controlled manner. While all laser gain media allow small shifts in output wavelength, only a few types of lasers allow continuous tuning over a significant wavelength range. This setup is based on externally injected gain switched DFB laser. [5] discussed about Improved Particle Swarm Optimization. The fuzzy filter based on particle swarm optimization is used to remove the high density image impulse noise, which occur during the transmission, data acquisition and processing.

The DFB slave laser is gain switched using an RF signal. The slave laser is externally injected using an ECL as the master laser tuned to match the wavelength of the slave laser. ECL have low line-width optical tone which tune the DFB laser to its line-width and make DFB laser to generate low line-width optical comb. Therefore, spectral output of the externally injected gain switched DFB laser is an OFC with low line width. As optical comb has low line-width, phase noise is reduced here. The remainder of the central station setup is similar to that in pre-compensation technique with the exception of the optical delay line not being required in Ch. 2. The two channels are recombined before being amplified using an EDFA.

The system is also analyzed with an additional delay of 5 m of SSMF in Ch. 2 to show that even with large time delays between the optical tones (5 m is equivalent to a relative delay of 25 ns), a low phase noise signal can still be generated. The received optical signal is passed through a VOA which is used to vary the power falling on the detector for BER measurements [10]. A photodetector is used to generate a electrical signal from the received optical signal. The mm wave signal is then passed through a EBPF before being amplified. The OFDM data signal is filtered with a ELPF before being sent to the RTS. Below layout represents the RoF system using a externally injected gain switched DFB laser designed and simulated using OptiSystem software. In which BER and SNR are calculated.

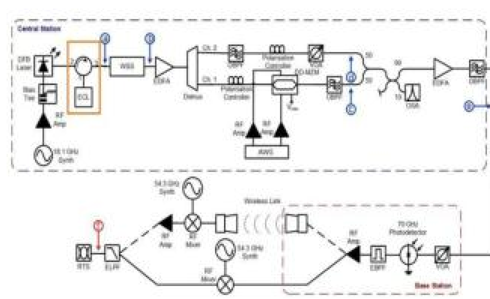

Fig 3: Schematic of the experimental setup utilizing an externally injected gain switched DFB laser.

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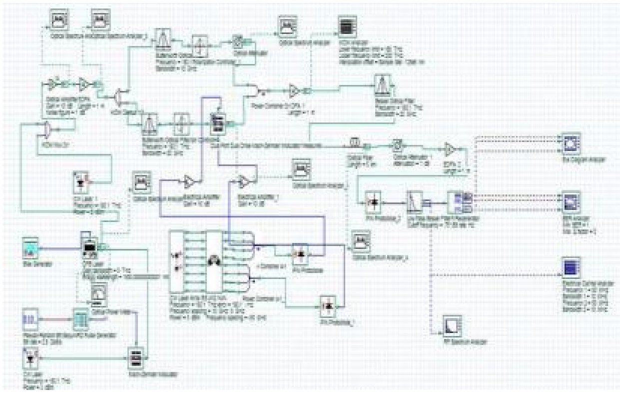

Fig 4: OptiSystem layout of RoF system using externally injected gain switched DFB laser.

III. SIMULATION RESULTS

A. *Results of pre-compensation technique*

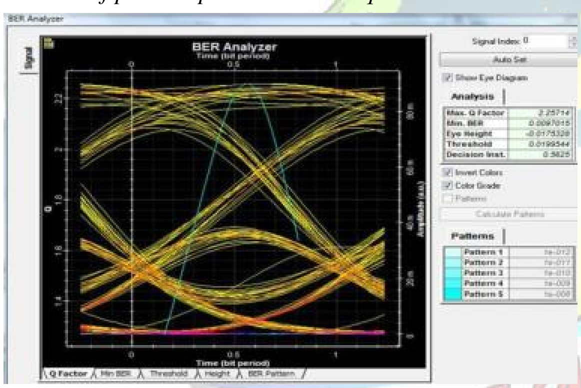

Fig 5: BER Analyzer for pre-compensation technique.

From above figure we can infer that Q value is minimum and BER value is high. For a good system Q value should be high and BER should be low. Eye diagram is distorted due to noise.

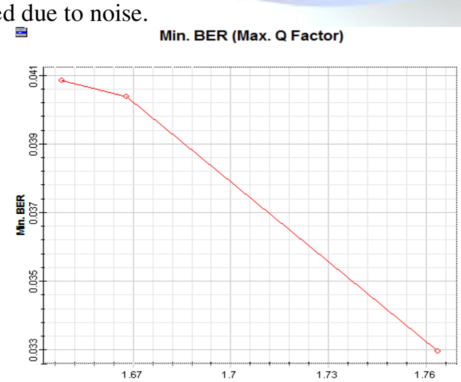

Fig 6: Q factor vs. BER

Above graph plotted between Q Factor and BER, Q Factor increased by decreasing the value BER. To have better tolerance to the noise and to get high Q value, low BER, we go for external injection of gain switched DFB laser technique.

B. *Result for external injection of DFB Laser*

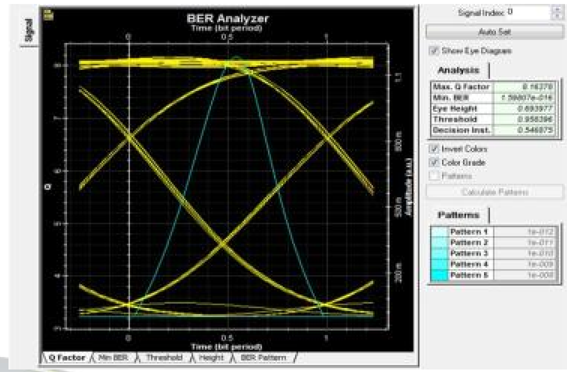

Fig 7: BER analyzer

Compared to pre-compensation technique Q value, BER, here we got high Q value and very low BER value. Signal strength is improved. This shows that, noise is reduced better compared to previous method.

Fig 8: Q factor vs. BER

Above graph plotted between Q Factor and BER, Q Factor increased by decreasing the value BER. Therefore, the proposed methodology reduces noise to great extent compared to pre-compensation technique.

C. *Comparison of two techniques*

TABLE I: COMPARISON OF RESULTS

S.NO	PARAMETERS	WITHOUT ECL	WITH ECL
1	Q- Factor	2.20	8.16
2	Bit Error Rate	0.0099	1.5e-16

Table 1 consists of BER, Q value and SNR value of the two techniques. By seeing this table, we can come to a conclusion that external injection is more superior to pre-compensation technique. In external injection technique, Q value is increased and BER is decreased compared to another technique.

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IV. Conclution

Initially a low complexity gain switched DFB laser with large line-width per comb line is used to transmit RF signal using pre-compensation technique to overcome noise due to chromatic dispersion. This technique requires a trade-off decision to be made between cost and tolerance to the noise induced by the chromatic dispersion [8]. In order to have better tolerance to time delay without the need for precise compensation technique, the DFB laser externally injected to generate a low line-width optical comb with using ECL laser, without the need for complex DSP and PNS algorithm. Moreover the comb flatness and relative intensity noise of the comb source is improved using injection locking technique. This system is extremely stable to changes in fiber length.

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