

FFT Optimization for Practical OFDM Implementations

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Abstract: We investigate scaling the FFT-size in OFDM signal generated with FPGA-DAC set. Increasing FFT-size, creates challenges in optical back-to-back scenario due to less tolerance to phase noise. However, for transmission nonlinear tolerance was the same.

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1. Motivation

Of late, optical communication society is venturing into the search for advanced modulation formats that have the potential to meet the stringent requirements of bandwidth hungry applications. Among the contenders undergoing scrutiny, coherent optical orthogonal frequency division multiplexing (CO-OFDM) has received considerable interest because of its immunity against inter-symbol-interference (ISI), scalability to higher level modulation formats and possibility to realize next generation agile optical networks [1,2]. Nevertheless, the dominating modulation format for 100 Gigabit Ethernet (100 GbE) is single-carrier polarization division multiplexed QPSK (PDM-QPSK).

One of the main challenges when scaling OFDM to higher data rates is the limited speed of digital-to-analog converters (DACs) and analog-to-digital converters (ADCs). With the advent of high speed DACs going upto 34GS/s, many results have been recently demonstrated in conjunction with field programmable gate arrays (FPGAs) [3-7]. In [3], the signal bandwidth of 21 GHz has been shown, which clearly shows the future possibilities for OFDM. In [4], we have compared the real time FPGA with FPGAs acting as arbitrary waveform generator (AWG), and have shown that the performance is similar. Hence in this paper we utilize the AWG mode of operation of FPGA, as we focus more on the effect of increasing the FFT size. Since OFDM suffers from high overhead, it is crucial that the right FFT size is chosen with minimal overheads. It is well know that as we increase the FFT size, the symbol length increases making it more vulnerable to phase noise. Hence, we have to find the tradeoff. In FPGA-DAC based configuration, an investigation on performance of the OFDM signal when we increase the FFT-size has to be performed.

In this paper we investigate the performance of an FPGA-DAC pair in coherent OFDM setup for varying FFT sizes. First the electrical back-to-back performance is scrutinized for different FFT sizes. A 1.8 dB of degradation in the E_s/N_0 for 4096 FFT size is observed compared to 512 FFT sized OFDM signal. Consequently, a very high BER penalty is seen in optical back-to-back, when scaling the signal FFT size from 512 through to 4096. This increase in penalty can be explained by the presence of phase noise and sampling frequency offset. Finally, these FFT sizes are compared for 400 km transmission scenario, where it is seen that the non-linear tolerance for each of them are same. The transmission link considered here was standard single mode fiber.

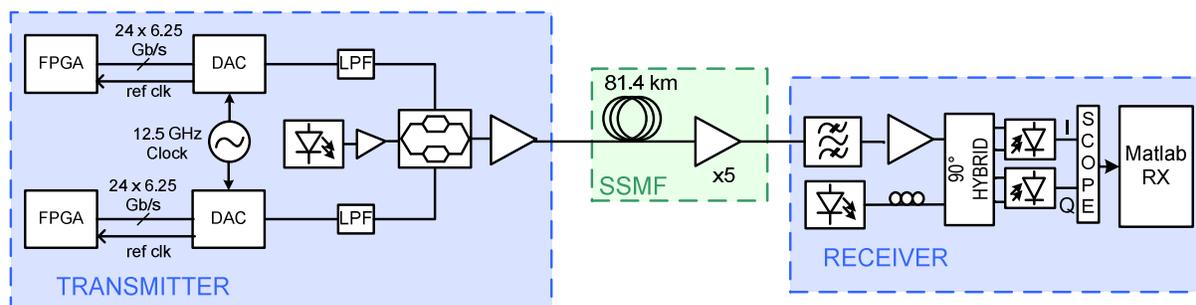


Fig 1: Schematic of coherent optical (CO-) OFDM system with transmission link

2. Experimental Setup

The experimental configuration for the transmitter, link and receiver of the CO-OFDM system is illustrated in Fig. 1. In the experiment, two FPGAs were used to generate the in-phase (I) and quadrature-phase (Q) components of the OFDM signal. The OFDM signal is initially generated offline, quantized to 6-bits and stored in the ROM tables of the Virtex-5 FPGAs. The FPGAs are subsequently connected to the DACs which operate synchronously at 25 GS/s to generate continuous baseband signal. A low-pass filter (LPF) after the DAC with 12.5 GHz bandwidth is used to suppress any aliasing products. When generating the OFDM signal, the FFT size is varied among 512, 1024, 2048 and 4096 points, from which 60.2% of subcarriers are effectively used as data carriers with a 4-QAM (quadrature-amplitude- modulation) constellation on each sample. 2.4% of the total subcarriers around the DC are padded with zeros to make place for the insertion of optical carrier/ pilot. A cyclic prefix overhead of 6.25% is used to increase ISI tolerance. The exact values for these parameters for individual FFT sizes are depicted in Table.1.The total bit rate is ~30 Gb/s. The signal bandwidth was ~15 GHz.

A laser at 1550.116 nm is used at the transmitter to generate a continuous wave (CW) signal that is subsequently modulated with the OFDM signal by an IQ Mach-Zehnder modulator (IQ-MZM). Similar to the CO-OFDM modulation format discussed in [1], the MZM is biased such that the carrier is not totally suppressed at the transmitter. This carrier is used in the receiver for phase noise compensation.

The transmission link consists of 5 spans of 81.4-km standard single mode fiber (SSMF) without any optical dispersion compensation. After every span, an erbium-doped fiber amplifier (EDFA) is used for amplification.

At the receiver, the polarization of the optical OFDM signal and the local oscillator (LO) are aligned with the help of a polarization controller. An external cavity laser (ECL) with 100-kHz typical linewidth is used as LO. With a 90° optical hybrid, the signals are heterodyne-detected. The succeeding single ended photo detectors (XPD) convert the received optical signal to electrical I and Q constituents. At the receiver, after detection, the signal is sampled with a real-time oscilloscope and processed off-line. The bandwidth of the oscilloscope is 16 GHz and the sampling frequency is 50 GS/s.

The off-line processing starts with RF-pilot based phase noise compensation. The synchronization is achieved with the aid of training symbols. Then sampling frequency offset estimation and compensation is performed. The training symbols are used also the get the channel response which is then used to invert the channel effect.

Table 1: OFDM parameters and electrical back-to-back Es/No measurements

FFT Size	Cyclic Prefix	RF-Pilot Gap	Modulated Subcarriers	EB2B Es/No (dB)
512	32	12	313	23.4
1024	64	24	616	23.1
2048	128	48	1232	22.8
4096	256	96	2464	21.6

3. Experimental Results

Initially, an electrical back-to-back analysis is done with a single FPGA and DAC set. A real OFDM signal is generated by the use of Hermitian symmetry before the input of iFFT. The output of the DAC is directly connected to the oscilloscope. The FFT size is varied and the Es/No were observed for each case. As depicted in Table. 1 (last column), a 1.8 dB degradation of Es/No is seen when comparing FFT size of 512 to 4096. The origin of this can be accounted to electrical phase noise or jitter and possibly to sampling frequency offset. It should be noted that as the FFT size increases the subcarriers become closely spaced, and are thus less tolerant to electrical phase noise or jitter, resulting in diminished performance. In electrical back-to-back, this phase or frequency difference arises from different clock sources connected to the DACs and ADCs. As we scale to higher FFT sizes, thus more effort has to be applied to mitigate these effects.

An optical back-to-back performance was measured for an OSNR of 18 dB for all the varied FFT sizes for CO-OFDM signal. A BER of 1.3×10^{-5} is measured for 512-FFT while the BER worsens to 4.3×10^{-4} for 4096-FFT as portrayed in Fig. 2(a). The signal with high FFT size is more susceptible to phase noise from the lasers. RF-pilot based phase noise compensation was implemented in these measurements; however the pilot to signal power ratio (PSR) for each of these measurements were not optimized. By optimizing the PSR this drastic difference in the performance of two FFT extremes can be minimized.

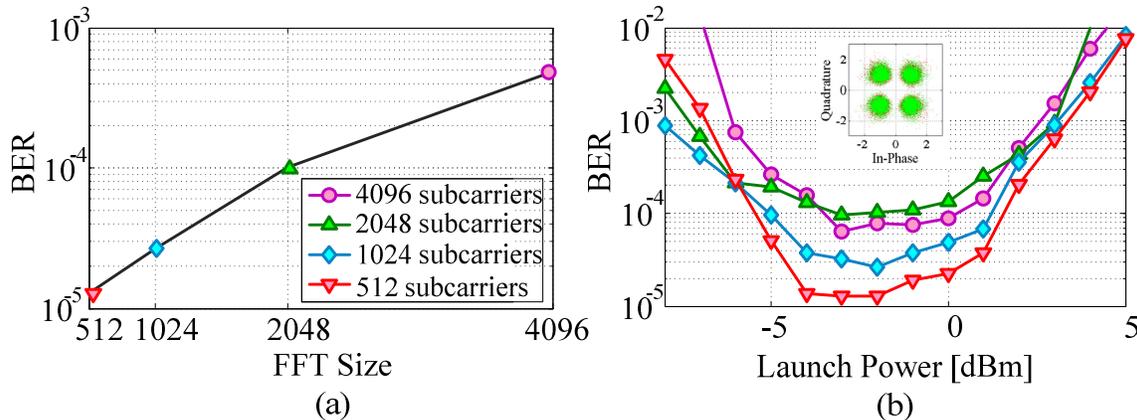


Fig 2: (a) Measured optical back-to-back performance for OSNR of 18 dB and (b) BER vs Launch power after 400 km transmission with inset constellation for 2048 FFT after transmission for launch power of -1dBm

Next, the performance of OFDM signal with different FFT sizes after 400 km of transmission is analyzed. The OSNR is set to the highest value for each of the FFT sizes and the launch power into the fiber is varied. Fig. 2(b) shows the plot for BER against the launch power. It can clearly be seen that the optimum launch power for each of the FFT sizes is around -2 dBm. It can be inferred that the nonlinear tolerance for varied FFT size does not scale with FFT size. The nonlinear penalty is same for all the FFT sizes. In the inset of Fig 2(b) a constellation for the OFDM signal with the FFT of 2048 after 400 km of transmission is depicted.

4. Conclusions

In this paper we have analyzed the performance of CO-OFDM with various FFT sizes for electrical back-to-back, optical back-to-back and transmission scenarios. Two FPGA and DAC sets were used to generate a 30 Gb/s OFDM signal. In electrical back-to-back scenario, 1.8 dB of degradation was seen in E_s/N_0 for the OFDM signal with 4096 FFT size compared to 512 FFT size. A severe degradation is seen in optical back-to-back case, which is due to electrical phase noise or jitter. We conclude that when increasing the FFT size, more stringent precautions have to be taken for the compensation of phase noise and sampling frequency offset. For transmission scenario, however, we see that scaling to higher FFT size does not deteriorate the non-linear tolerance of the signal. All the signals suffer the same amount of nonlinear impairment from transmission.

5. References

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