4.2.2 Orthogonal Frequency Division Multiplexing

Orthogonal Frequency Division Multiplexing (OFDM) has been applied in many communication fields; in copper and wireless applications it is a mature technology with wide commercial availability. Since 2005, research on optical domain OFDM technology has been conducted and has become a very hot field. However, the need for high speed digital-to-analog converter (DAC)/ analog-to-digital (ADC) components and the relatively high complexity has hampered its adoption in optical access networks.

Depending on the modulation, the optical domain OFDM technology is divided into Coherent Detection OFDM (CD-OFDM) and Direct Detection OFDM (DD-OFDM). DD-OFDM has lower cost and smaller packaging, so it's more likely to be adopted in optical access.

The basic electrical architecture for a DD-OFDM transmitter (TX) and receiver (RX) is shown in Fig.1.

In the TX side, incoming serial data is converted to a parallel format, mapped to symbols from Quadrature Amplitude Modulation (QAM) constellation, and then applied to a n-point Inverse FFT (i.e. IFFT) to generate a digital OFDM signal with n orthogonal subcarriers. A cyclic prefix is added to minimize inter-symbol interference (ISI) and then the output data is serialized and converted to an analog signal using high speed DAC technology. The analog signal is converted to an optical signal using a laser for optical domain applications.

In the RX side, signal processing and data flow are opposite to the TX side. The incoming signal is first converted to an electrical signal using an O/E converter and then applied to an ADC. The serial ADC output is converted to parallel and the cyclic prefix is removed. An FFT is used to decode the n OFDM subcarriers, and an equalizer may be used to compensate for chromatic dispersion. After equalization the FFT the signal is sent to a QAM symbol detection module. Finally, the received signal is serialized to recover the transmitted data.

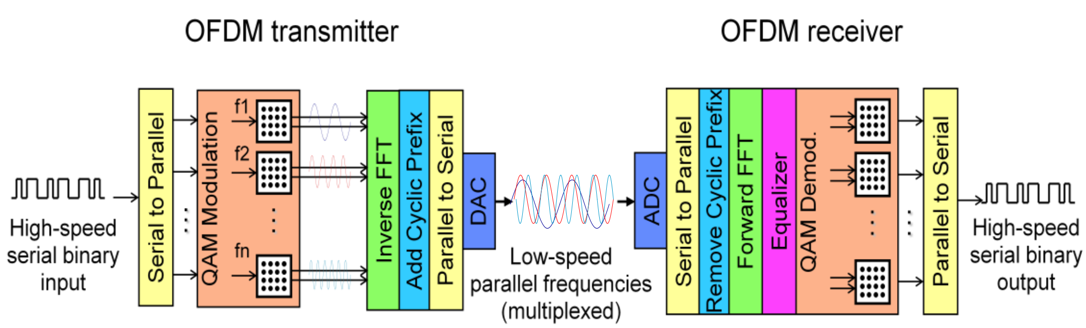

Figure 1: Base electrical physical architecture of DD-OFDM

In addition, one point should be explained. In normal practice the TX side uses two DAC chips and the RX side two ADC chips. This is because the Inverse FFT output is complex signal (i.e.

I+jQ), and it is divided into in-phase (I) component and quadrature (Q) component and each are transmitted through separate DAC channels. The question then becomes how to use a single laser to transmit the two signals. There are several methods to accomplish this. One method is to use an electrical analog I/Q modulator to combine the two signals into one. In this case the RX side can use a single electrical analog I/Q demodulator.

There is one way to avoid the need for two DACs and ADCs. The Fourier transform of a real number sequence has conjugate symmetry, so when QAM symbols are applied to an Inverse FFT, they are mapped to half of the entire subcarriers set, and the other half is assigned as the conjugate of this set. The process is illustrated in Fig.2. Using conjugate symmetry method, a single DAC in the TX and single ADC in the RX are needed.

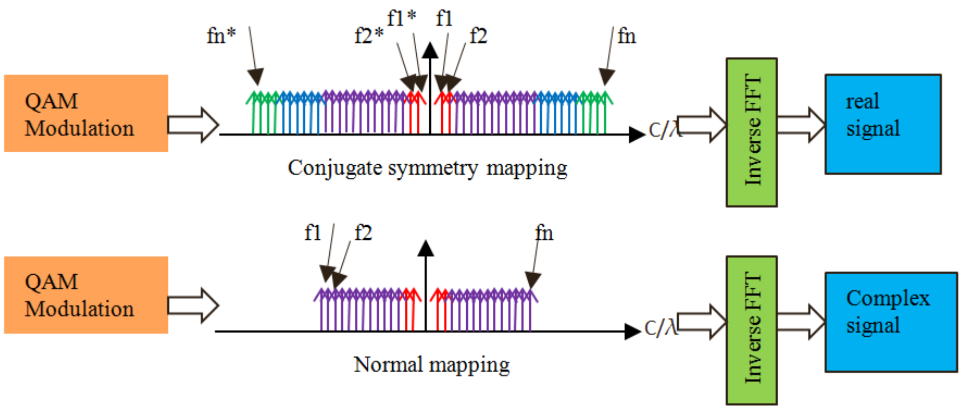

Figure 2: Two mapping method

In OFDM systems multiplexing can be accomplished in either the time domain or the frequency domain. In strict time domain multiplexing the entire OFDM frequency spectrum would be assigned to a single user for some number of symbols, In frequency domain multiplexing a user is assigned one or more subcarriers as illustrated in Figure3. By assigning groups of users to different subcarrier sets the advantages of both time and frequency domain multiplexing can be realized.

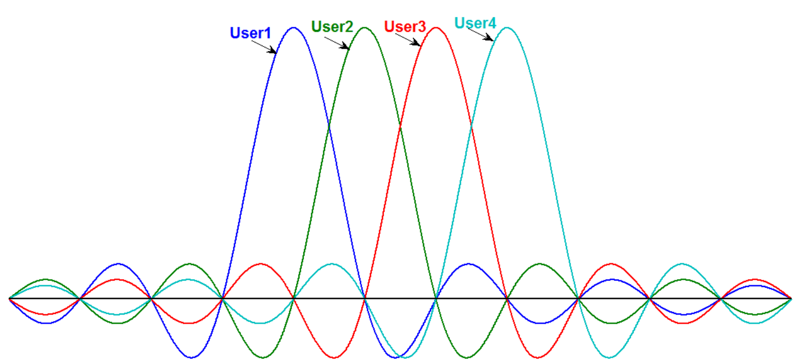

Figure 3: OFDM multiplexing

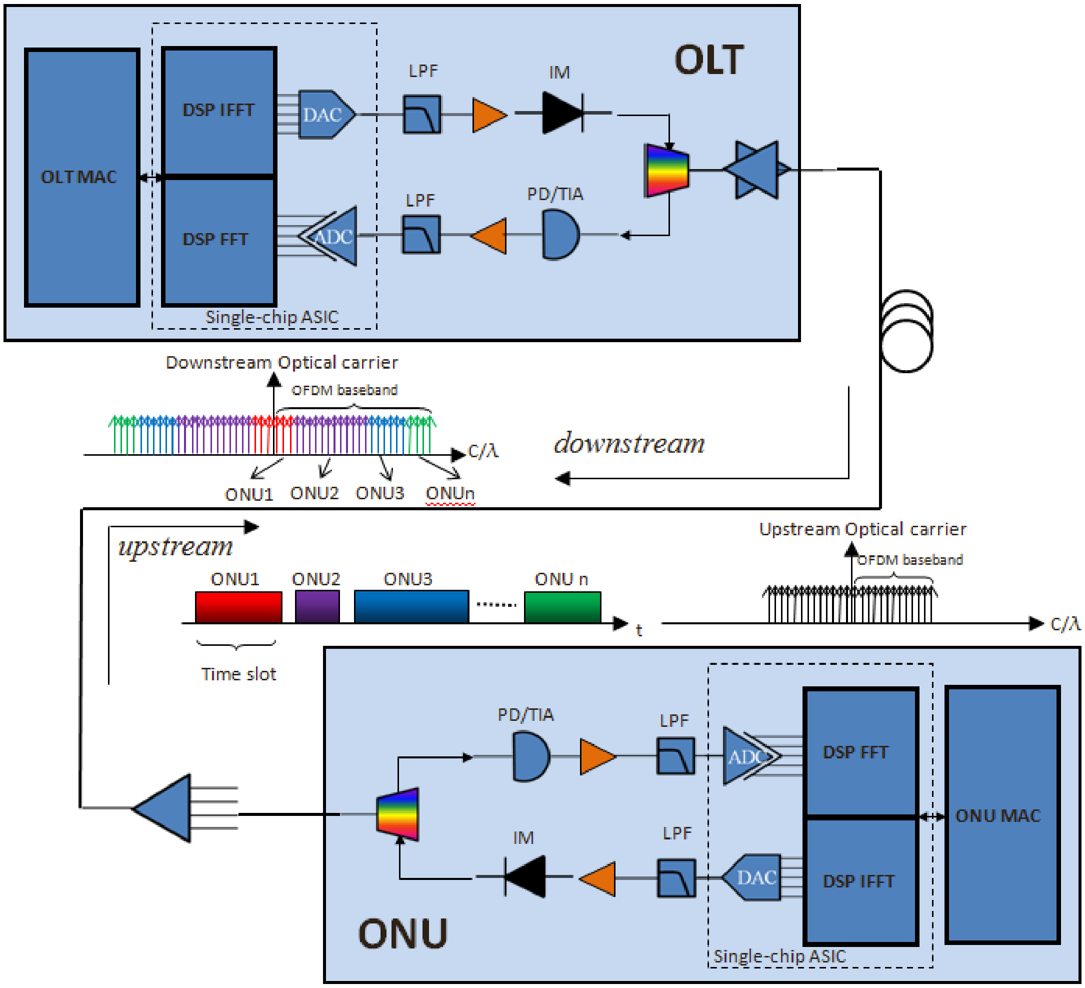

Figure 4: Architecture of DD-OFDM PON

One possible DD-OFDM PON architecture is shown in Fig.4, detailed component requirements are shown in Table 1.

Table 1: DD-OFDM PON Parameters

Modulation	10 Gb/s	25 Gb/s	40 Gb/s	**100 Gb/s**
Bandwidth (OFDM+16QAM)	2.5GHz	6.25 GHz	10 GHz	25 GHz
LASER	2.5G DML/EML	10G DML/EML	10G DML/EML	25G DML/EML
PD	2.5G APD	10G APD	10G APD	25G APD
DAC	5GS/s	12.5GS/s	20GS/s	50GS/s

ADC	5GS/s	12.5GS/s	20GS/s	50GS/s

OFDM has higher spectral efficiency than NRZ, PAM4 and duobinary. For 40Gbps OFDM modulation, 10G optical components are sufficient, but component cost savings are transferred to electrical high speed ADC/DAC components. This has become one of the major limitations of OFDM applications in access.

Another limiting factor is the optical power budget. OFDM has good dispersion resistance performance, better than PAM and duobinary, but has higher linearity requirements than either PAM or duobinary. Both the nonlinearity of the optical components and the electrical components affect the system performance and reduce the overall power budget.

Experimental results show that in a DD-OFDM system the sensitivity at the bit error rate (BER) level of 1×10^{-3} without FEC can reach -21dBm for 40Gbps downstream transmission and -26dBm for 10Gbps upstream transmission. An optical amplifier could be used to increase the launch power and achieve a higher optical budget.