OFDM with Real-Only Transmission

An OFDM communication system is illustrated in Fig 1. Starting on the left, the transmitter computes *A, B* grid points where each grid point is mapped from a bit-sequence. There will be N grid points that define the phase and amplitude of each of the N OFDM subcarriers. This *A, B* vector (with complex terms *A+jB*) becomes the input to an Nth-order IFFT which will transform the subcarrier frequency specification into real and imaginary time-sequences – shown below as I, Q. The I, Q are input to an IQMixer at the transmitter that translates the I, Q low frequency information to a much higher carrier frequency for transmission across a channel. At the receiver, a second IQMixer translates the received signal back into the original I, Q low frequency form but with the addition of extra terms at twice the carrier frequency. The Low Pass Filter (LPF) removes these high frequency terms leaving the original I, Q information. The I, Q is input to an Nth-order FFT which recovers the original *A, B* terms. A lot of the OFDM detail has been left out but Fig 1 captures the basic steps in the OFDM transmit/receive process.

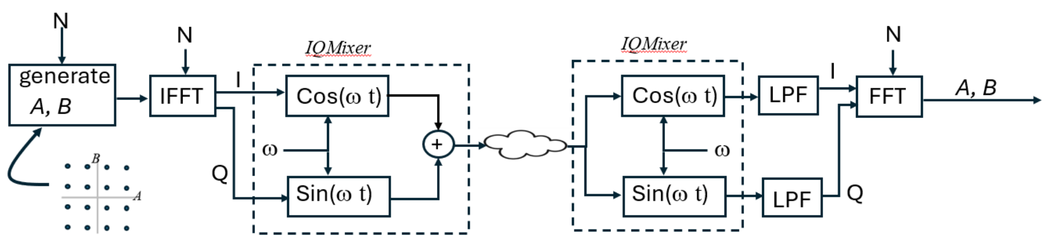

Fig 1 Traditional single symbol OFDM Mechanization

The original DSP Forum question suggested an alternative OFDM mechanization as shown in Fig 2. The Nth-order IFFT at the transmitter is replaced with an M*Nth-order IFFT where M is greater than or equal to two. The added terms in the *A, B* vector will include the complex conjugate of the original N terms so that the output of the IFFT is a real-only sequence. As shown in Fig 2, the original IQMixer configuration is retained which allows a second completely independent datapath to be transmitted across the same frequency spectrum. The penalty for this alternative configuration is that the digital sampling at the receiver must be higher by a factor of M. Also, there will be higher computational burden because of the larger order of the IFFT and FFT.

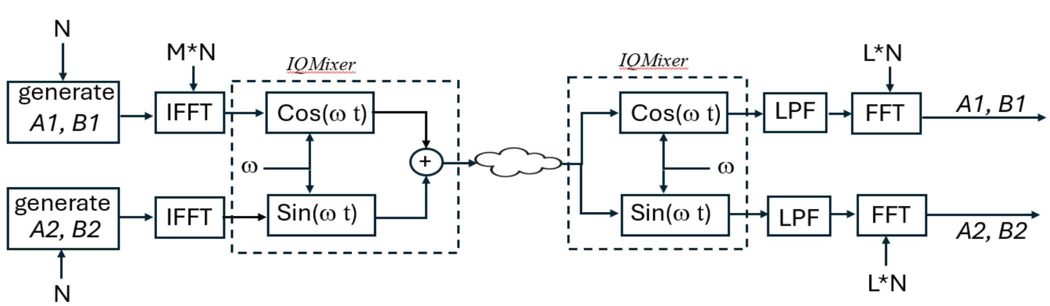

Fig 2 OFDM mechanization with real-only data for a single symbol transmission

A digital simulation of Fig 2 was implemented using C# on a Windows PC. The number of subcarriers N was assumed to be 64 and the frequency spacing of the subcarriers was normalized to 1 rad/sec. With this normalization, the modulation period (symbol period) is 1.0 sec and the bandwidth of the information signal is 64 rad/sec. We assume a QPSK modulation with randomly-selected +/- 1.0 at the corners of the 2X2 grid. We will assume the carrier frequency is 100 times the information bandwidth – 6400 rad/sec. The value for M was selected to be 128 so that the order of the IFFT was 8192. *This results in 8192 real-only digital samples from the IFFT over the normalized 1.0 sec period.* This high-order IFFT produces the same real digital sequence as if we had used the minimal IFFT order (M=2) -- but the resulting real sequence sent to the IQMixer is perfectly interpolated to the higher datarate. We will also use L=M at the receiver to continue the high sampling – but note that this does not have to be the case. The eventual goal will be to implement this using a Direct RF sampling mechanization. With M=128, there are 2π*8192/6400 = 8 digital samples per carrier cycle.

The LPF was mechanized using three sequential 1st-order filters each with the same time-constant (two samples). The time-delay associated with this LPF was removed by averaging forward and backward LPFs applied to the recorded 8192 sample points. Without removing this delay Δt, the receiver *A, B* estimates are rotated with a frequency-dependent phase of n $\Delta\omega$ Δt. The two independent datapaths *A1, B1* and *A2, B2* were treated identically for this simulation.

Fig 3 shows the IFFT output time history (*A1, B1* only) at the transmitter with both M=2 (minimum for real-only output) and M=128. The higher sampling will provide a more accurate dynamic representation of the summed subcarriers. The minimal sampling provides accurate sampling but does not capture the dynamics. This improved transmitted signal fidelity suggests an improved ability of the receiver to compensate for the receiver's sample timing error.

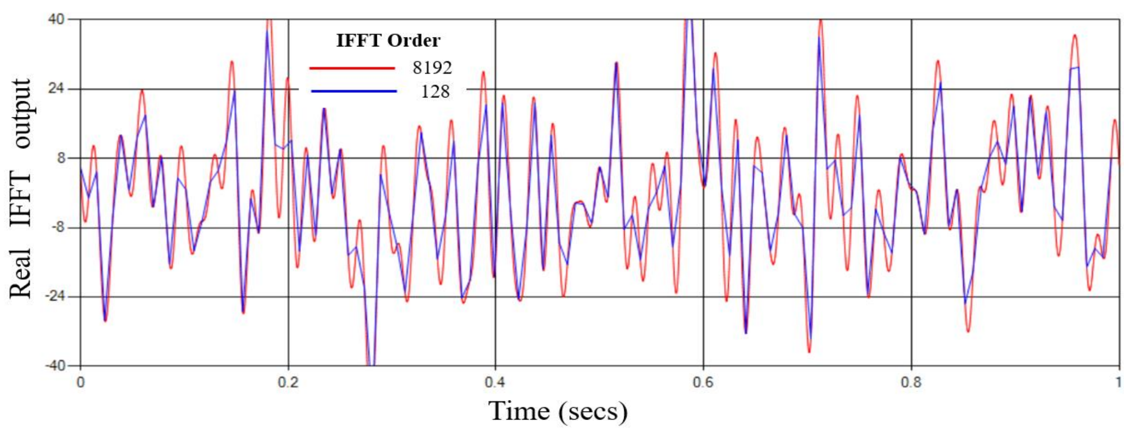

Fig 3 Real-Only IFFT output (*A1, B1*) for 128-point and 8192-point IFFT for OFDM

Fig 4 shows the upconverted (to carrier) transmitter time-histories for both datapaths before and after summation over a symbol period segment of 0.1 secs. The top pane of Fig 4 shows the *A1, B1* datapath IFFT output as well as the IFFT output multiplied by Cos(ω t). The middle pane of Fig 4 shows the *A2, B2* datapath IFFT output as well as the IFFT output multiplied by Sin(ω t). The bottom pane of Fig 4 shows the summed upconverted (and orthogonal) transmitted signal along with the IFFT output for both datapaths. The receiver detects the high frequency transmitted signal and must recover the two lower frequency information signals.

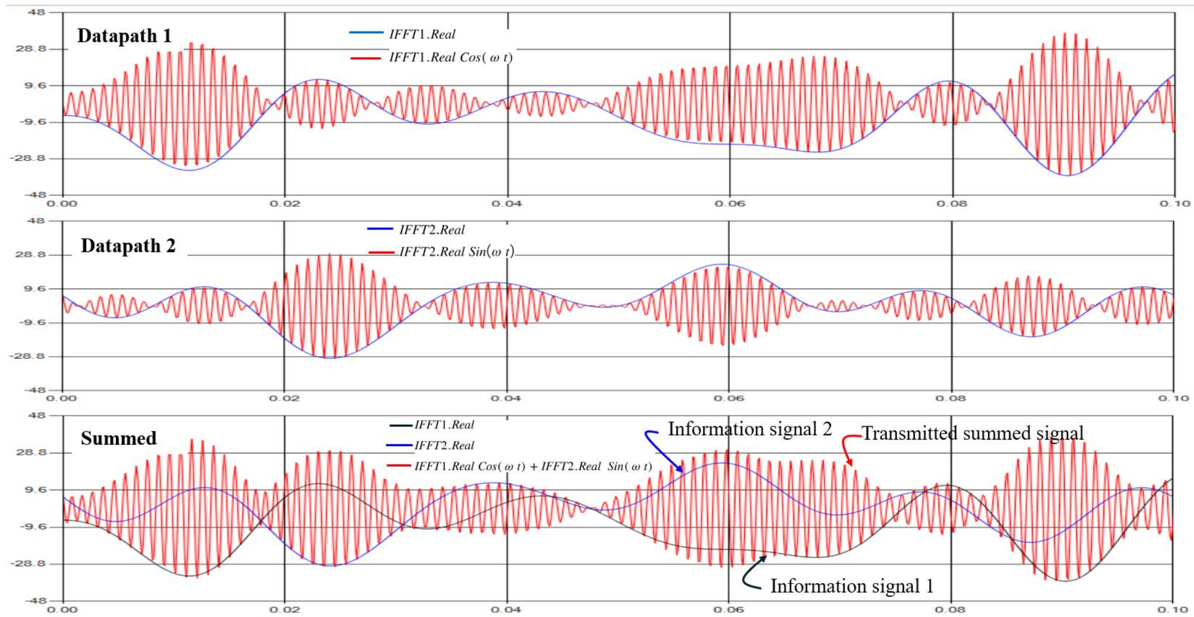

Fig 4 Trasmitter Upconversion to carrier for the two datapaths

Fig 5 shows the receiver processing where the originally transmitted data-carrying signals are recovered. The two panes of Fig 5 shows the downconverted received modulated carrier (red) along with the LPF transformed signals for both datapaths. The original IFFT outputs (the data-carrying transmitted signals) are also shown but are not distinguishable. The two-times-carrier frequency components are clearly seen by comparing Fig 4 and Fig 5. The data-carrying signals are well-recovered by this process.

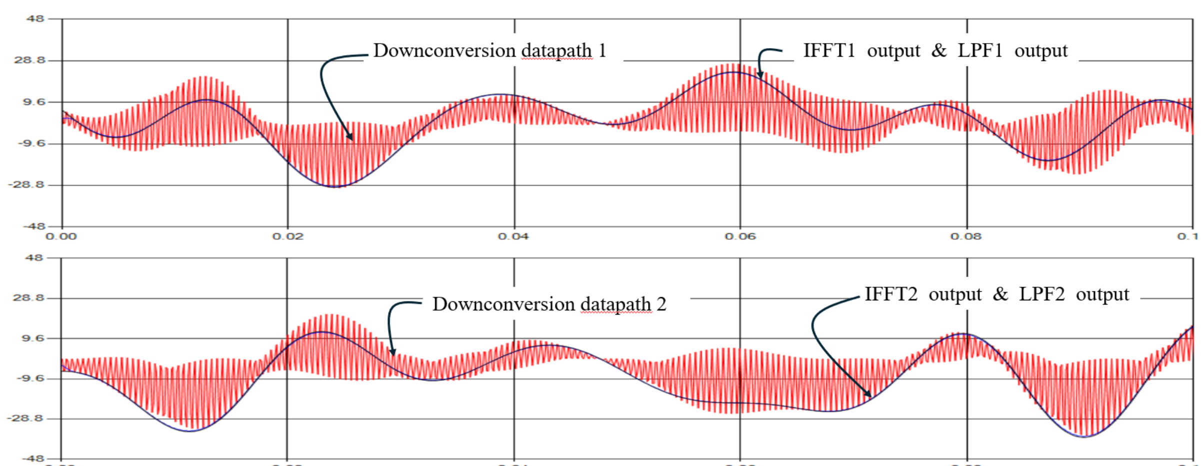

FIG 5 Receiver-side processing shows excellent recovery of original data-carrying signals

When there is no noise introduced by the channel, the estimation of the *A, B* coefficients is almost perfect. Fig 6 shows a case where we have introduced an AWGN with noise of 10. Note that for 64 QPSP modulated subcarriers with amplitude of 1.414 (*A,B* = +/- 1.0) the standard deviation of the summed subcarriers will be 1.414 * 8 = 11.3. Fig 6 also shows the random scatter in the 64 *A,B* grid points for both datapaths.

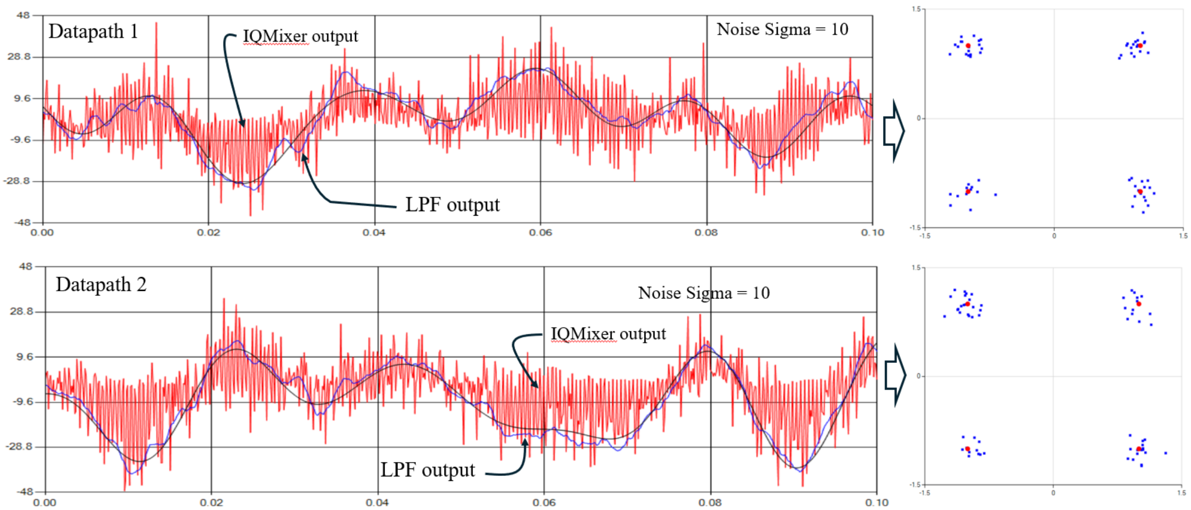

Fig 6 Datapath 1 and 2 estimation and the A,B estimation accuracy with AWGN.

Discussion

- This development has suggested a means to increase the OFDM datarate by a factor of two without adding to the complexity of the transmitter or receiver. The penalty will be faster digital sampling and higher computational burden.
- The higher receiver sampling rate suggests better noise rejection for channel AWGN.
- The results can be scaled to practical system values. A 20MHz signal bandwidth would suggest 2.0GHz Direct RF sampling at 16GHz (8 samples per carrier cycle).
- The receiver could be sampled at a lower datarate so long as this sample rate is greater than twice the signal bandwidth.
- Methods for multipath treatment (Cyclic Prefix) and time, phase, and frequency synch might be accomplished using methods from traditional OFDM.
- Could the Fig 2 mechanization be used to implement a down/up link over the same frequency? Using the same antenna?