Tips on Exploring the OFDM Synchronization Model

This model implements a generic OFDM TX and RX, and is not tied to any particular industry standard. The objective of this model is to develop and explore a continuous (not "bursty") carrier and timing tracking synchronization scheme. The techniques incorporated can then likely be extended and modified to suite specific communications standards. The model uses an "acquisition" technique that exploits the correlation properties of the cyclic prefix to get a rough estimate of the frame boundary before attempting to accomplish the fine tracking algorithms. The model implements a 64 carrier OFDM waveform with a 16 point cyclic prefix. The OFDM symbol has 16 pilots, 3 guard tones (0 amplitude at band edge) and uses 4 QAM for the 45 remaining data streams.

References follow:

"*On Synchronization in OFDM Systems Using the Cyclic Prefix*" - Jan-Jaap van de Beek, Magnus Sandell, Per Ola Borjesson
Div. of Signal Processing Lulea University of Technology, S-971 87 Lulea, Sweden

"*Pilot Tone Selection for Channel Estimation in a Mobile OFDM System* " - Rohit Negi and John Cioffi, Information Systems Laboratory, Stanford University, Stanford, CA 94305
IEEE Transactions on Consumer Electronics, Vol 44, No 3, august 1998. pp 1122-1128

"Optimum Receiver Design for Wireless Broad-Band Systems Using OFDM—Part I"
Michael Speth, Stefan A. Fechtel, Gunnar Fock, and Heinrich Meyr , IEEE Transactions on Communications, Vol 47, No 11, November 1999. pp 1668-1677

"Optimum Receiver Design for OFDM-Based Broadband Transmission—Part II: A Case Study" Michael Speth, Stefan Fechtel, Gunnar Fock, and Heinrich Meyr, IEEE Transactions on Communications, Vol 49, No 4, April 2001. pp 1668-1677. pp 571- 578

References on the general topic of synchronization:

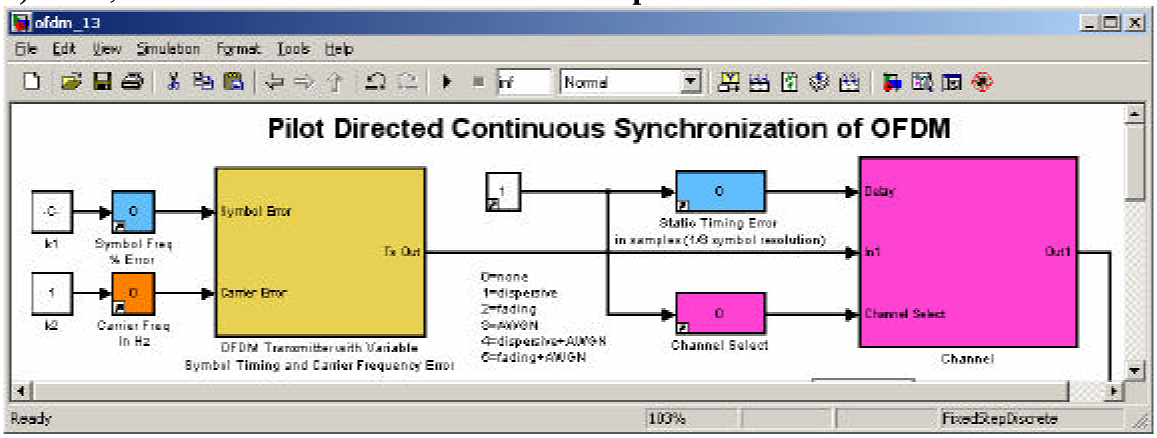
"Interpolation in Digital Modems --- Part I: Fundamentals", Floyd M. Gardner, IEEE Transactions on Communications, Vol 41, No 3, March 1993. pp 501-507

"Interpolation in Digital Modems --- Part I: Implementation and Performance", Lars Erup, Floyd M. Gardner, Robert Harris, IEEE Transactions on Communications, Vol 41, No 6, Jun. pp 998- 1008

"Digital Communications Receivers -- Synchronization, Channel Estimation and Signal Processing " Heinrich Meyer, Marc Moeneclaey, Stefan Fechtel, Wiley Series in Telecommunications and Signal Processing 1998

The top level of the model includes sliders to insert impairments in the data presented to the receiver as well as switches in the receiver to activate the corrections for the impairments. The model, as provided, has all four the slider values set to ZERO, and all three of the switches in the DOWN position.

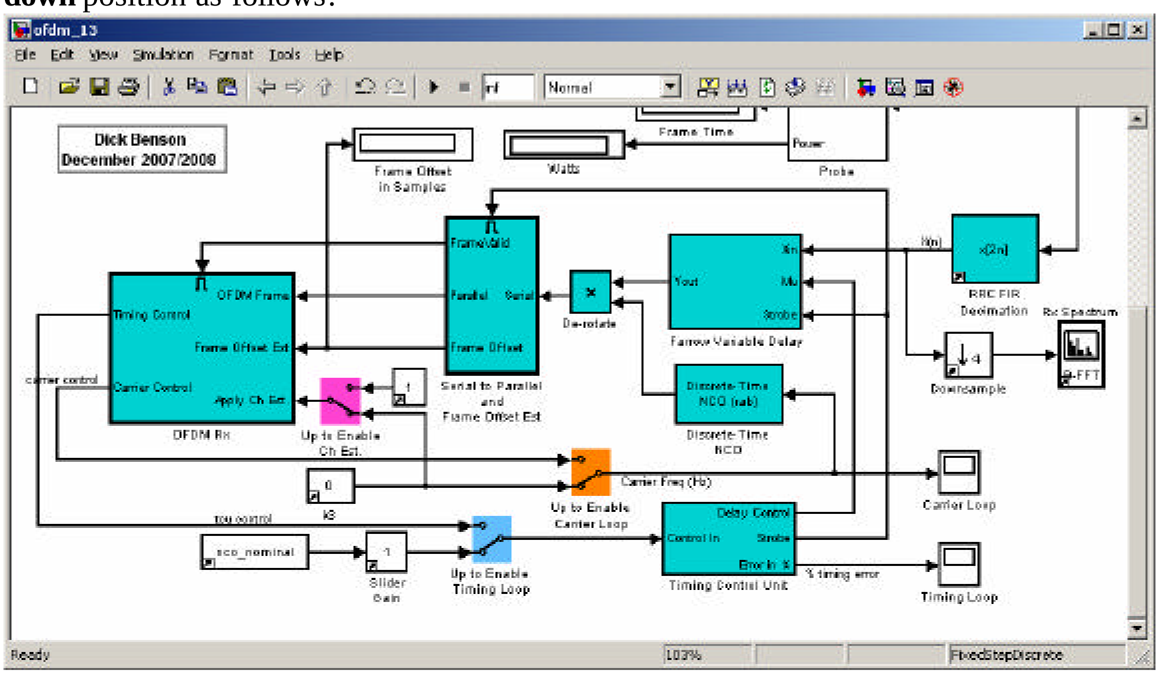
1) First, start the model with **no transmitter impairments** as follows:



Notice the four sliders have 0 values. There are 6 selections of channel impairments selected by the magenta "Channel Select" slider:

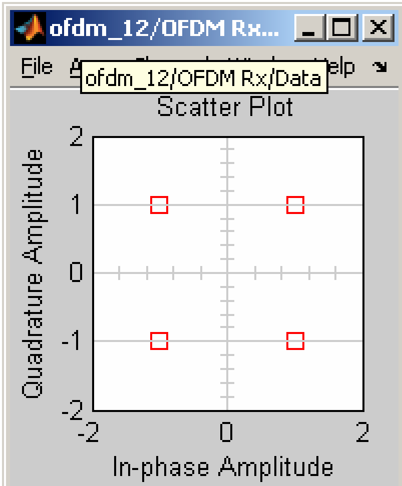
0=none
1=dispersive
2=fading
3=AWGN
4=dispersive+AWGN
5=fading+AWGN

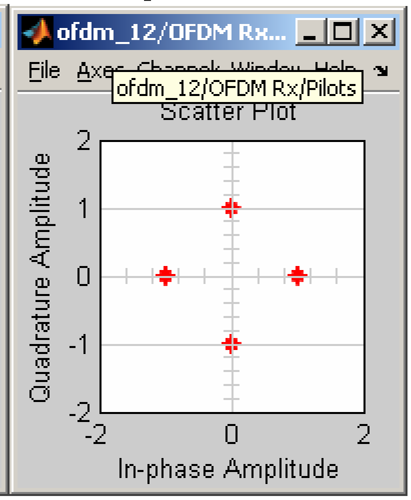
Also, **disable all corrections** in the receiver by placing the **three switches** in the **down** position as follows:



The transmitter and receiver user controls are COLOR CODED as follows.
Magenta: channel related
Orange: carrier frequency
Light Blue: symbol timing (both symbol rate and static time offset)

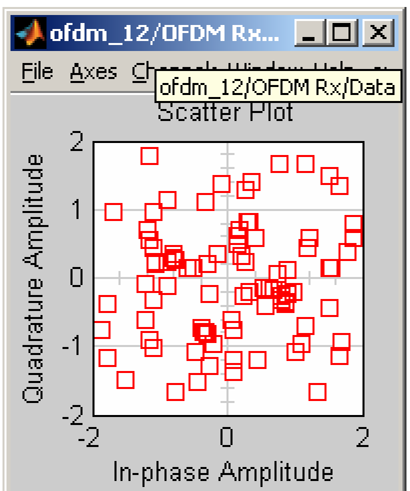
Running the model with these settings (no impairments) represents the perfect world situation which is never realized in practice but serves as a starting point.
The RX and pilot tone constellations are ideal:

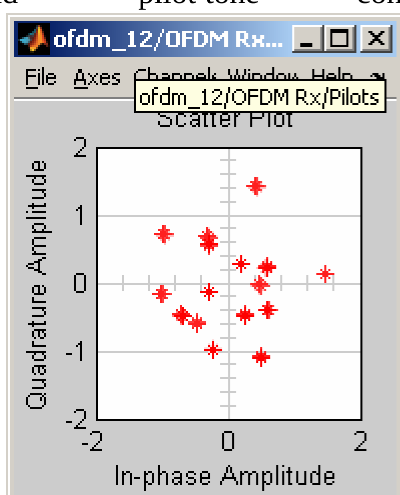




2) Next, enable the channel impairment by changing the MAGENTA slider to a ONE. This inserts a multi-tap complex FIR filter (dispersive channel) into the path between TX and RX.

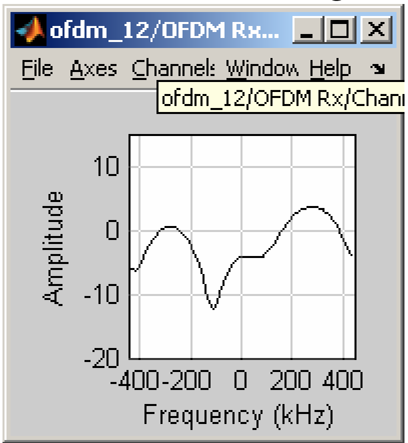
The RX data and pilot tone constellations are now:

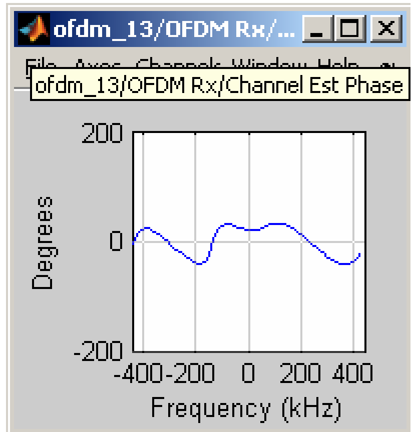




As you can see, the RX data is hopelessly scrambled by the effects of the channel.

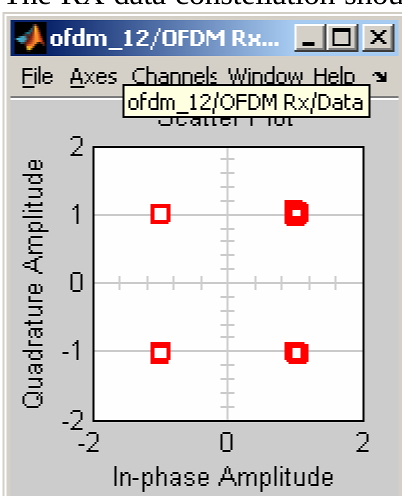
The **pilot tones** are used to estimate the channel magnitude and phase. These estimates have now have gone from flat lines (a perfect zero delay channel) to:





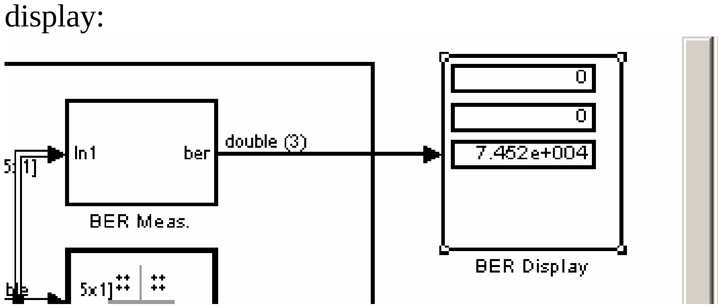
Next, incorporate these channel estimations in the RX by changeing the MAGENTA switch in the RX to the UP position (Up to Enable Ch Est).

The RX data constellation should now look like this:



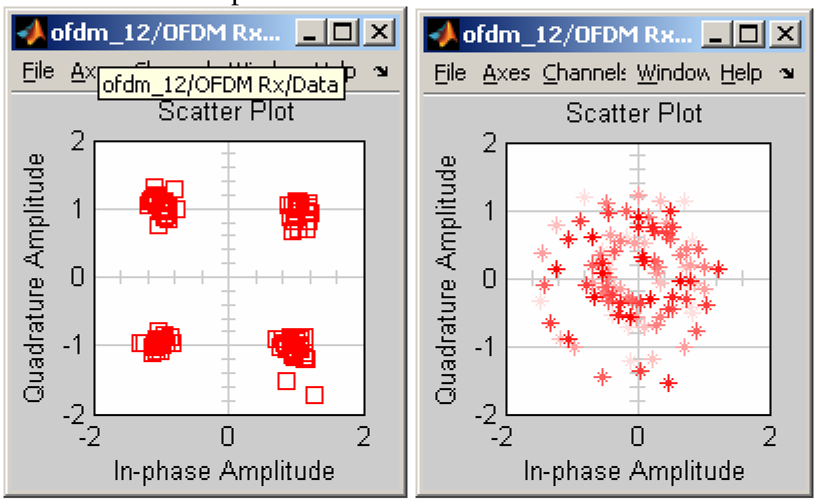
while the pilot constellation will be unchanged.

The above plot indicates that the errors that were being introduced by the channel are being successfully mitigated. You can confirm this by restarting the model with the current selections, and then opening the OFDM Rx subsystem and observing the BER display:



3) Next, introduce a TX carrier frequency error of 600 Hz by changing the ORANGE slider outside the TX subsystem from 0 to 600.

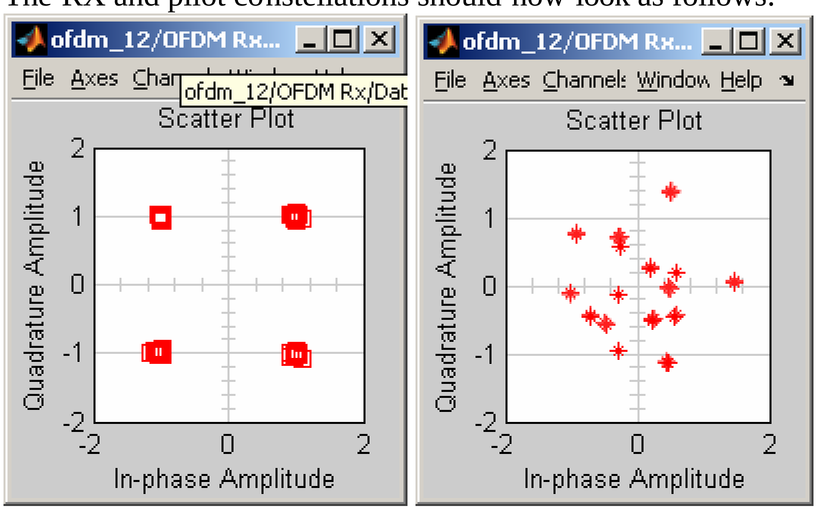
The RX data and pilot constellations will looks as follows:



Note the pilots are not static, but are rotating about the center. The phase estimate of channel is helping the RX data quite a bit. But the correction is NOT perfect because there is a time varying phase (watch the channel estimation phase plot) that is not constant over a symbol period. The higher the carrier offset frequency, the more the phase changes over one OFDM symbol time, and the more difficult the situation.

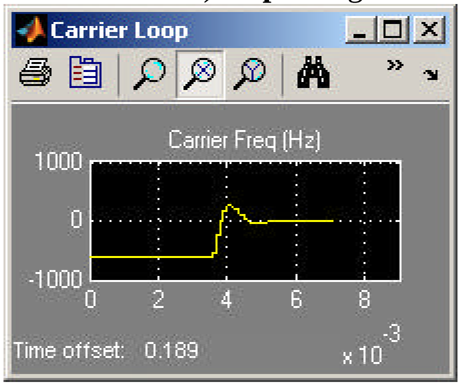
To fix this, activate the carrier loop in the RX by changing the ORANGE switch (Up to Enable Carrier Loop) to the up position.

The RX and pilot constellations should now look as follows:



Note that the pilots are no longer rotating and the channel phase estimate is stable as well. With this switch up, the Carrier Loop control is now driving a complex NCO to "de-rotate" the OFDM signal and doing (virtually) all of the work to correct for this impairment.

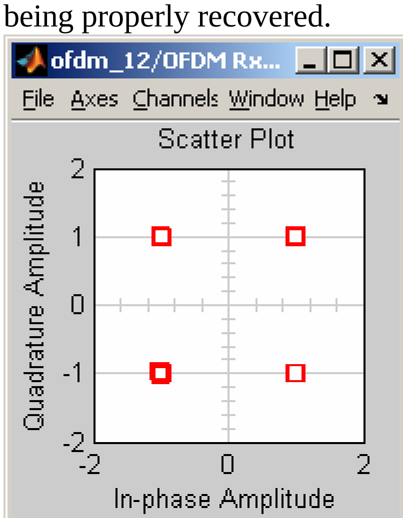
You can get a sense of the dynamics (rise time, overshoot, settling time) of the carrier control loop by observing the Carrier Loop scope when making large (say from 600 back to zero Hz) **step** changes in the TX carrier offset control slider:

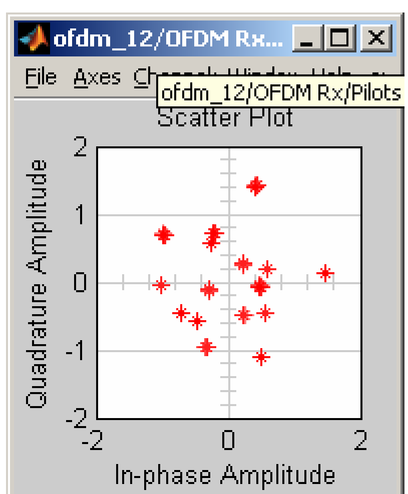


4) The next, and most difficult impairment to correct is symbol rate error. Introduce +0.2% TX symbol frequency error (LIGHT BLUE slider in TX) and notice the RX and Pilot constellations are again hopelessly confused. Observe the "Frame Offset in Samples" numeric display. It will be decreasing in value as the simulation proceeds. This represents a COARSE estimation of how far the TX frame has drifted (due to its symbol frequency error) with respect to the expected RX frame timing.

To mitigate this, while the simulation is running, change the LIGHT BLUE switch in the RX ("Up to Enable Timing Loop") to the UP position. Let the simulation run and you will see that the numeric display will be driven back to approximately zero. **HAVE PATIENCE, it may take a few seconds.**

This **coarse estimate** of the time offset is used to steer the RX timing to a point where it is close enough to activate the FINE TIMING control loop. When this is done (it is automatic), you will see that the RX data and pilot constellations are now being properly recovered.





5) Finally, introduce a step change in the TX timing by changing the LIGHT BLUE Static Timing Error channel slider from 0 to a positive value of circa 10 samples. This will cause the RX to come out of fine timing lock and the coarse timing estimator will then be used to reacquire OFDM synch. This is the sort of channel timing change one might experience when crossing from one cell site into another or is simply the norm when the RX starts up.

Changes in the latest model include:

1) The channel model has been enhanced to include a variety of channel impairments that can be selected by changing the slider. Note that the slider should be set to an integer value to be certain of the selection being made.

2) A BER indicator. To compare BER results, set a simulation run time (eg 0.03 seconds), start the simulation, and then note the number of errors after the simulation stops.

3) Loop tuning to improve RX robustness with a fading channel.

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