Multicarrier Ranging

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Authors:

Name	Company	Address	Phone	email
Ivan Reede		Montreal,CA	514-620-8522	i_reede@amerisys.com

Presentation goals

- **Deliver a synopsis of the progress**
  - Of the ranging and location mechanism
  - Described in IEEE 802.22-06/0206r1
  - From October 2006 to March 2010
- **Propose improvements**
  - in the pilot carrier selection allowing improved performance
- **Explain the relation of the M-RADAR© method**
  - to classic radio advanced detection and ranging (RADAR)

System validation

- **Confirmed and tested by**
  - Industry Canada Communications Research Center (CRC)
  - In cooperation with AmeriSys
- **Double blind tests were conducted**
  - First, CRC devised tests to simulate various field conditions without detailed knowledge of the AmeriSys analysis process
    - using RF test equipment
      - Complex signal generators, channel simulators, sampling receivers
  - Next, AmeriSys, without knowledge of the test conditions
    - Processed the sampled signals and returned results to the CRC
  - Lastly, CRC studied the results
    - Reported expected findings vs results comparison to AmeriSys

Further work

- **The CRC offered its help**
  - In improving the method
  - Using its expertise in modern DSP techniques
  - In cooperation with AmeriSys
- **AmeriSys, in conjunction with the CRC**
  - Implemented the suggested process adjustments
- **Double blind tests were conducted iteratively**
  - Using test results
    - DSP method was refined
  - This led to significant performance improvements
    - By gradually pushing back limitations

Result Overview

- **Results were conclusive**
  - Double blind tests demonstrated the method's potential
  - After improvements,
    - Confirmed ranging method always works and lives up to its claims
  - Operates even when
    - Direct line of sight is seriously attenuated
    - Large and multiple echoes are present
  - Multicarrier RADAR (M-RADAR) is
    - a significant improvement of RADAR technology

OFDM System Example
Founding Premises

- **OFDM systems inherently transmit**
  - A set of coherent pilot carriers
- **The transmission channel**
  - Introduces a complex warping in the signal
    - Caused by reflections and dispersion
- **OFDM receivers sample the complex warped signal**
  - Introduce an additional simple warp to the signal
    - Caused by sampling misalignment to allow for reception despite echoes
  - Attempt to compensate all this warp
    - Using reference pilot carriers at regular intervals in the frequency domain
    - To observe and neutralize the overall warp via interpolation

OFDM Systems

- **Inherently obtain channel cepstrum information**
- **Such information is required for their operation**
- **Such information value is usually**
  - Annoying for communication systems
  - Eradicated in the hope of improving communication

M-RADAR

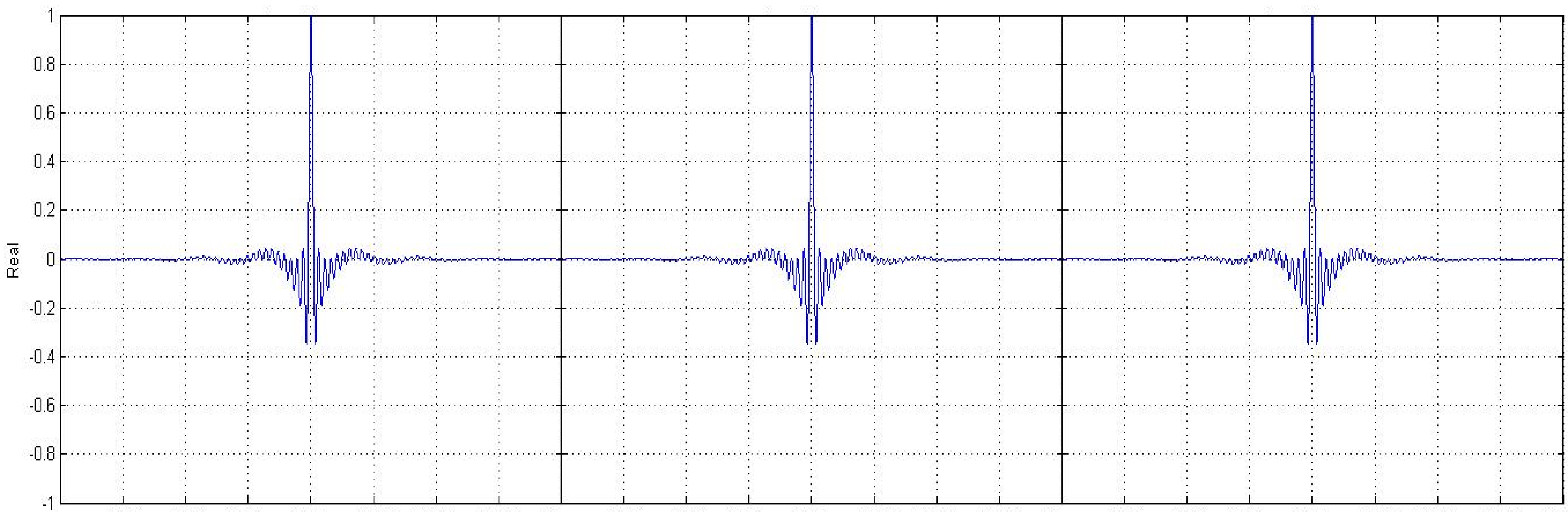
- **A means to economically range targets**
  - Active
  - Cooperating
  - Passive
- **A means to precisely sound and model**
  - Propagation channel characteristics including
    - Echoes
    - Obstructions and dispersion causing attenuation
    - Passive reflectors

M-RADAR

- **Is an economical system**
  - Multiple implementation possibilities
    - simultaneous sounding with coherent OFDM carriers
    - sequential sounding with carrier sequences such as DSSS
- **Supports fixed and mobile applications**
- **Is a generalization of methods to range**
  - Special cases of M-RADAR
    - Classic, Dirac pulse based RADAR
    - Modern, Chirping RADAR

Classic RADAR

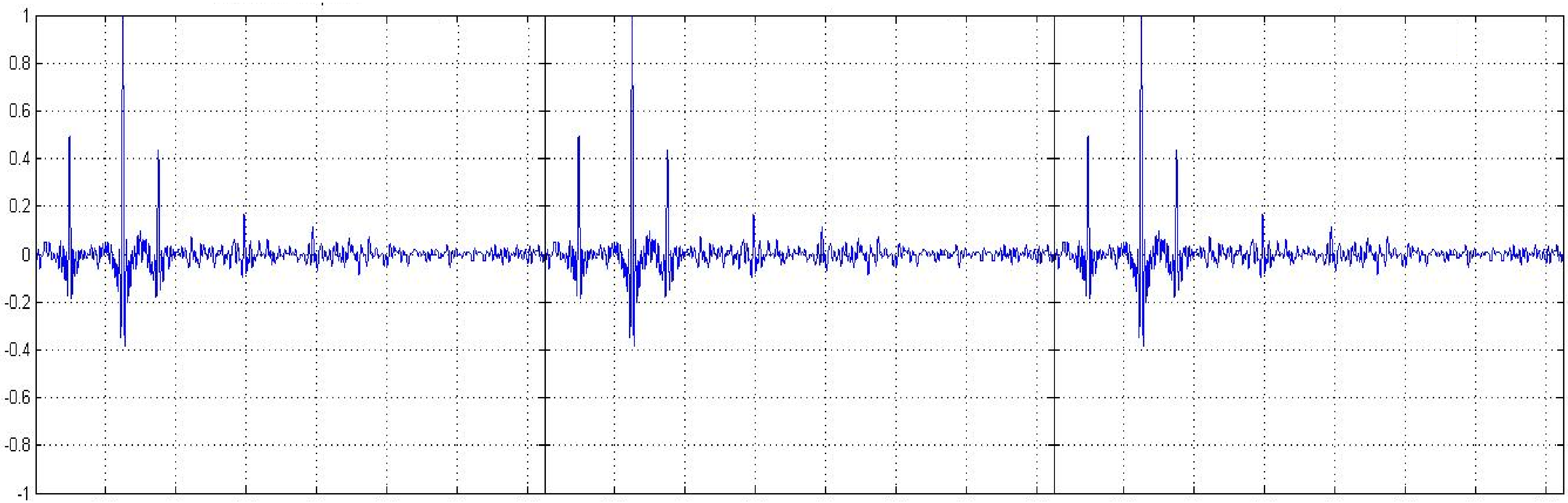
- **OFDM can be used to generate bandwidth-limited repetitive classic Dirac RADAR pulses**
- **This can be achieved using specific PN sequences**



OFDM Dirac pulse train with DC carrier removed

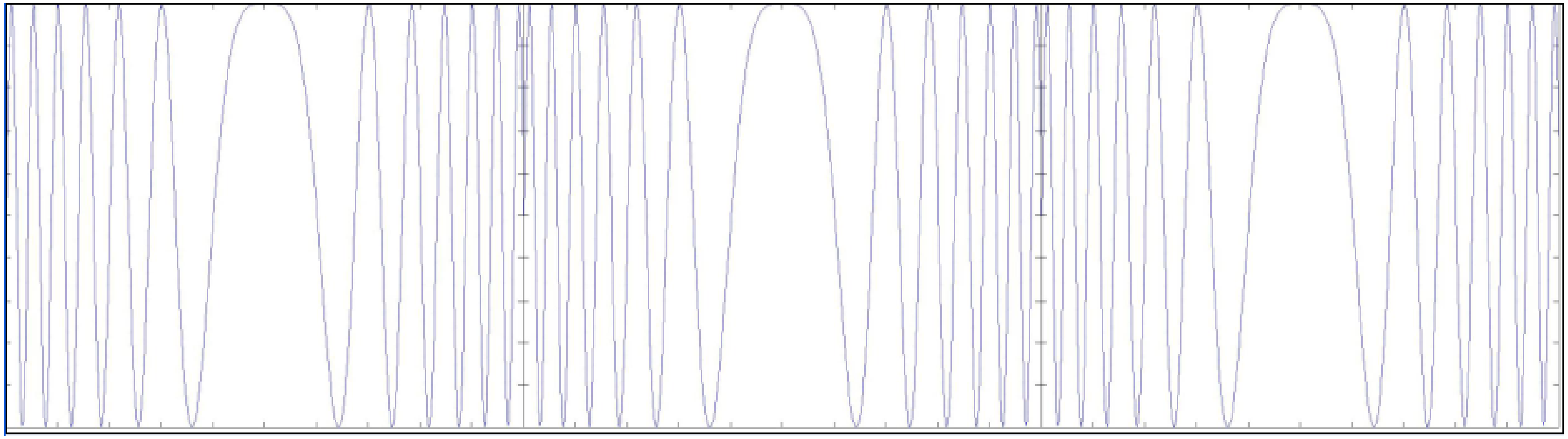
Classic RADAR

- **OFDM receivers are able to**
  - receive and process bandwidth-limited Dirac pulses
  - economically and very accurately determine arrival times



Chirping RADAR

- **OFDM can be used to generate bandwidth-limited repetitive RADAR chirps**
- **This can be achieved using well documented PN sequences**

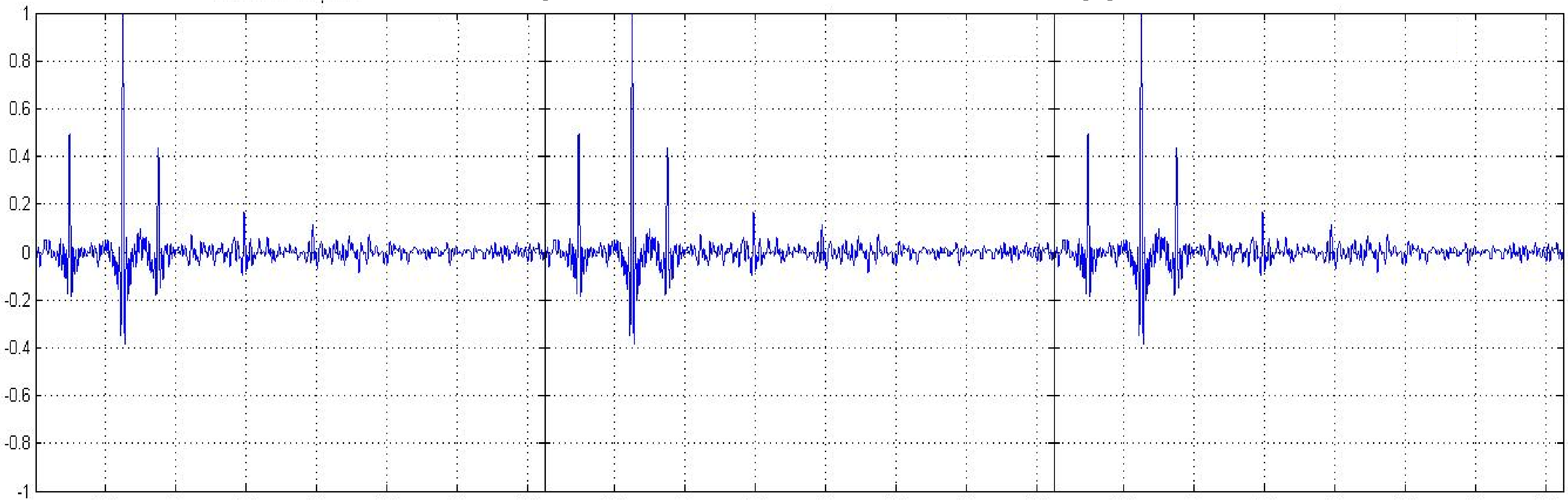


Chirping RADAR

- **OFDM receivers are able to**
  - receive and process bandwidth-limited chirps
  - economically and very accurately determine arrival times

M-RADAR

- **OFDM transceivers are able to**
  - Perform RADAR functions with above well known PN sequences
  - economically and very accurately determine arrival times
  - Use other PN sequences to tailor to various application needs



Sampling Rate Barrier Paradigm

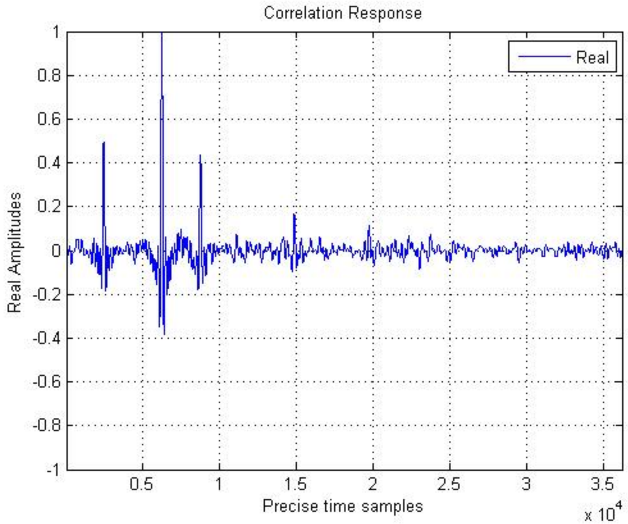
- **For 802.22, the sampling period is 146 nsec**
- **This is not the resolution barrier**
  - At first glance, theory states
    - One can't obtain information to a finer resolution than the sampling period
  - This has proven to be a false impression
  - Based on premises leading to a self-fulfilling paradigm
- **Not all information below this barrier is lost**
  - Since the receiver analog bandwidth prevents aliasing

Sampling Rate Barrier Paradigm

- **The complex input to the IDFT**
  - Is a set of real and imaginary spectrum values
  - In polar representation each ranging tone
    - Has an amplitude and a phase term
- **The complex output of the IDFT**
  - Is a set of real and imaginary time values
  - In polar representation, each time sample
    - Has and amplitude and a phase term

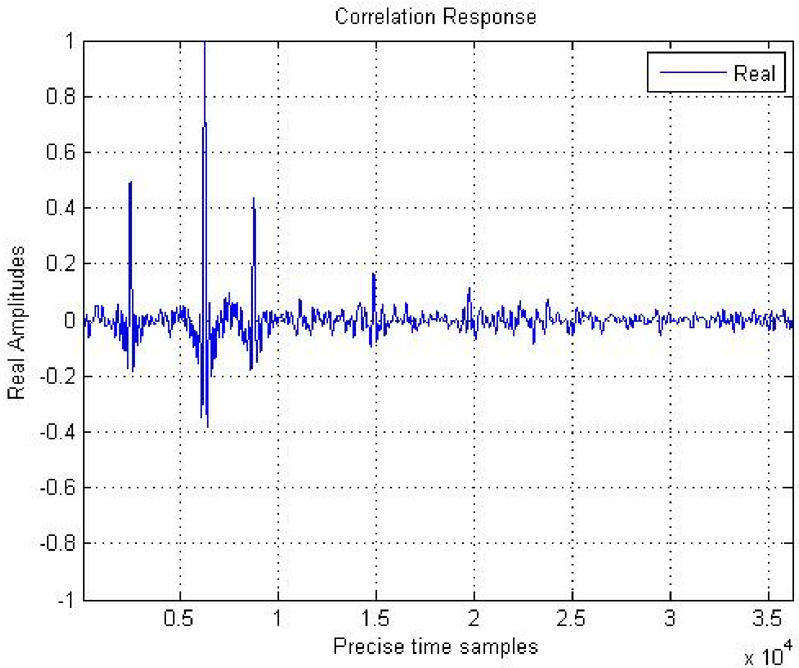
Sampling Rate Barrier Paradigm

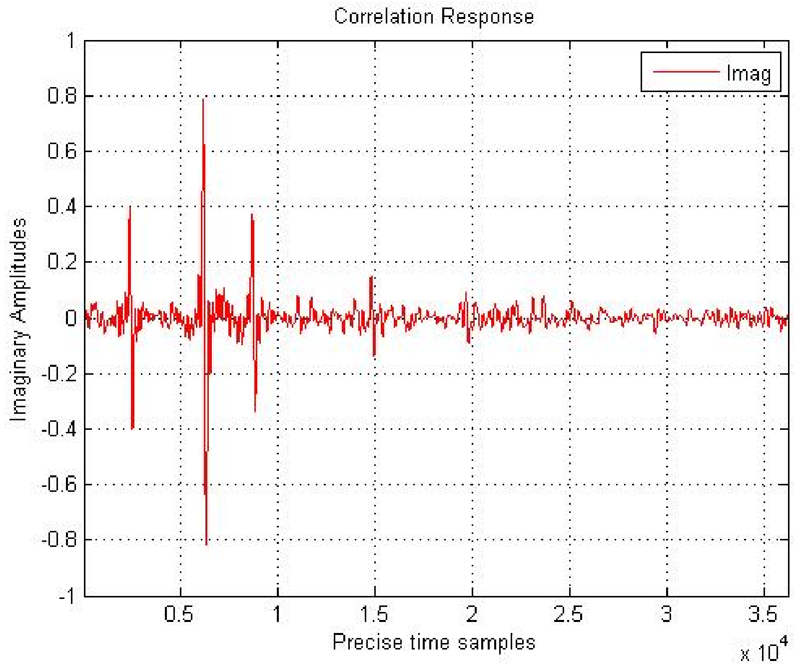
- **Classic IDFT theory only preserves**
  - The real values of time output components i.e the channel impulse response
- **Discarding the imaginary component**
  - Causes the apparent sampling rate timing barrier



Sampling Rate Barrier Paradigm

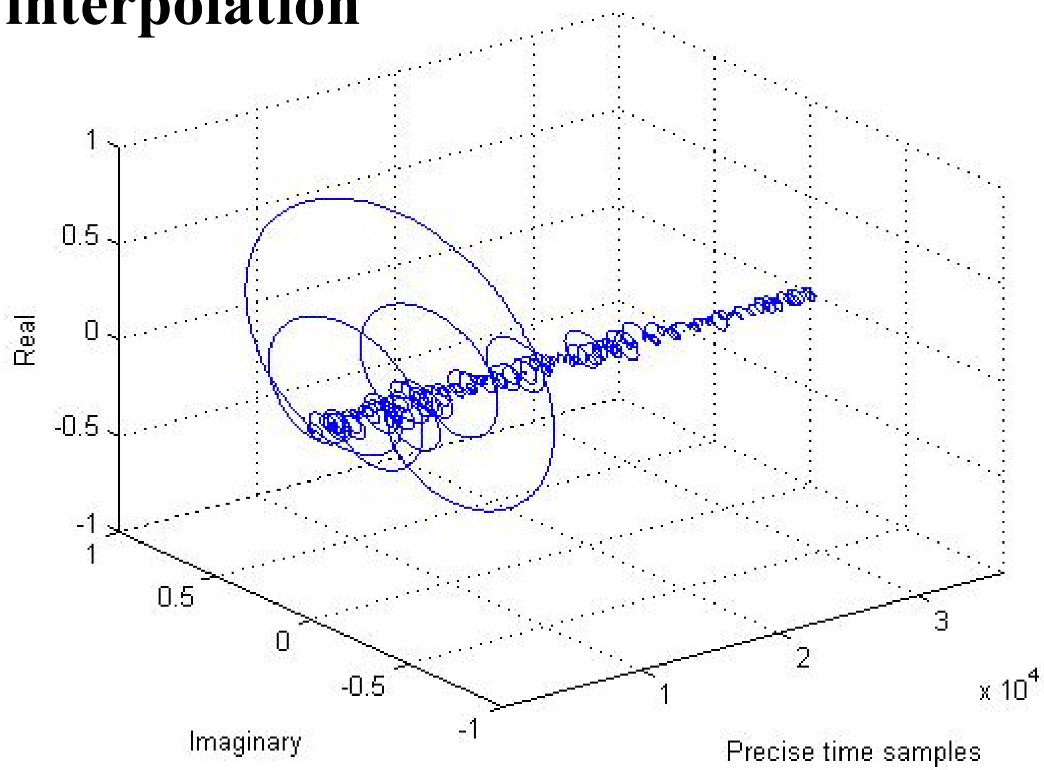
- **The imaginary component**
  - Embeds precious timing information





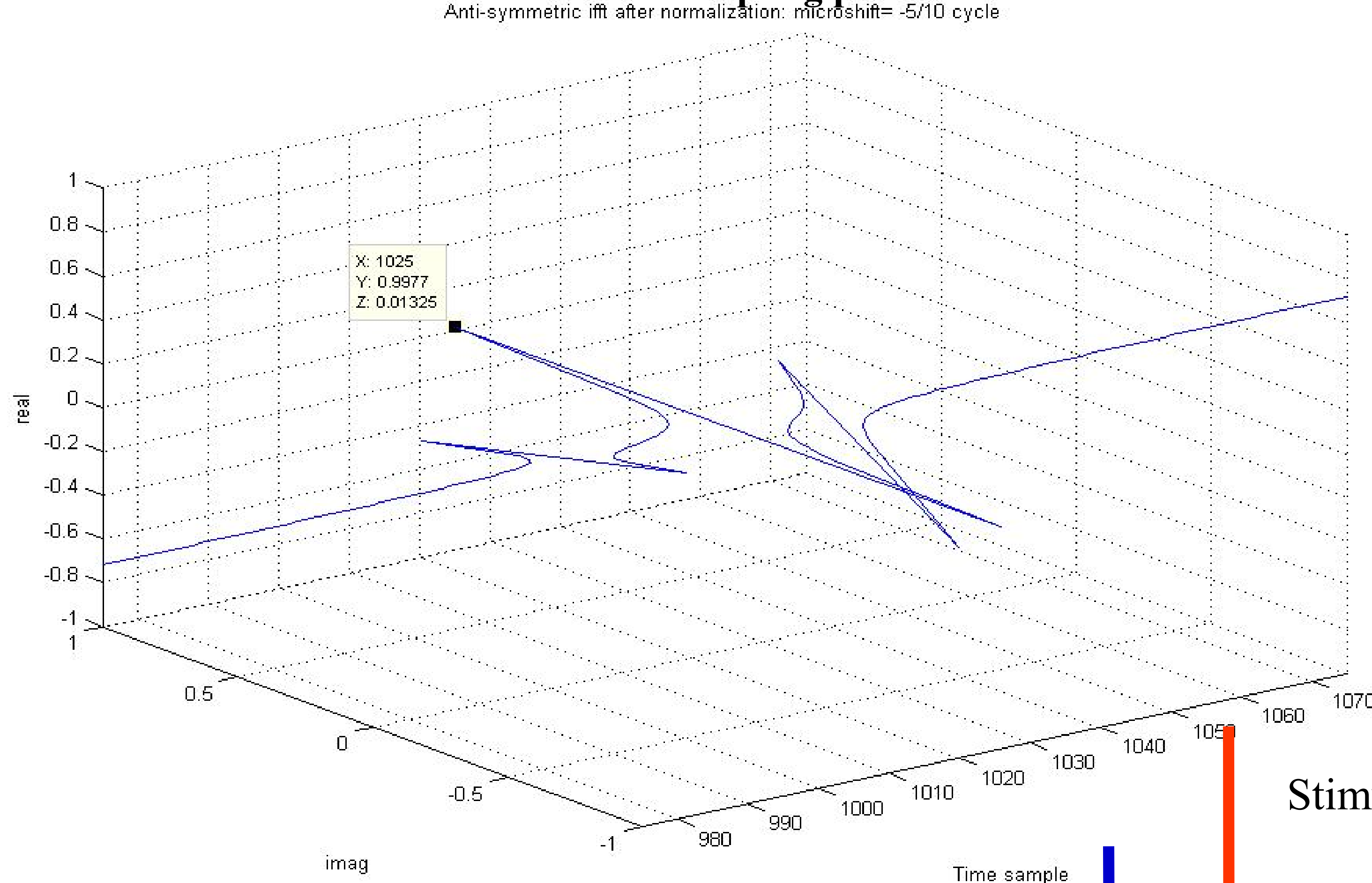
Sampling Rate Barrier Paradigm

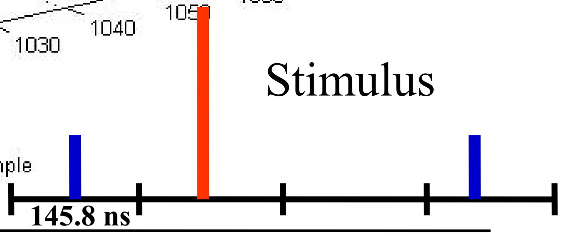
- **Combining both allows for very fine correlation and interpolation**



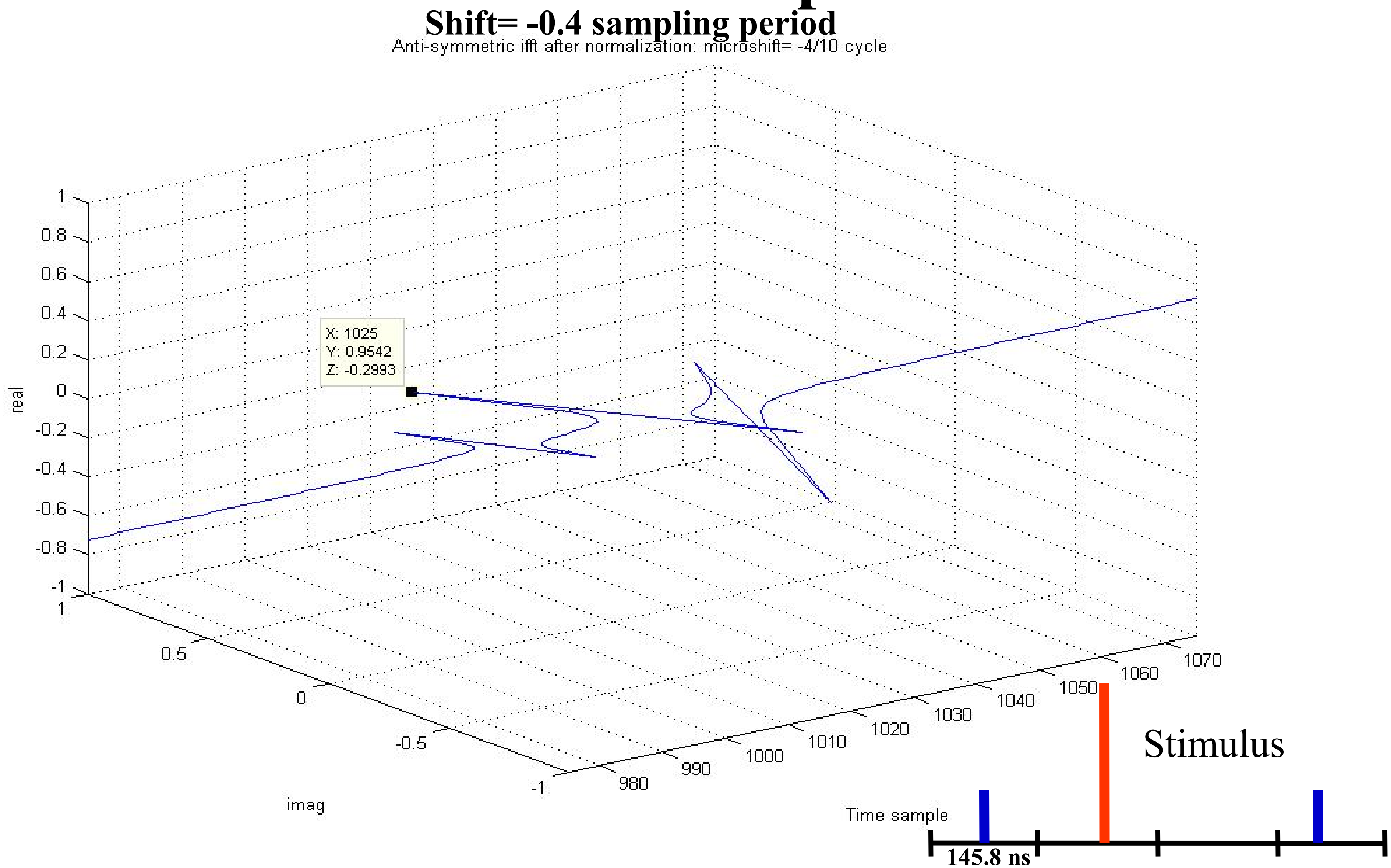
Proof of Concept I

Shift= -0.5 sampling period



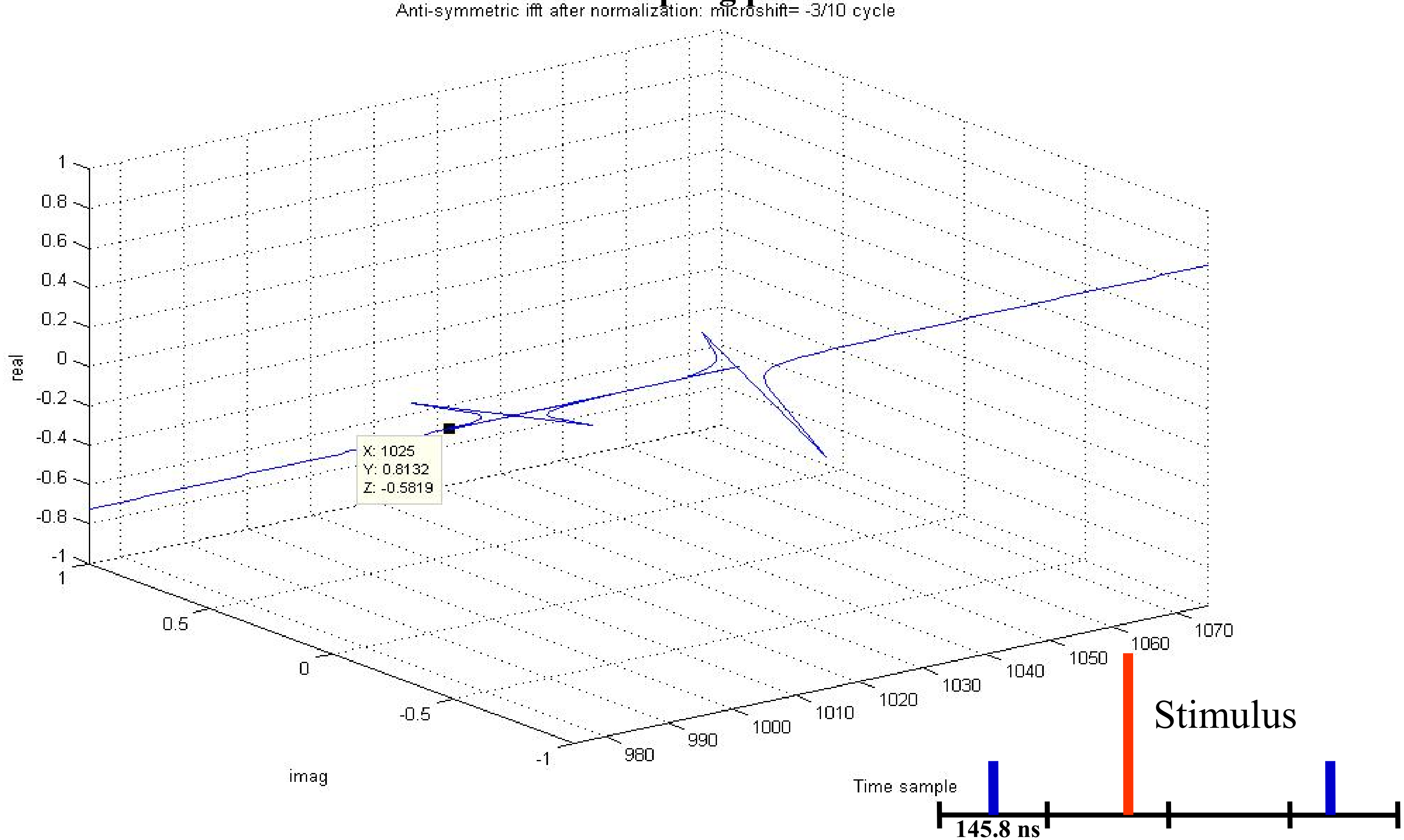


Proof of Concept II



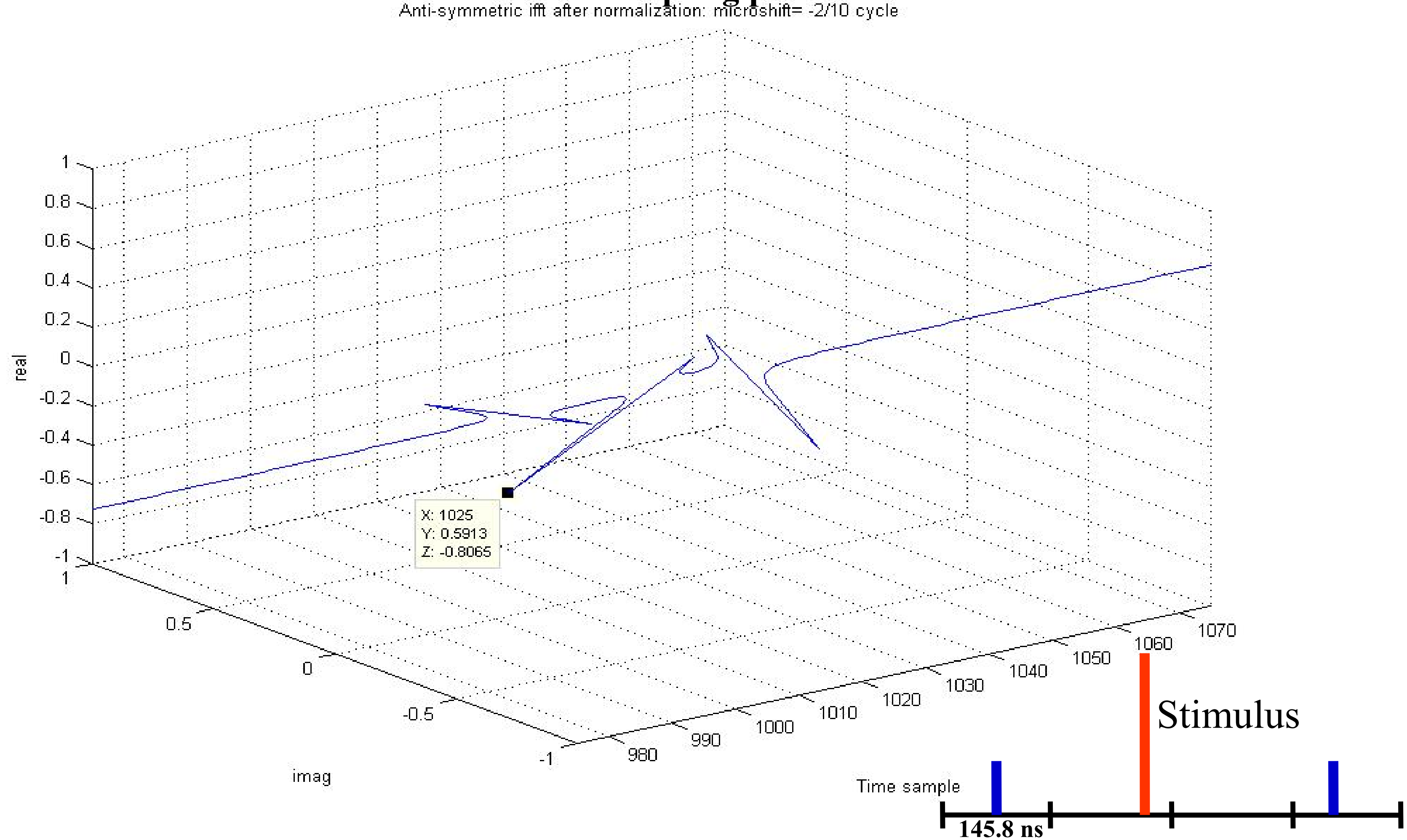
Proof of Concept III

Shift= -0.3 sampling period



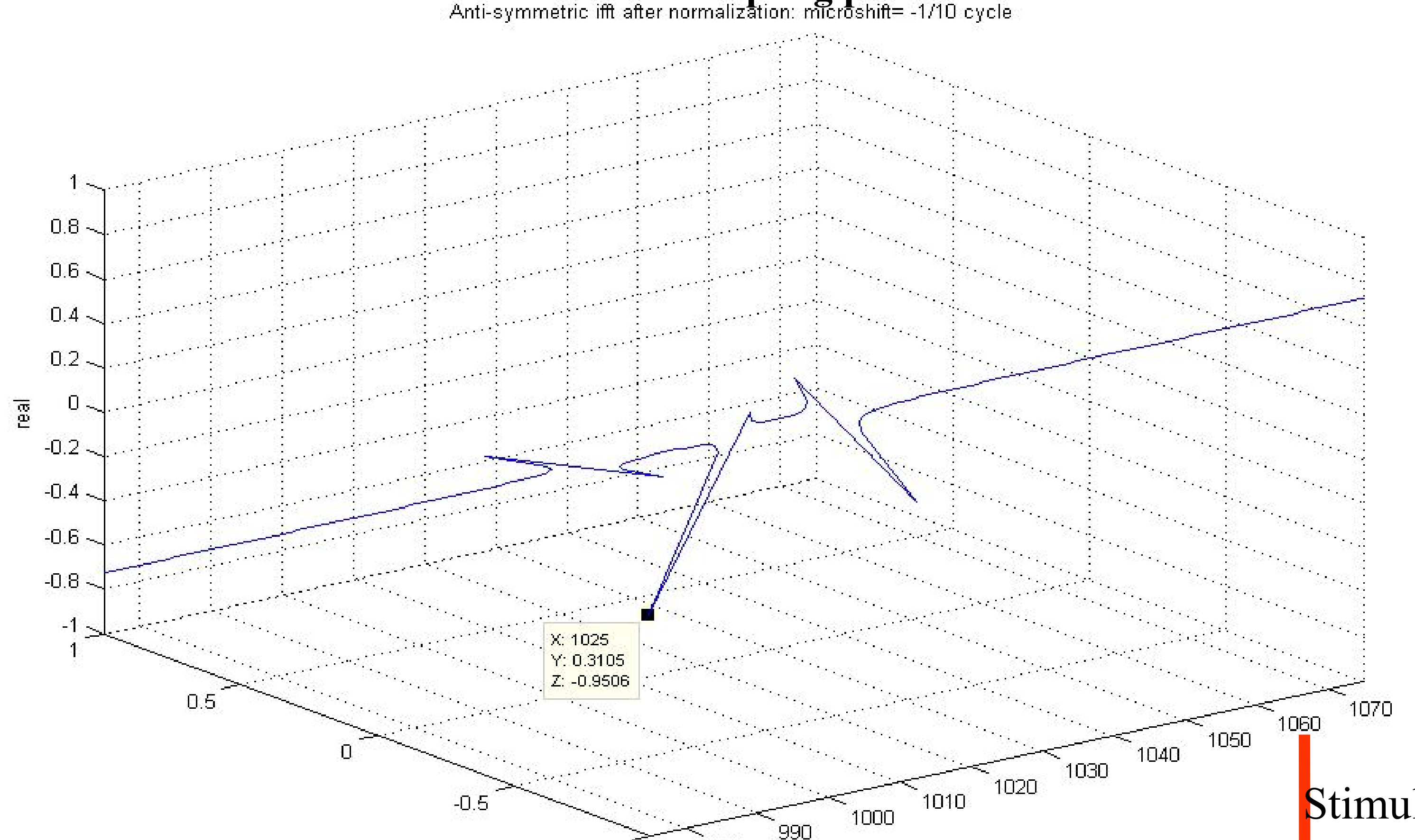
Proof of Concept IV

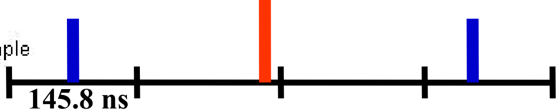
Shift= -0.2 sampling period



Proof of Concept V

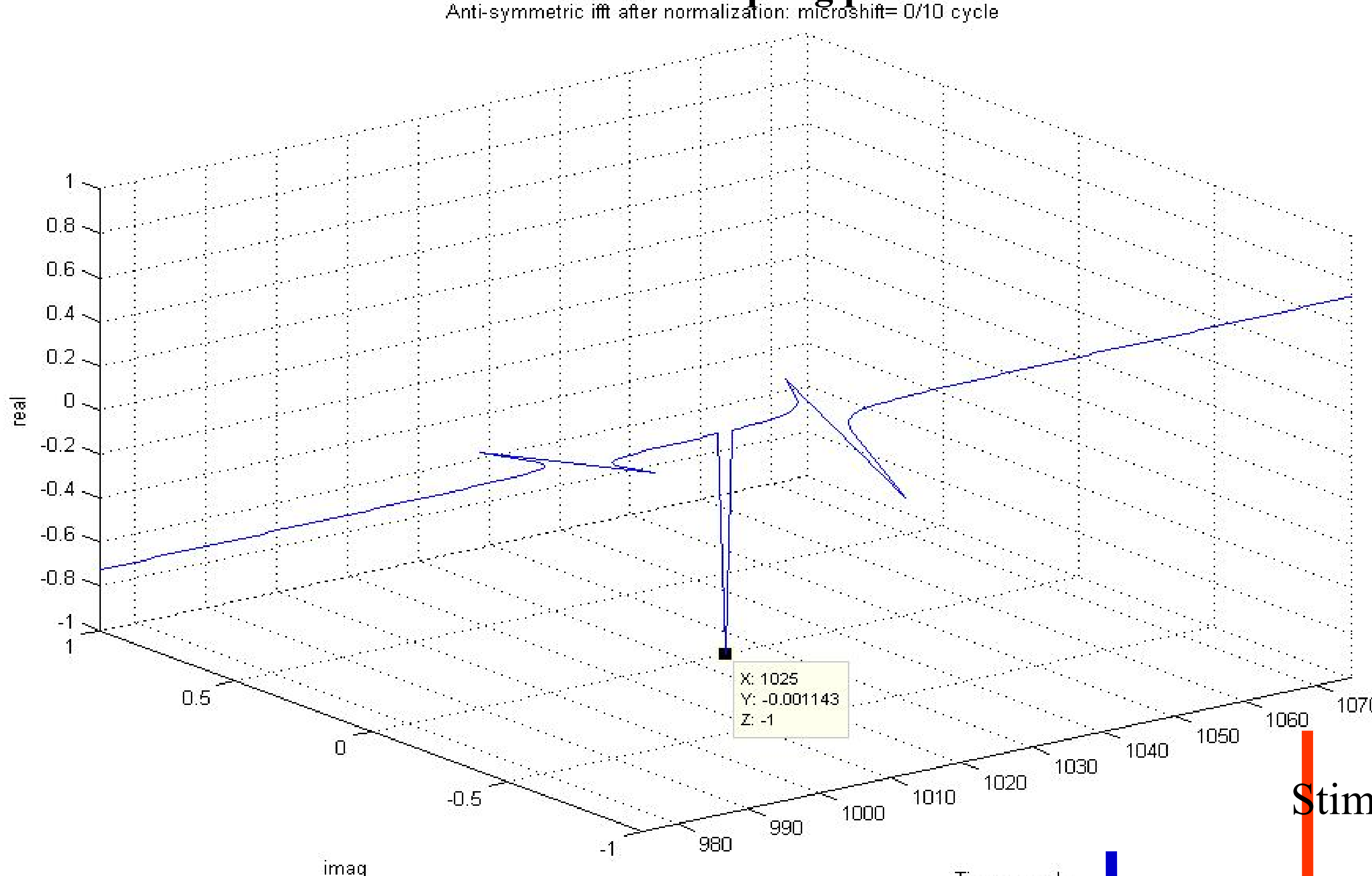
Shift= -0.1 sampling period

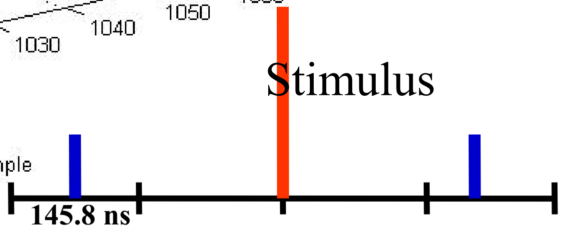




Proof of Concept VI

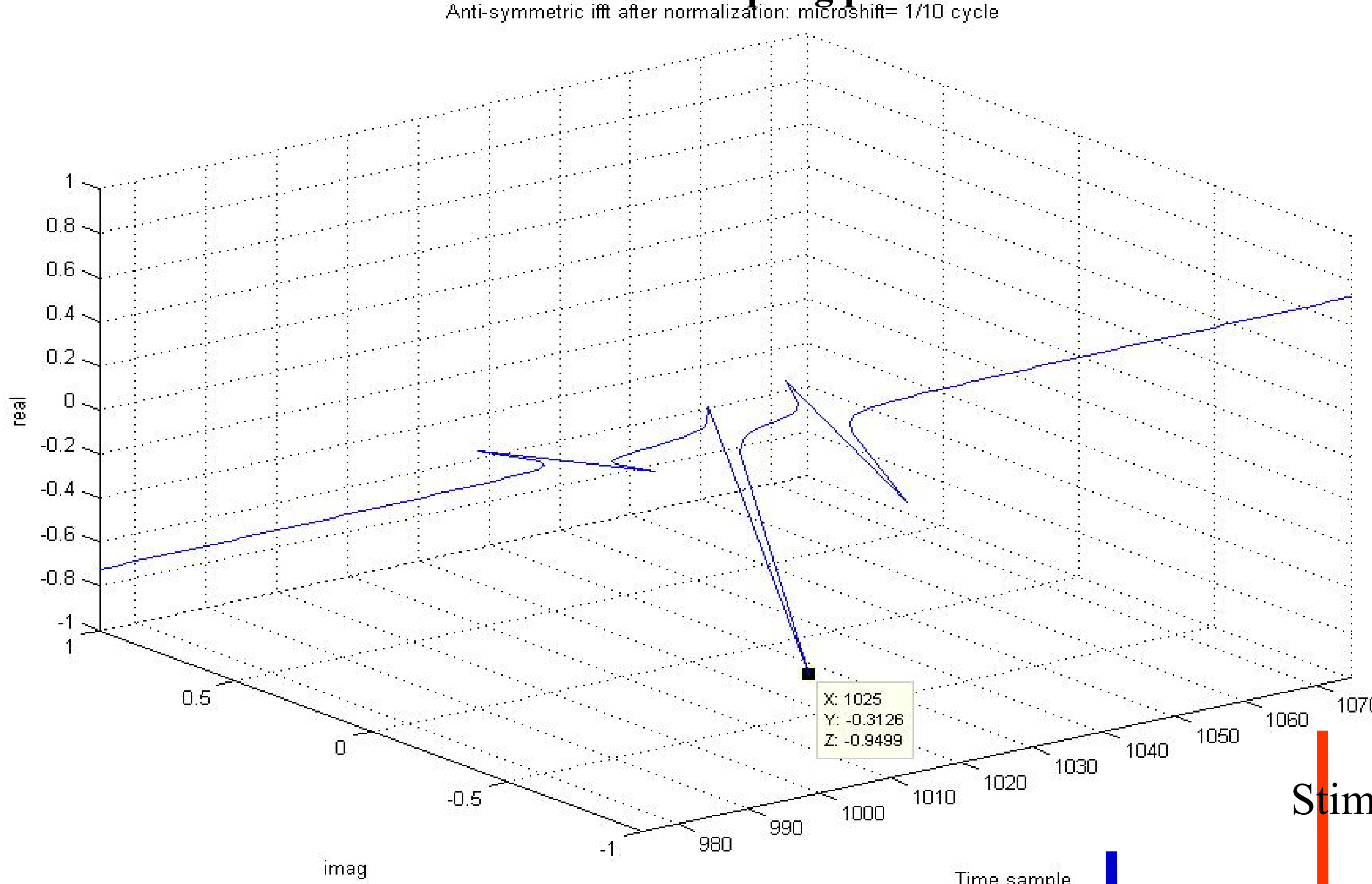
Shift= +0.0 sampling period

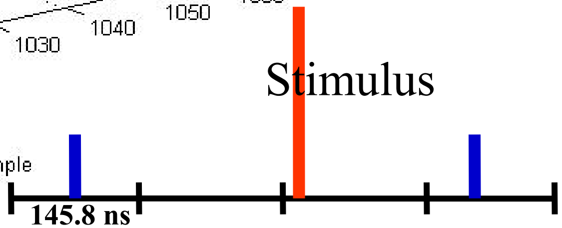




Proof of Concept VII

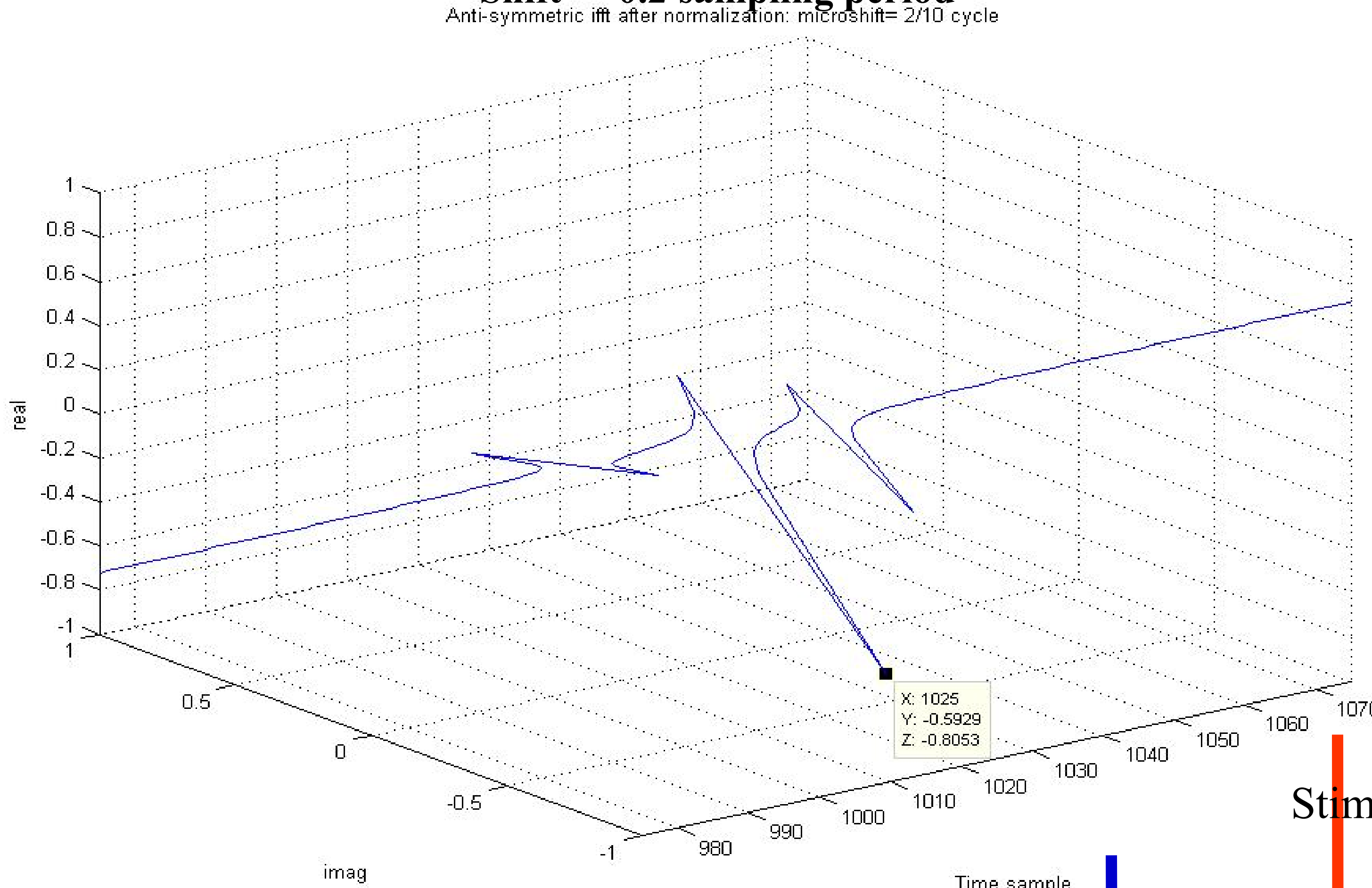
Shift= +0.1 sampling period

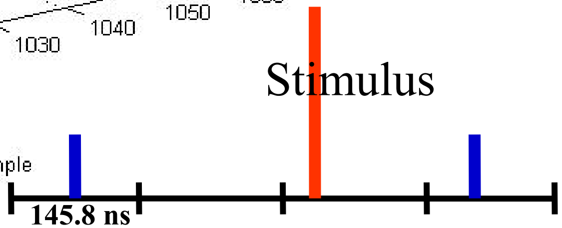




Proof of Concept VIII

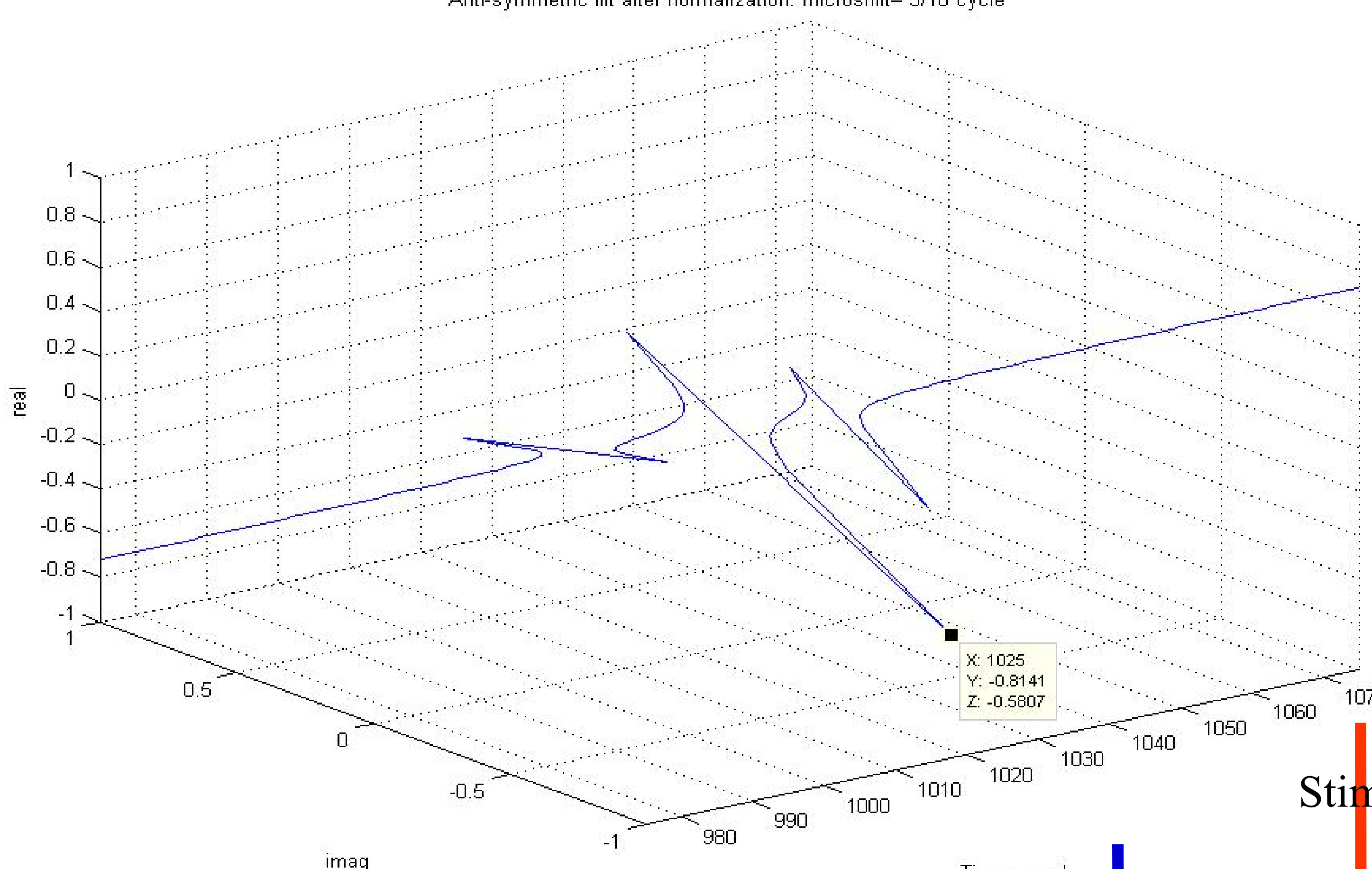
Shift= +0.2 sampling period

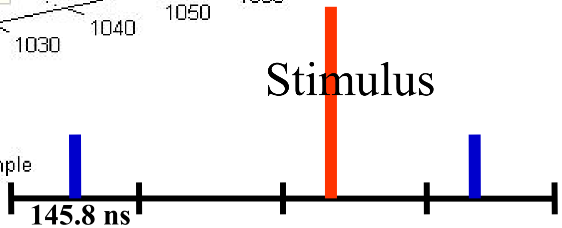




Proof of Concept IX

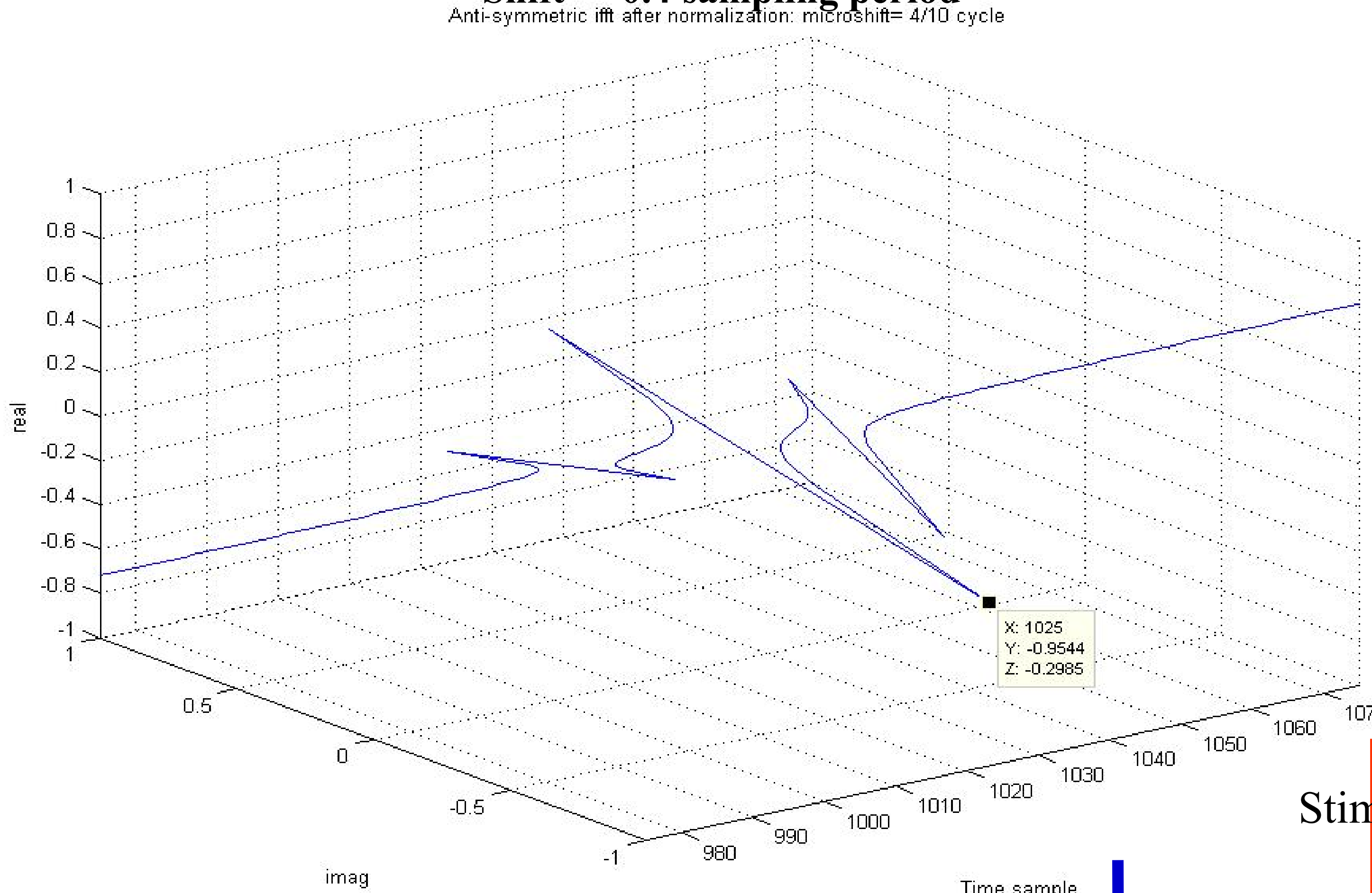
Shift= +0.3 sampling period

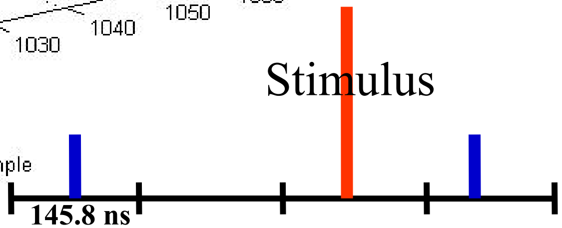




Proof of Concept X

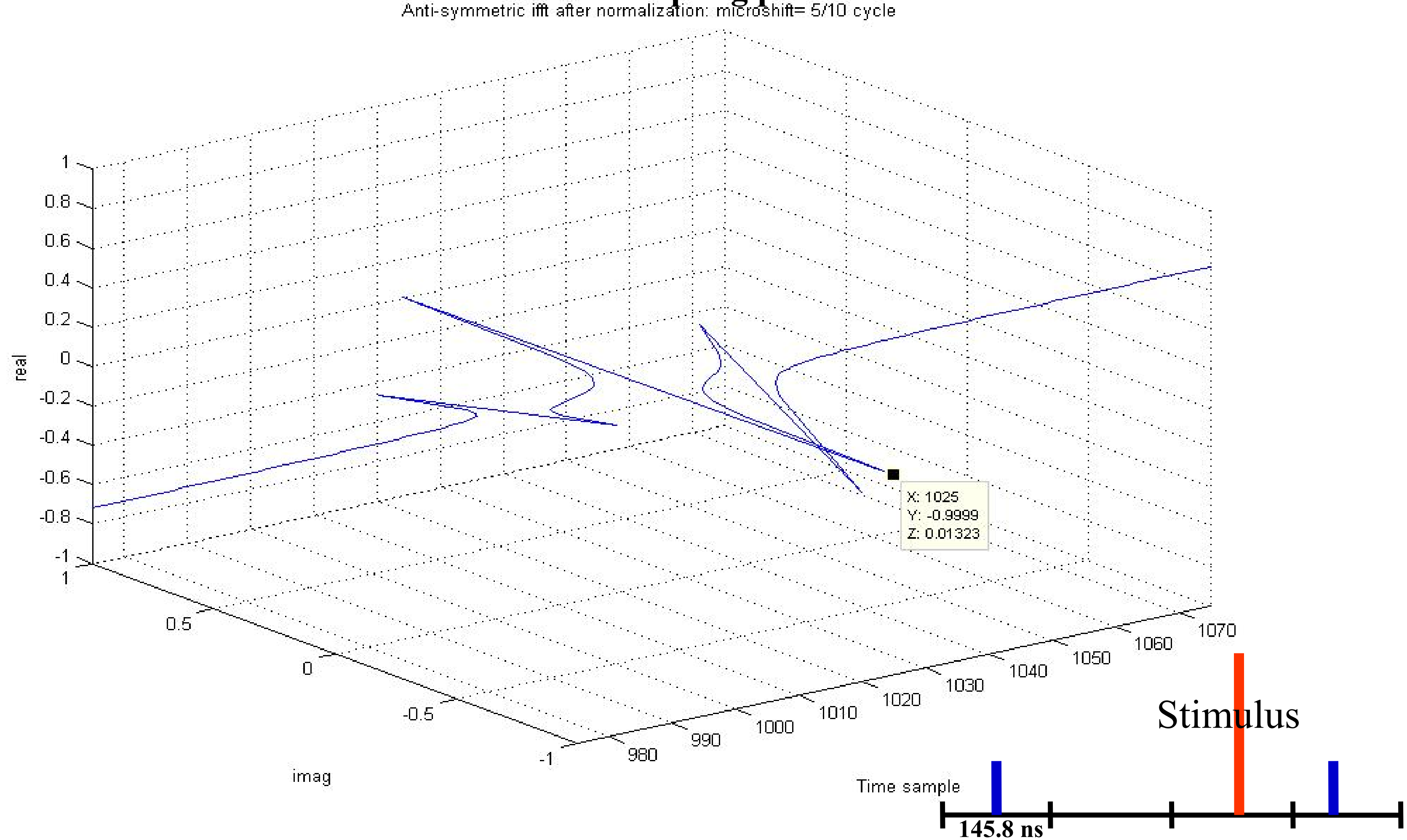
Shift= +0.4 sampling period





Proof of Concept XI

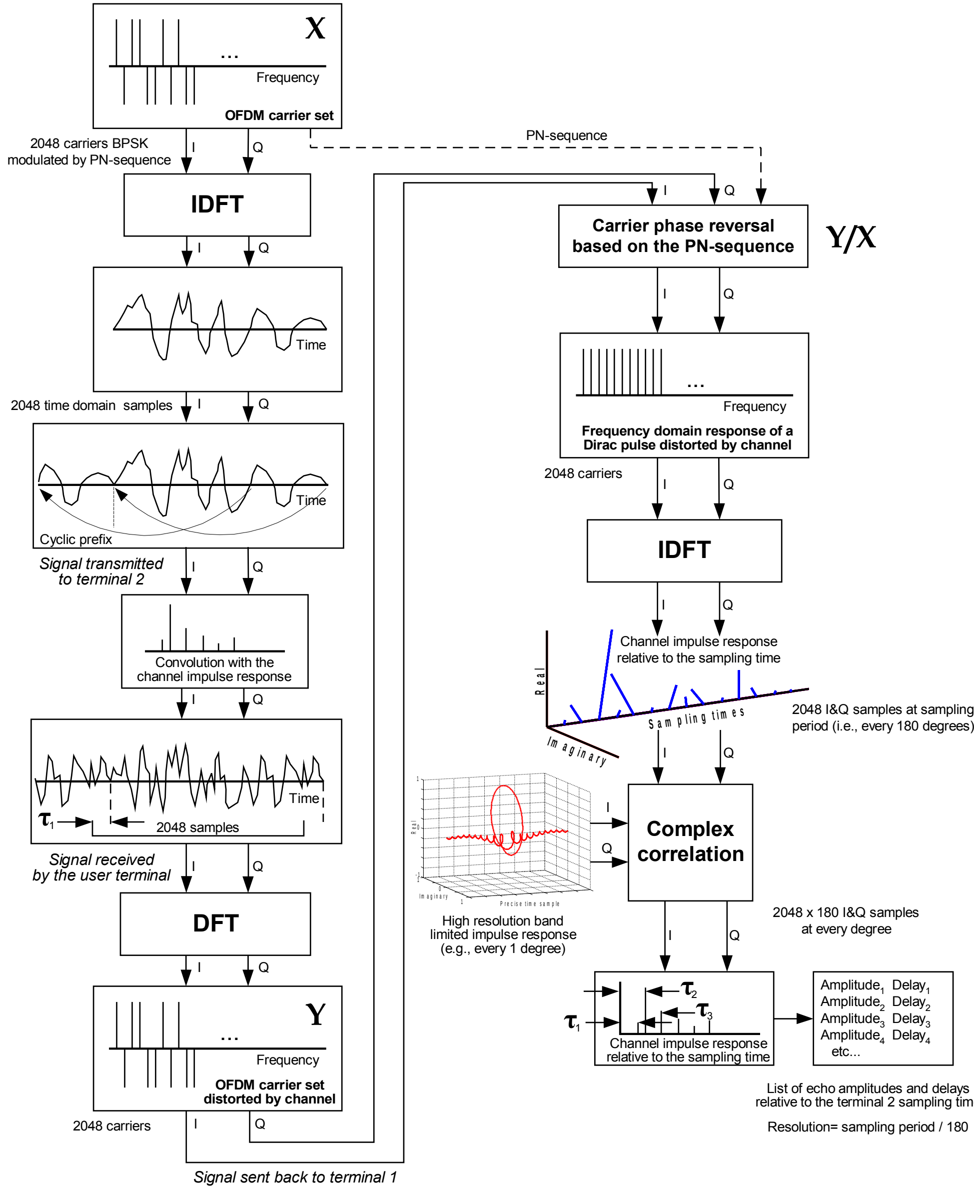
Shift= +0.5 sampling period



The Barrier is Broken !

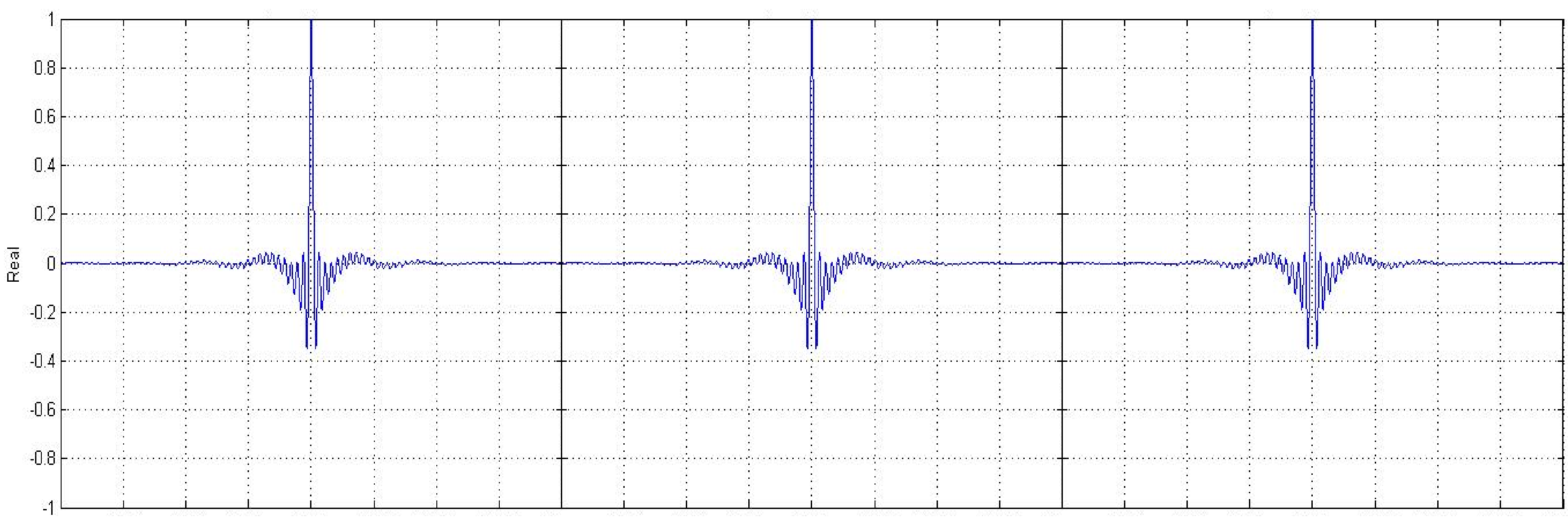
- **Sampling rate is not the precision and resolution limit**
  - Discrete echoes are very precisely located
  - Only limited by the A/D and DFT/IDFT resolution (bits/sample)
- **Sampling rate only limits dispersion resolution**
  - i.e. echoes within the 146ns sampling window
    - appear to be clumped together
  - Timing of each echo clump is not limited to the sampling rate
- **Dynamic range limit**
  - 802.22 downstream 840 tones results in ~40dB dynamic range
  - 802.22 upstream 56 tone range
    - Already found to exceed 19dB

Reference Model



Operating Principles - I

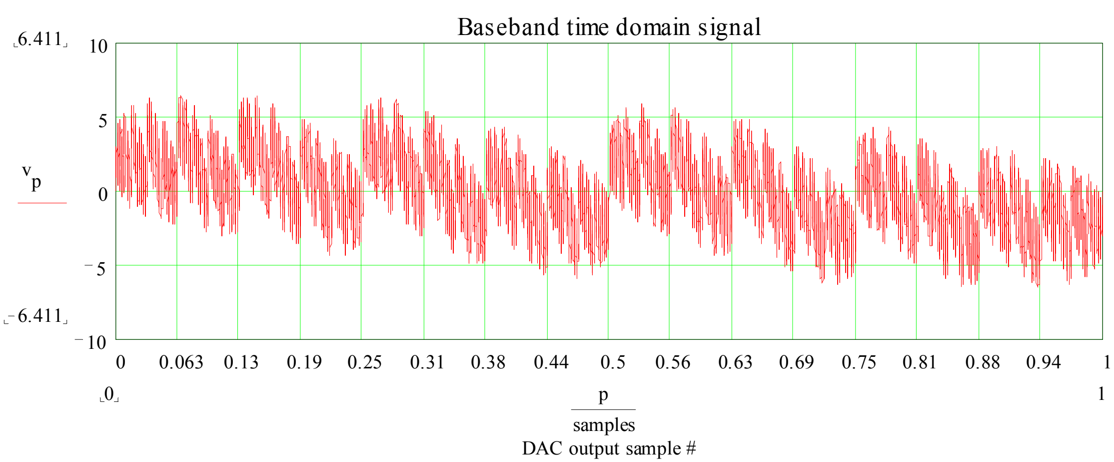
- **OFDM generates bandwidth limited repetitive classic Dirac RADAR pulses when PN = 1 + j0**

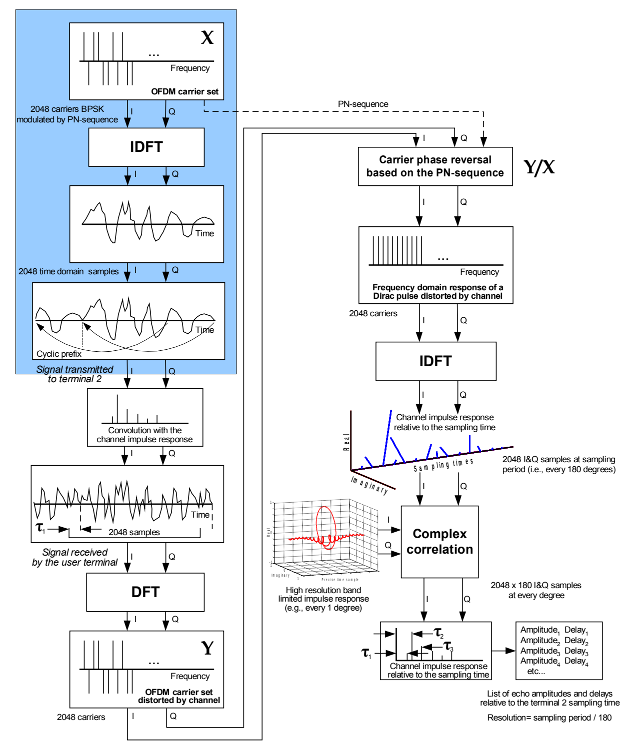


OFDM Dirac pulse train with DC carrier removed

Operating Principles - II

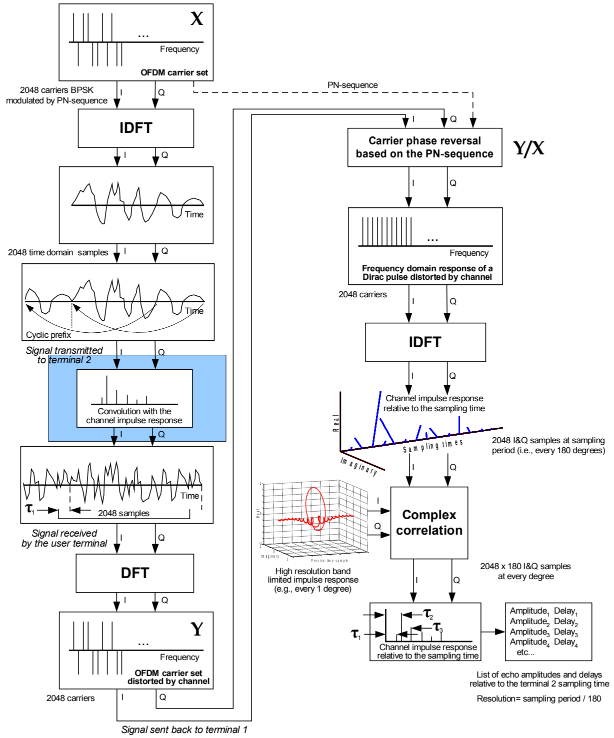
- **OFDM generates all possible bandwidth limited repetitive signals with other known complex PN sequences**





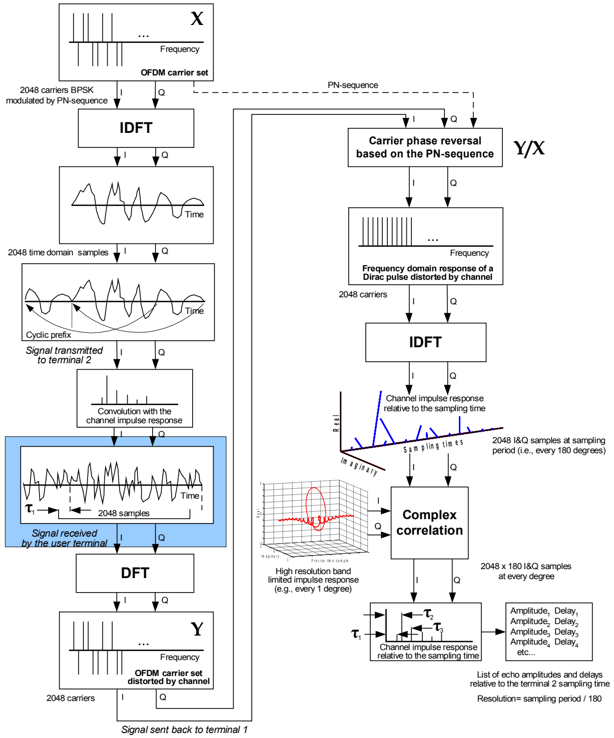
Operating Principles - III

- The channel generally alters the signal waveform due to echoes, reflections and dispersion
- Range (distance) delays and attenuates the signal



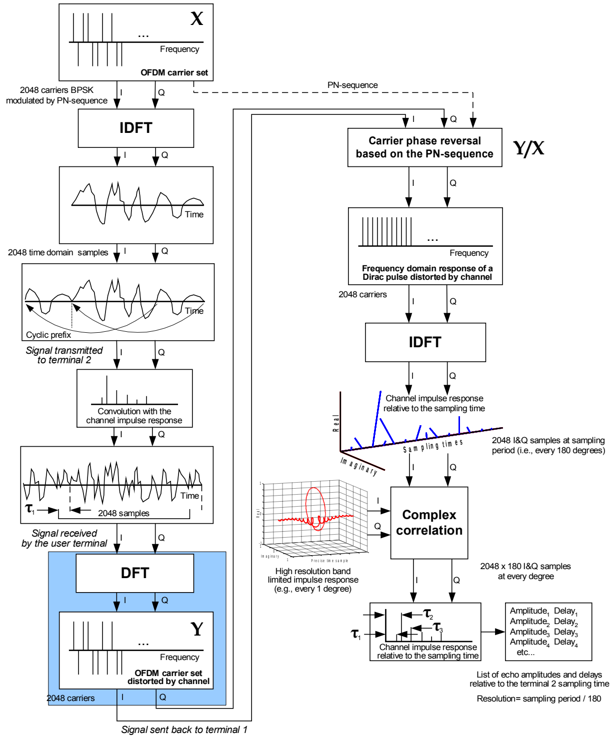
Operating Principles - IV

- **The OFDM receiver amplifies and samples the received waveform**



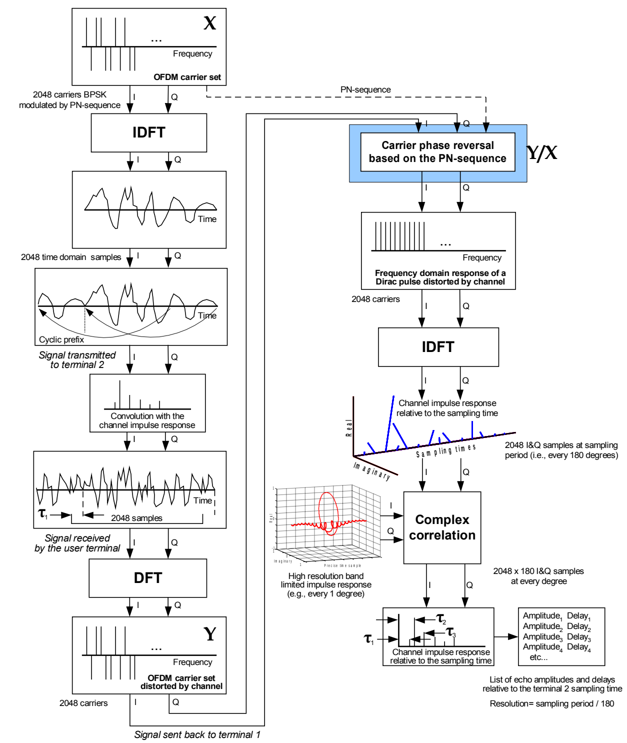
Operating Principles - V

- **The OFDM receiver performs a DFT on the received samples**
- **Up to this point, nothing really new**



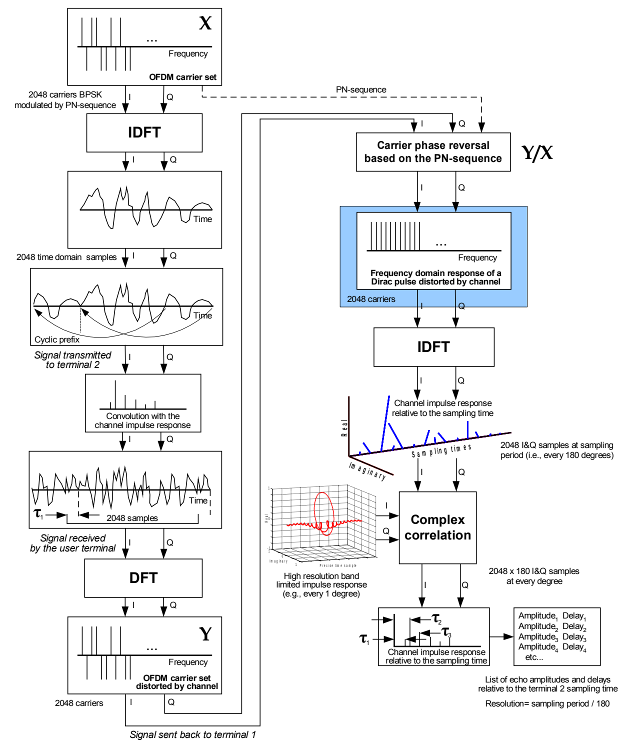
Operating Principles - VI

- **The known complex PN sequence is removed**
- **The result is**
  - A mathematical representation of the complex channel impulse response in the frequency domain



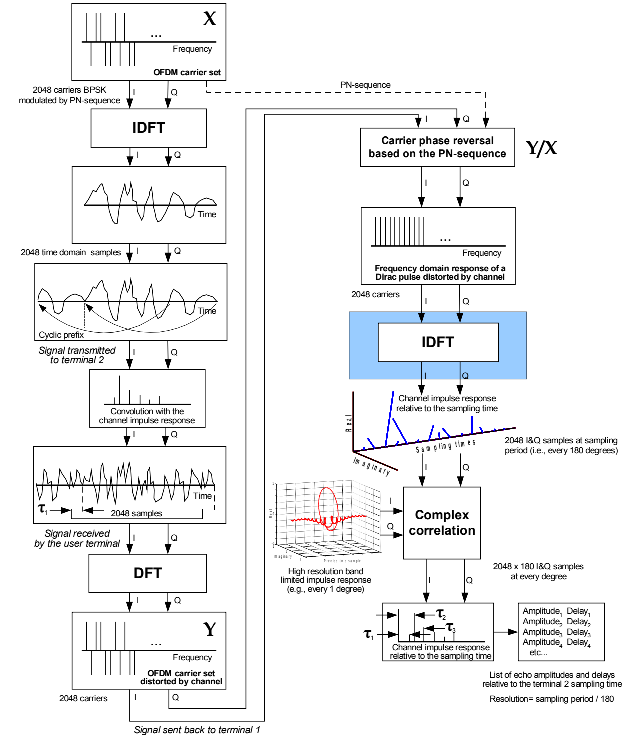
Operating Principles - VII

- **Non ranging carriers are removed**
- **Only ranging carriers are kept**
- **The result is now**
  - Practically identical to that of a classic Dirac Pulse RADAR in the frequency domain after propagation through the channel



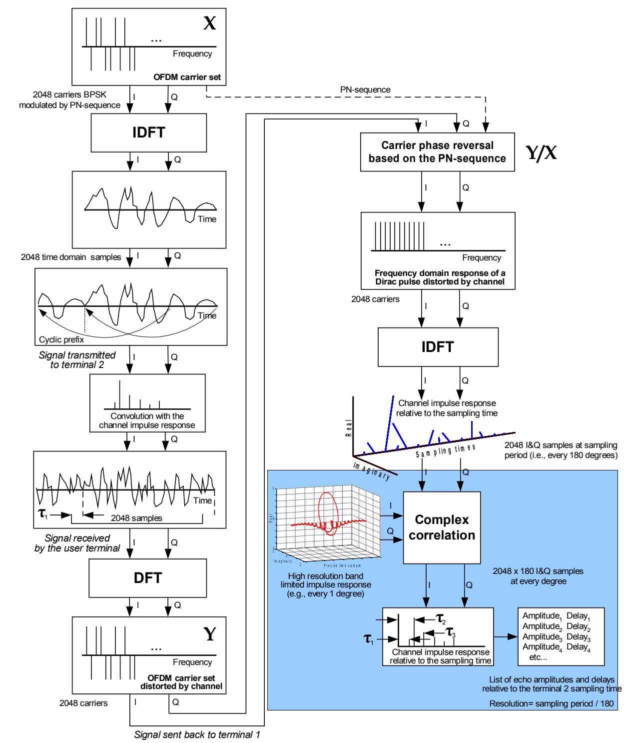
Operating Principles - VIII

- An IDFT is performed
- Result is a complex time domain impulse response



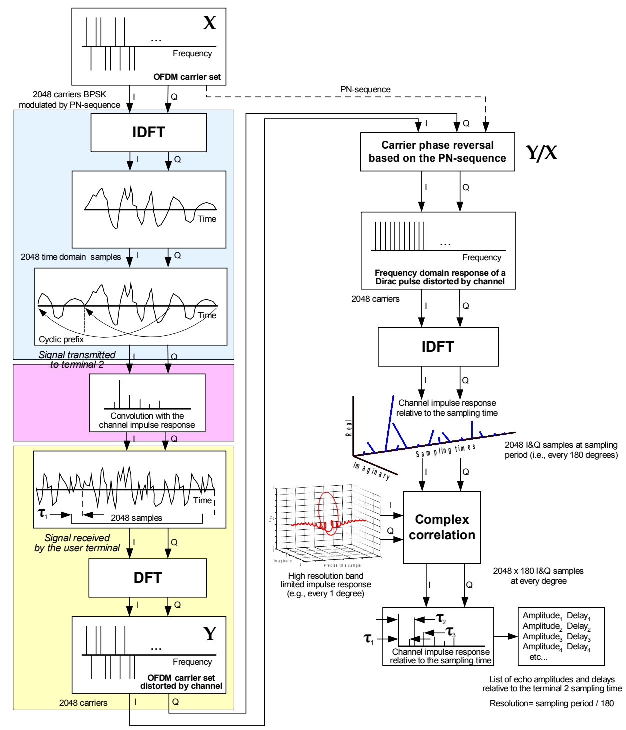
Operating Principles - IX

- **A cross correlation to a high resolution complex prototype function corresponding to an ideal channel is performed**
- **Result is**
  - A very precise channel echo profile identical to that obtained from a classic Dirac impulse RADAR with the same bandwidth but with a significantly finer precision due to the available processing gain resulting from the IDFT



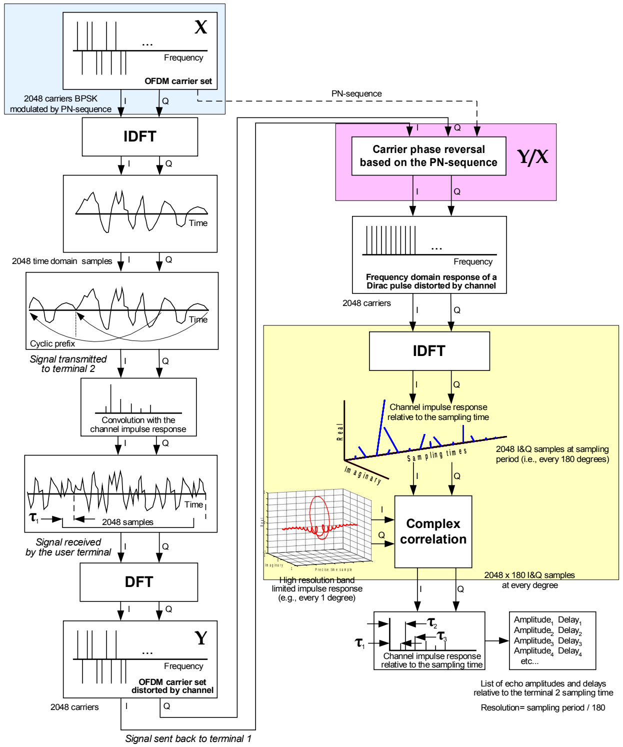
Sounding & Acquisition

- Transmission using a PN sequence
- Convolution through the channel
- Reception and acquisition
- **Nothing new**
  - This is done by all OFDM systems
- **Practically no hardware costs !**
  - No wiring
  - No additional antenna
  - No additional installation
  - Guaranteed co-location
  - Tamper resistant



Channel Modeling

- PN sequence selection
- PN sequence removal
- Deconvolution
- All this can be done
  - By a NOC processor
- Practically no hardware costs !
  - For BS or CPE



Multicarrier RADAR

- **Classic RADAR requires**
  - High power, large bandwidth
  - In digital circuits, very high frequency sampling clocks
- **M-RADAR reduces these requirements**
  - By 2 orders of magnitude in sampling clock frequency
  - Allows for an additional 40 dB processing gain
  - Yields higher precision
    - In a 6 MHz BW
    - With sampling frequency as low as 8/7 * 6Mhz
    - With 3 bit quantization → better than 1 meter precision
    - With 8 bit quantization → ~ 1 inch precision

Summary

- **M-RADAR can accurately range**
  - active and passive targets
- **Adding a third device allows**
  - Crude 2D RADAR imagery
- **Adding more devices**
  - Refines image quality and can allow 3D imagery
  - Provides for redundancy/correlation of results
    - May circumvent hidden node problems
    - Allowing for
      - terrain effects
      - 3D channel modeling/imagery provision
- **Opens a path for channel response deconvolution**