Analog and Digital combined: Mixed-Signal Design and Verification in MATLAB and Simulink

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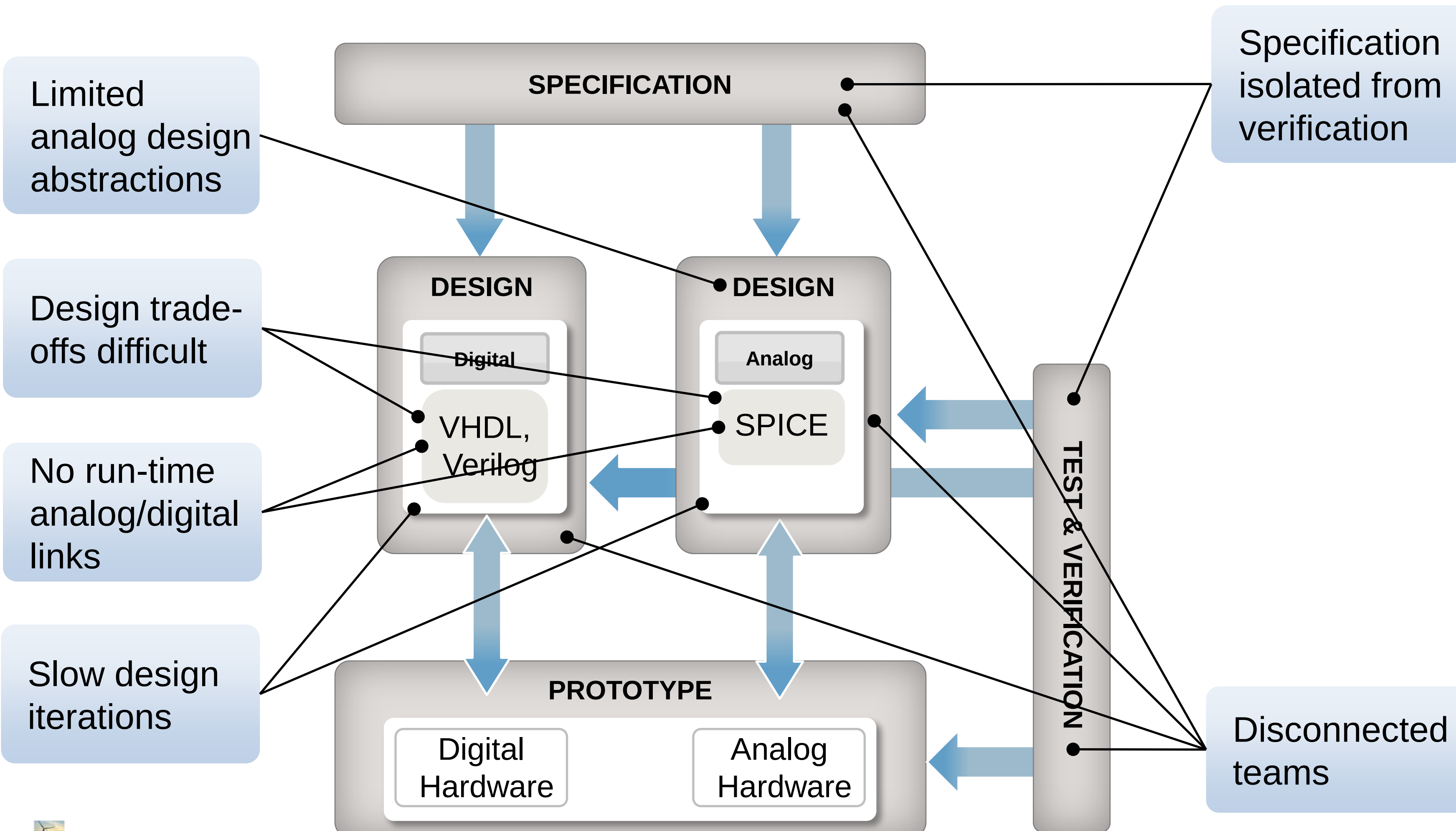
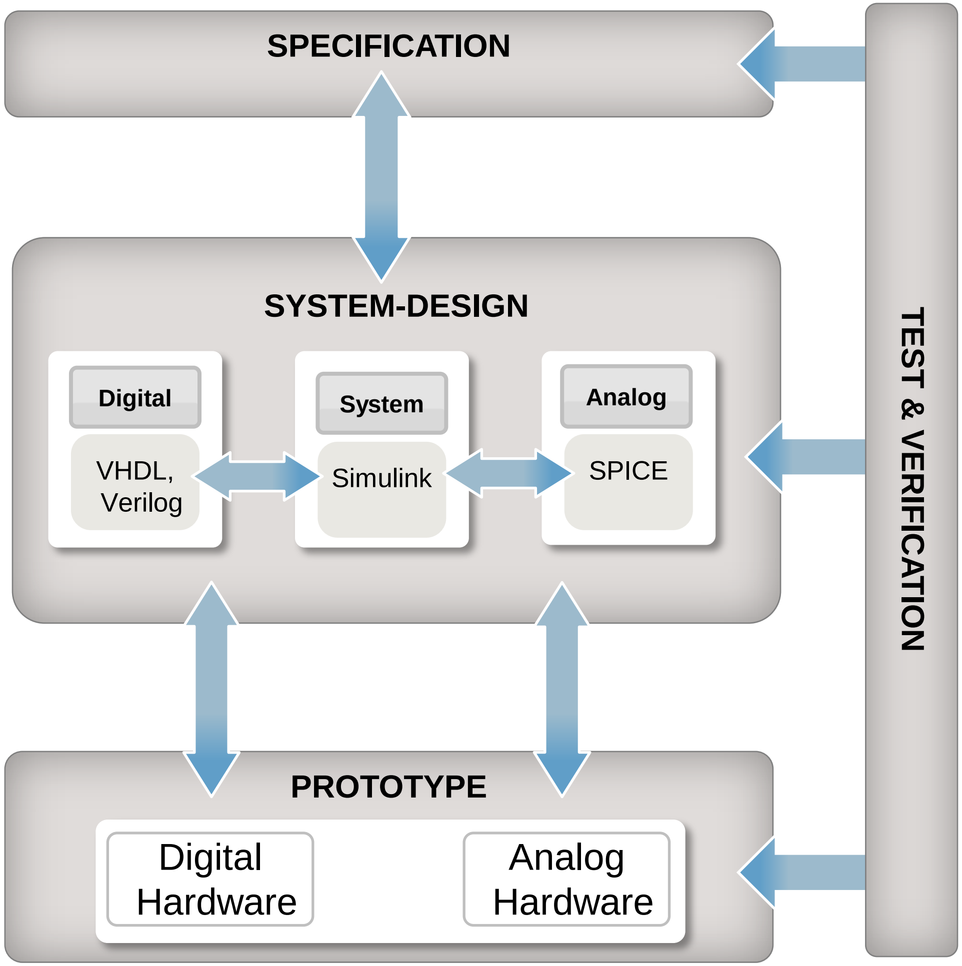
Agenda

- Analog/Mixed-Signal Design Challenges
- Case Studies
  - Analog-Digital-Converter
    - Modelling on different levels of abstraction
    - Architectural Exploration
  - Digital Pre-Distortion
    - Device characterisation (transistor-level simulation, measurement)
    - Device modelling
    - Compensation algorithm development
    - Verification
- Summary

Classical Mixed-Signal Design



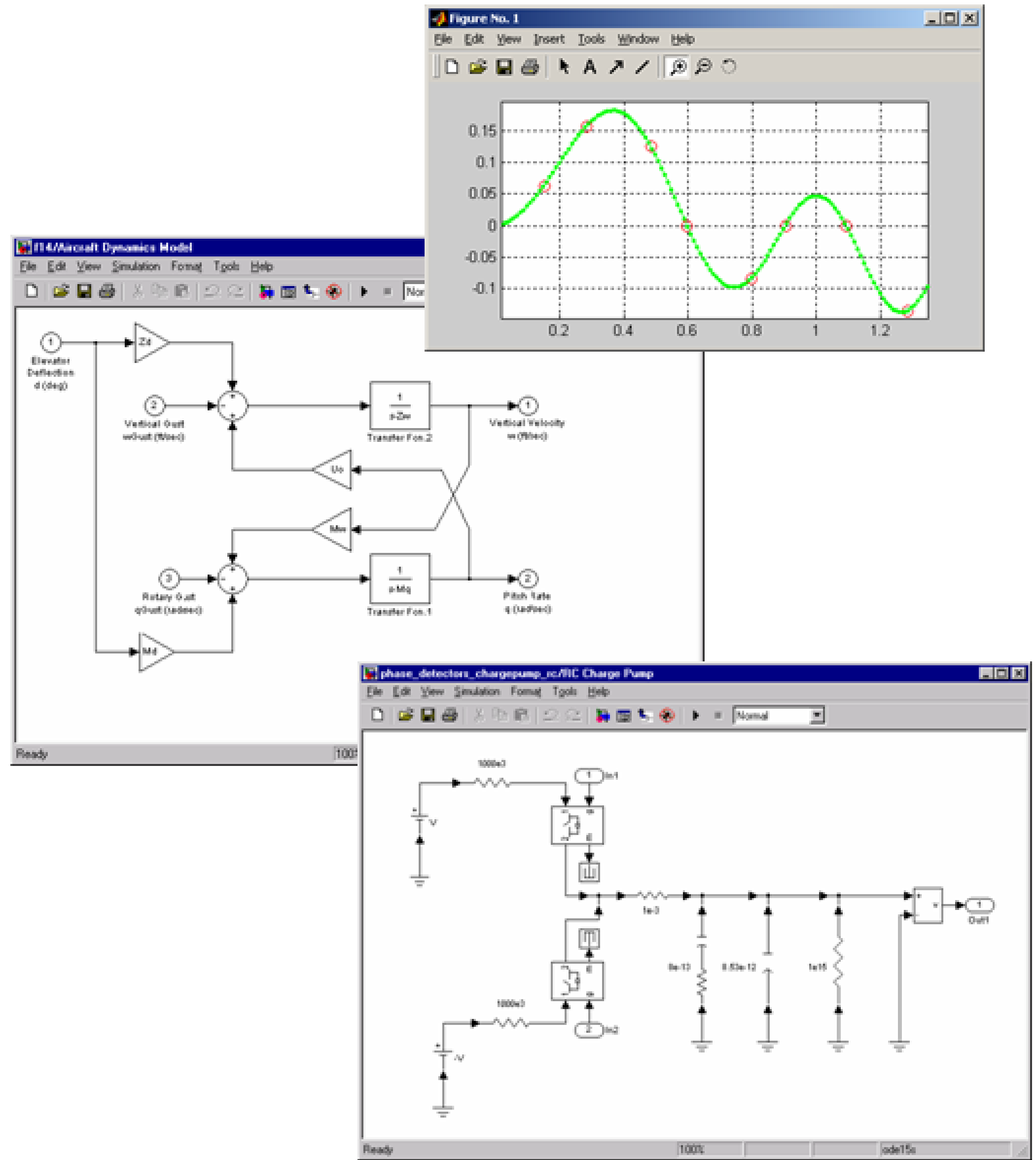
Model-Based Mixed-Signal Design



- Design & simulation speed
  - rapid construction
  - design abstractions
- Design links
  - multiple domains (analog, digital, network, …)
  - multiple tools (ModelSim, Spectre…)
  - specification and verification
  - system-level and test equipment

Simulink for Mixed-Signal Design

- Laplace transforms
  Variable step ODE solvers
- Zero crossings and discontinuities
- Feedback control loops, VCOs, PLLs, phase detectors
- Circuit-level Modeling:
  - SimPowerSystems
  - SimElectronics
- Spice Co-Simulation



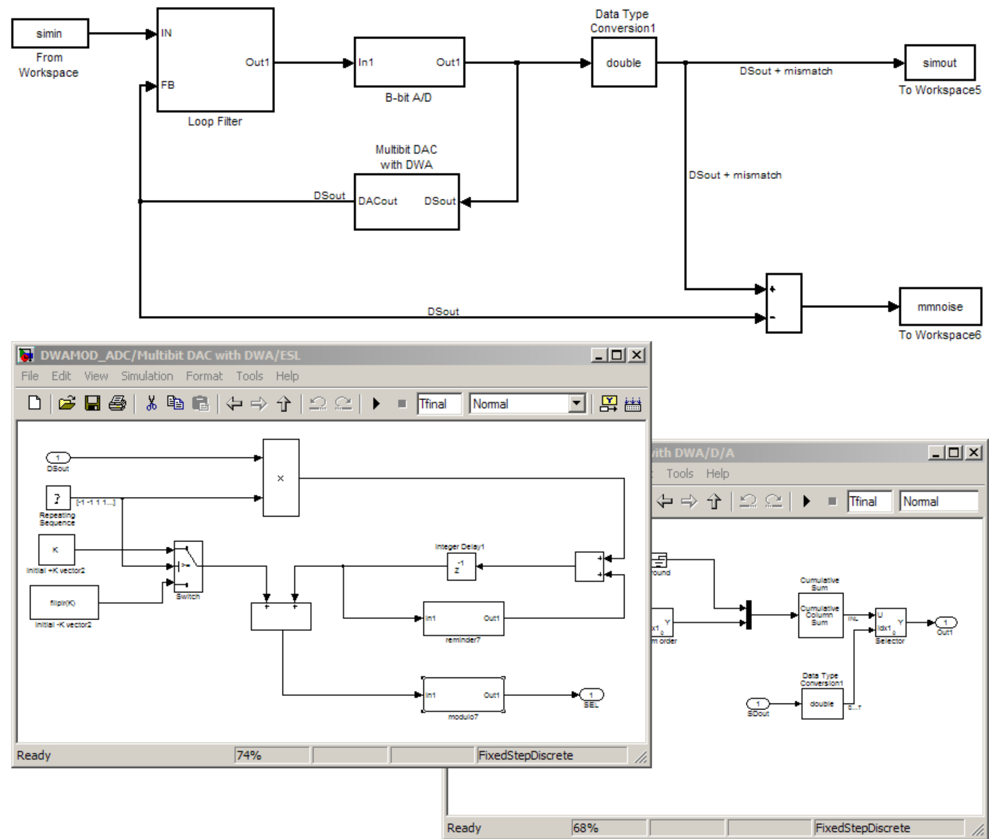
Case Study:
ADC Design

Agenda

Case study	What we'll show
Analog-Digital Converter	Introduction to methods – sigma-delta ADC Design abstractions Analog/digital in same model

Ideal tool features

Wish list
Intuitive
Quick & easy to build
Analog & digital together
Fast



Data Weighted Averaging for Simulink
Marko Neitola - University of Oulu

Case study: ADC design

Purpose:

- Introduce methods using straight forward design

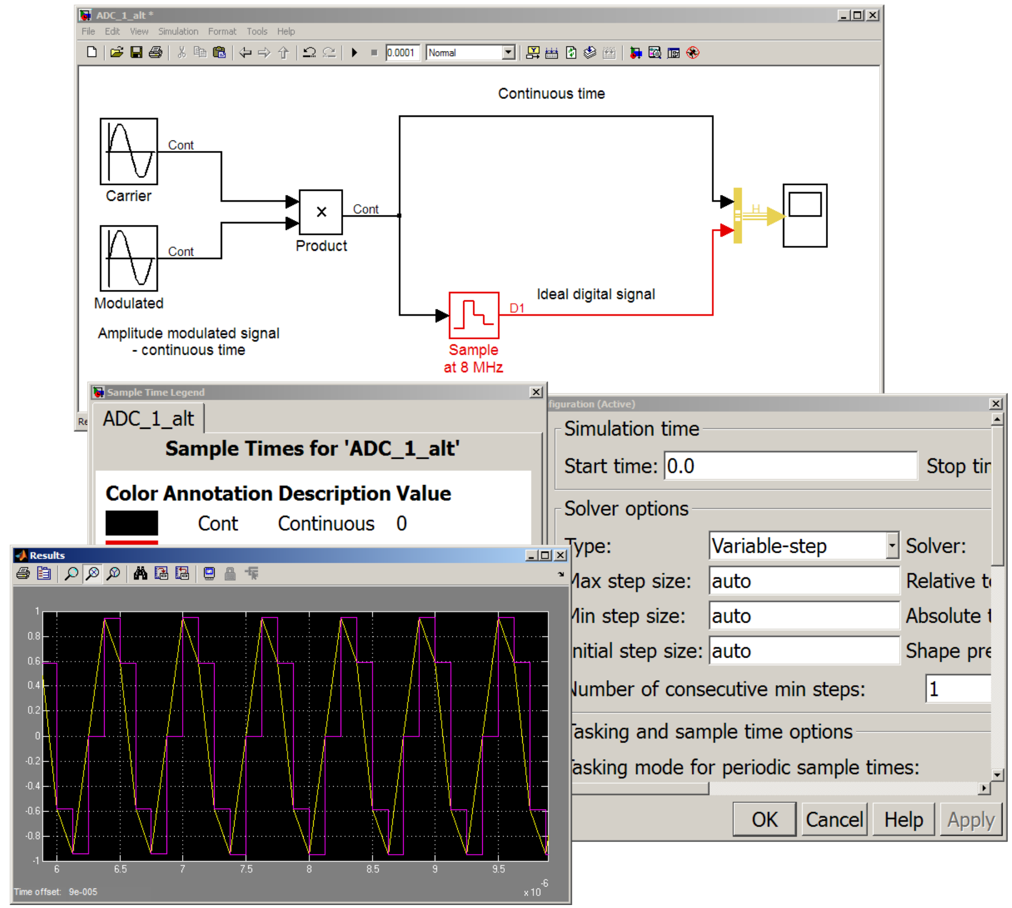
Design Challenge:

- Sigma-delta ADC to process AM signals around 1,600 kHz

Demo: Simulink Introduction

Simple model to illustrate concepts:

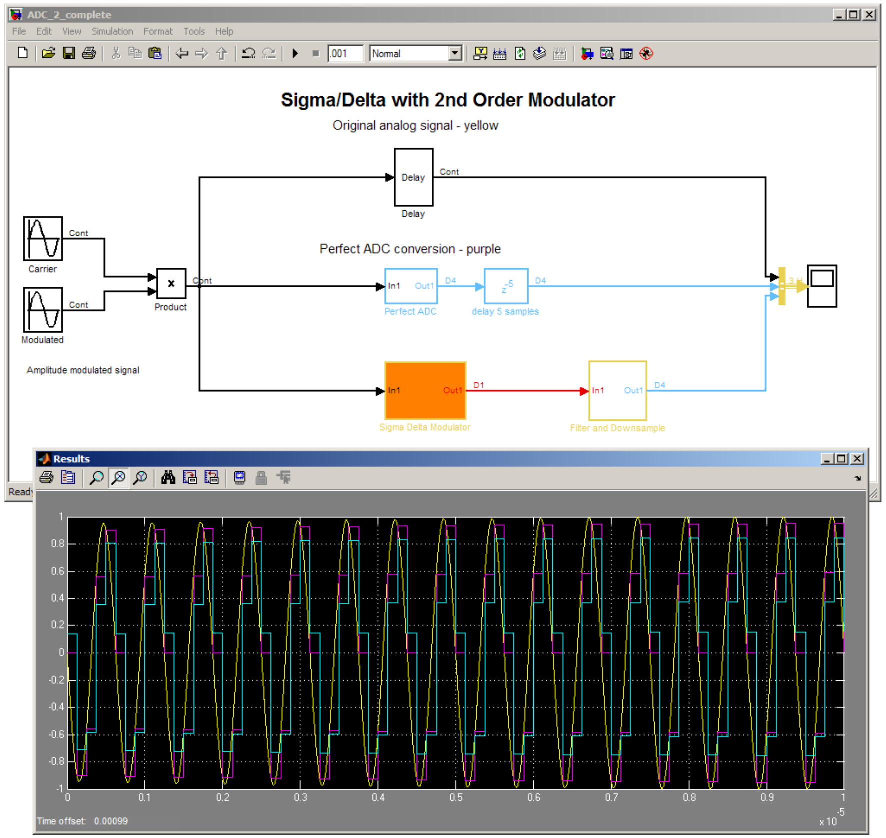
- Controlling blocks
- Time handling
- Analog and digital in same model



Demo: ADC built from (almost) scratch

Second-order sigma-delta ADC

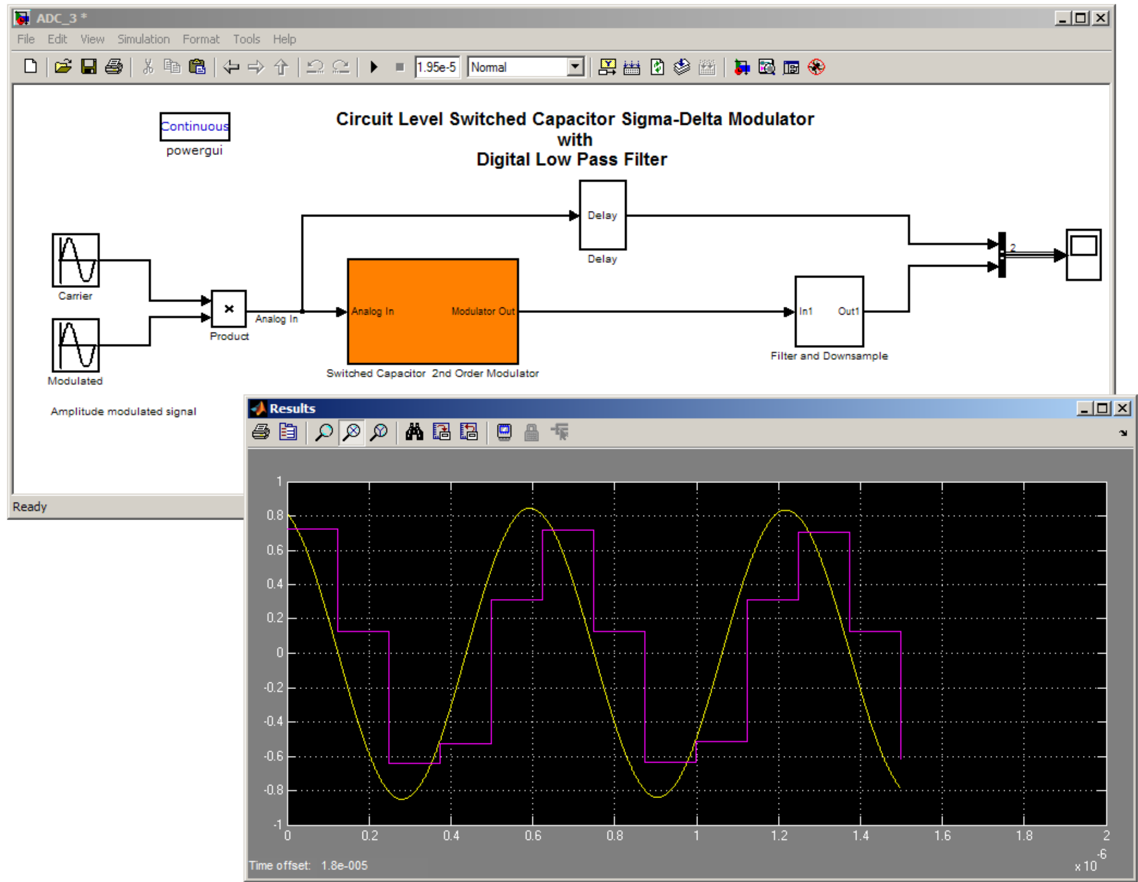
- Rapid model construction
- Feedback
- Filter design



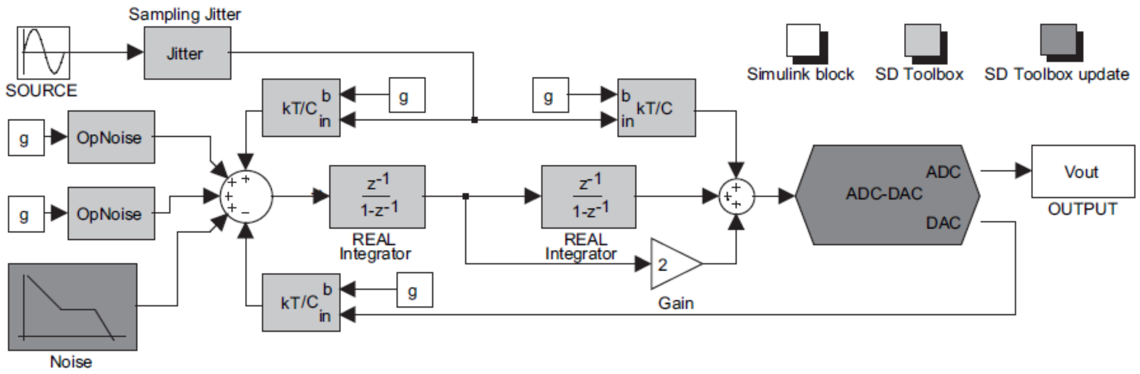
Demo: Circuit elements

Switched capacitor ADC

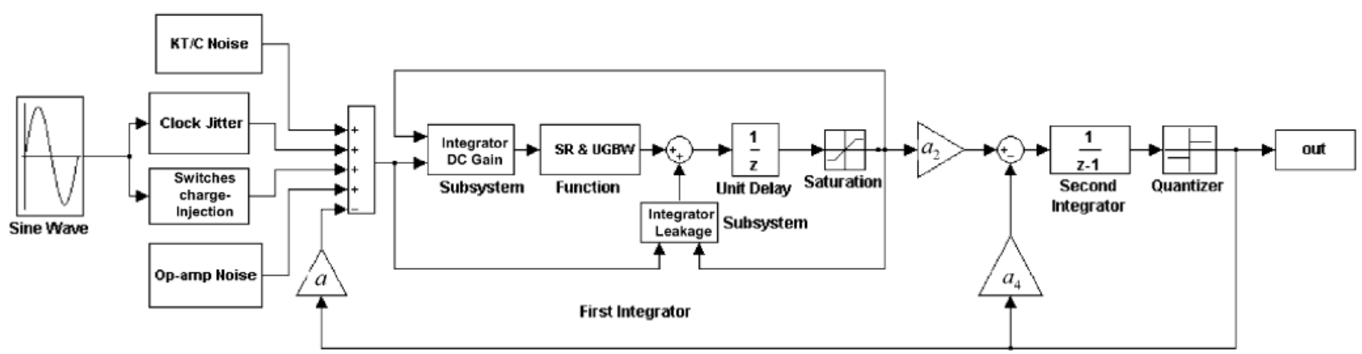
- Circuit elements
- Mixed-behavioral and circuit design



More complex ADCs & DACs possible



Improved Modeling of Sigma-Delta Modulator Non-Idealities in SIMULINK, A. Fornasari, P. Malcovati and F. Maloberti, ISCAS 2005

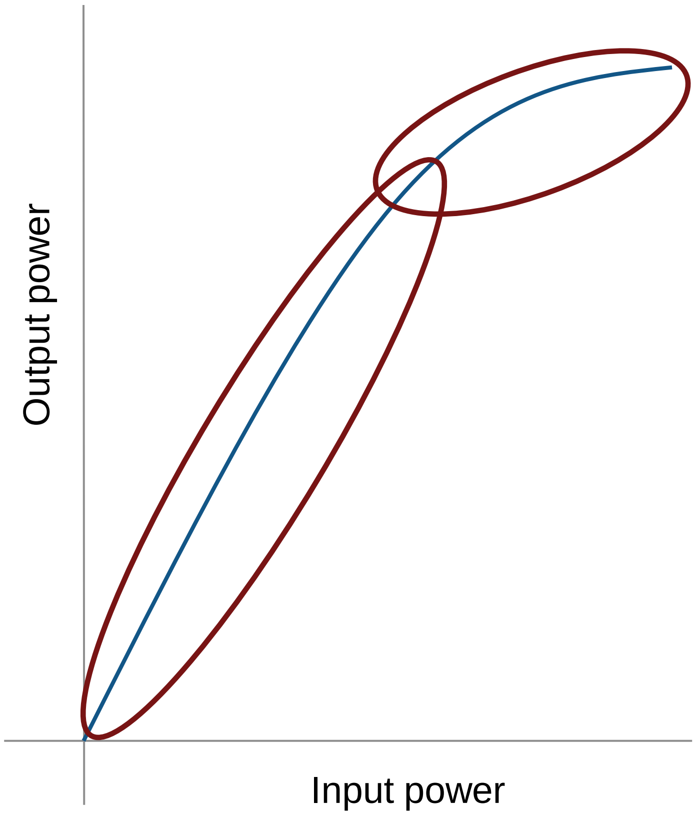


Modeling of Switched-Capacitor Delta–Sigma Modulators in SIMULINK, Hashem Zare-Hoseini, Izzet Kale, and Omid Shoaei, IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, 2005

Case Study:
Digital Pre-Distortion

Why DPD?

Power amplifier characteristic



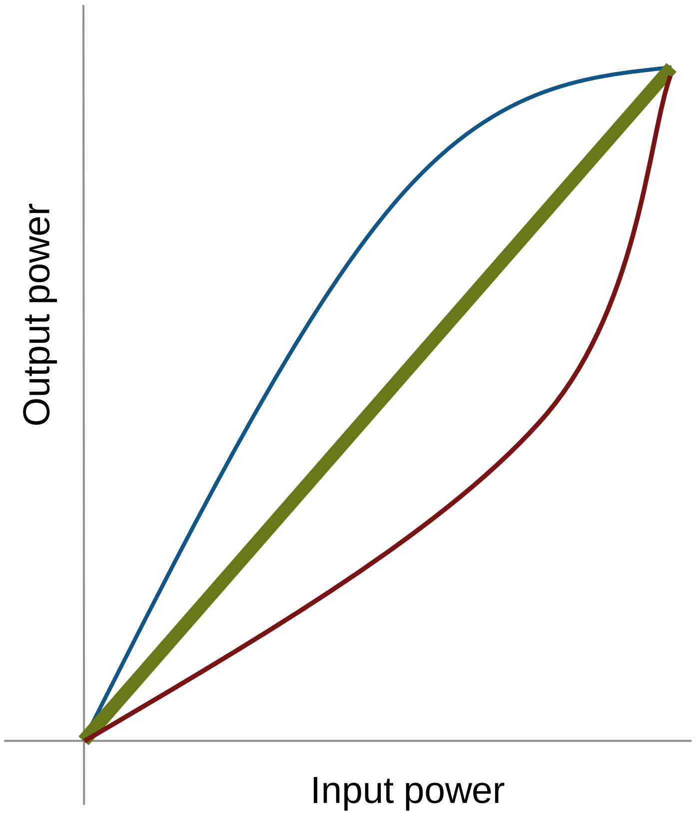
- High PAPR for OFDM systems
- Standards and regulators require low leakage

- Real power amplifiers distort at higher powers
- Back-off mode very inefficient

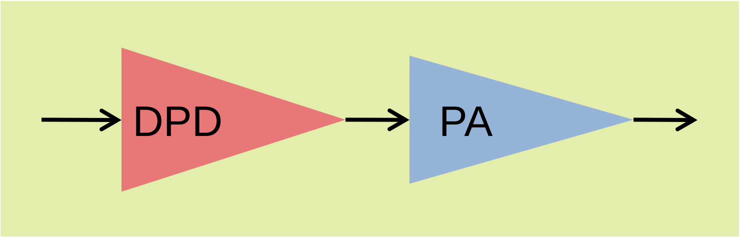
Can we have efficiency *and* low distortion?

What is Digital Pre-Distortion?

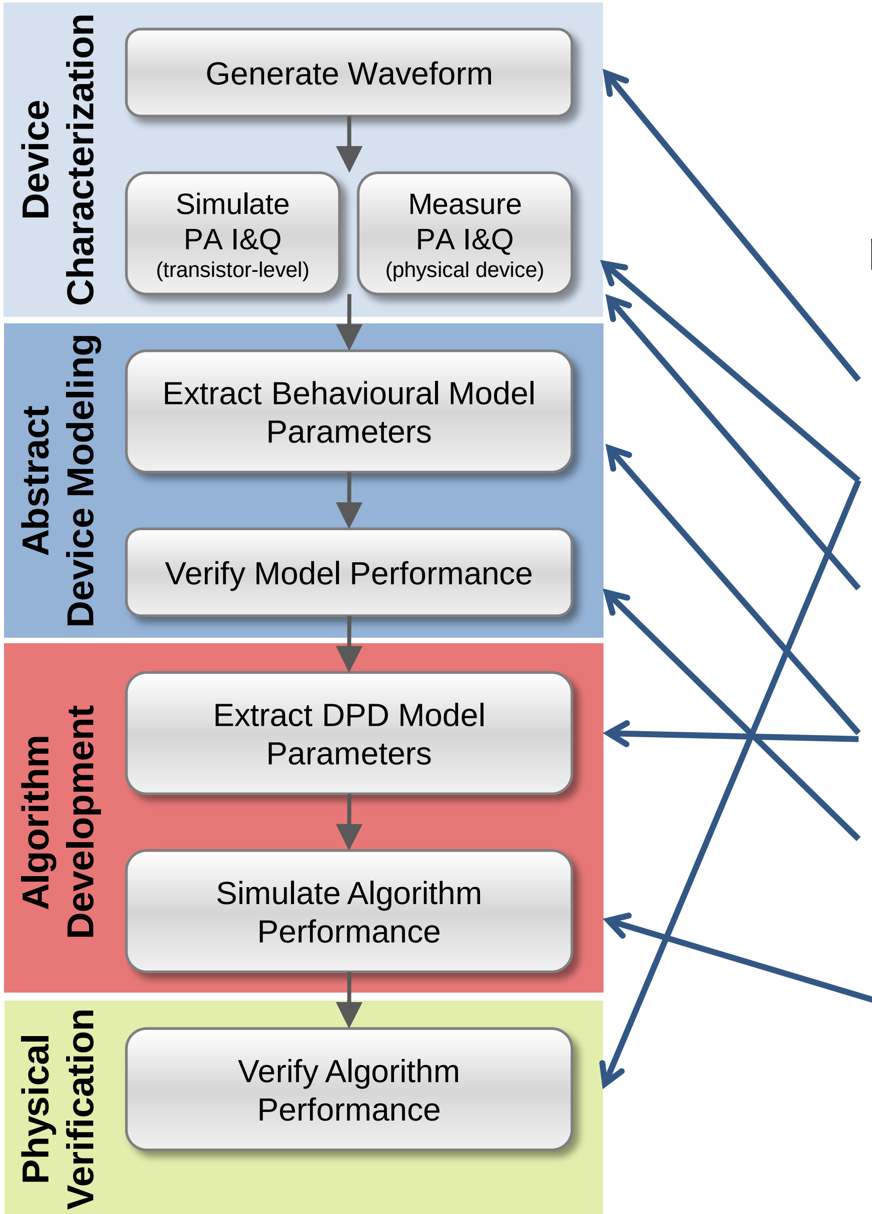
Power amplifier characteristic



- Power amplifier distorts signal
- Digitally pre-distort signal
- Predisortion + power amplifier = ideal result



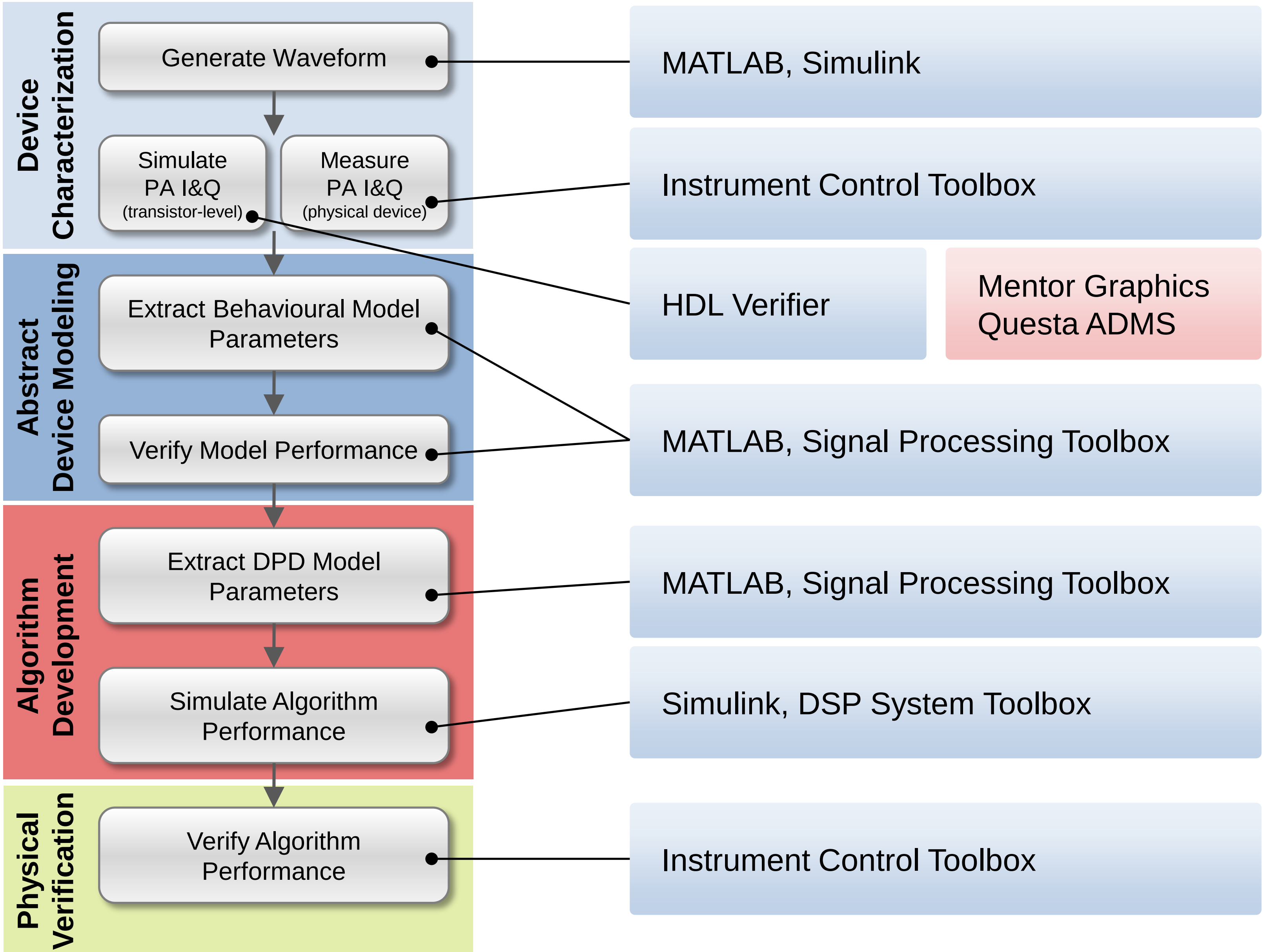
Modeling Challenges



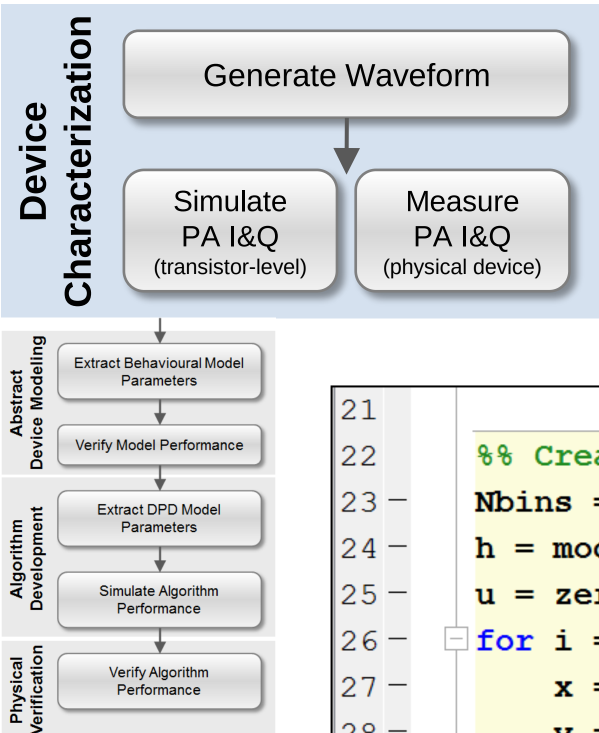
PA and DPD modeling solutions require:

- Signal generation capabilities
- Test & measurement interfaces
- Link to transistor-level simulators (e.g. Mentor Graphics Questa ADMS)
- Powerful linear algebra tools
- Advanced signal processing capabilities
- Time domain simulation capabilities

Modeling Challenges

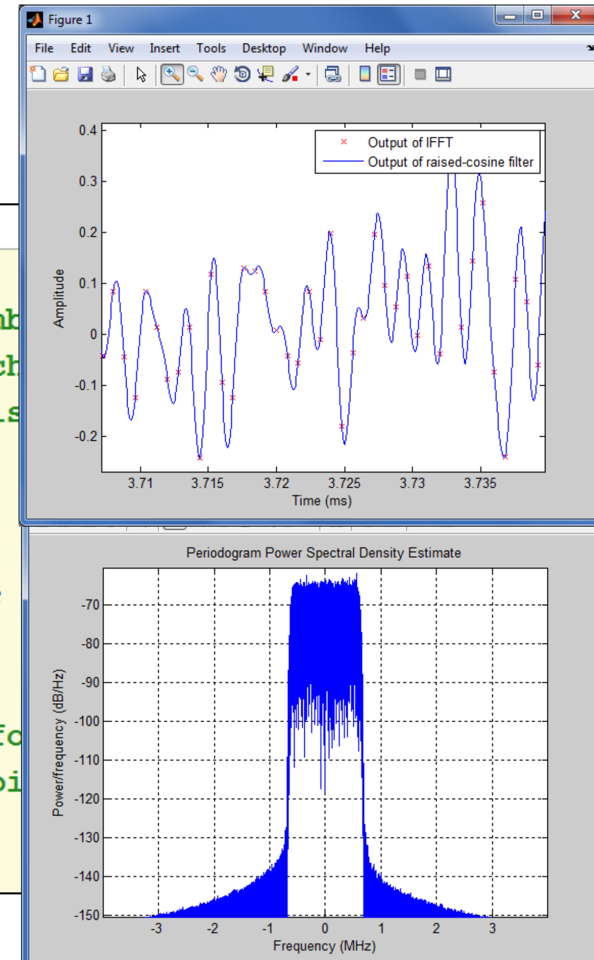


Waveform Generation

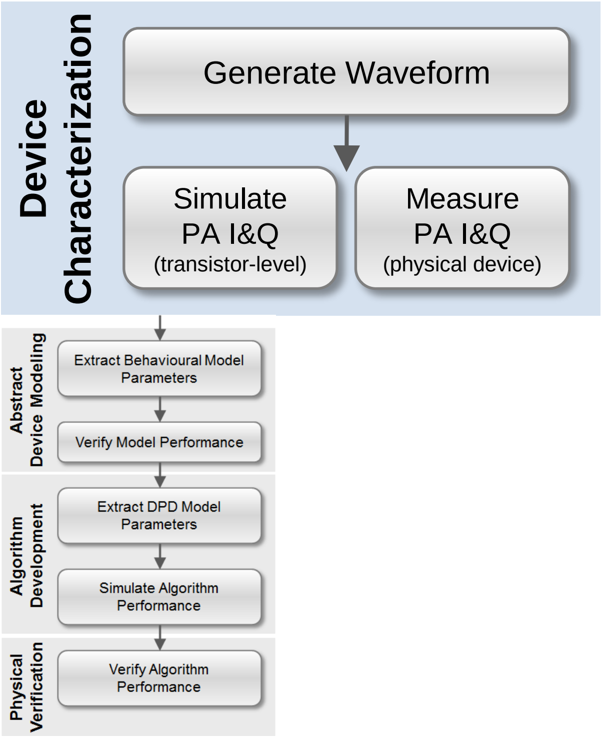


- MATLAB and extensions provide rich set of ready-to-use algorithms
  - Pre-defined
  - Parametrizable

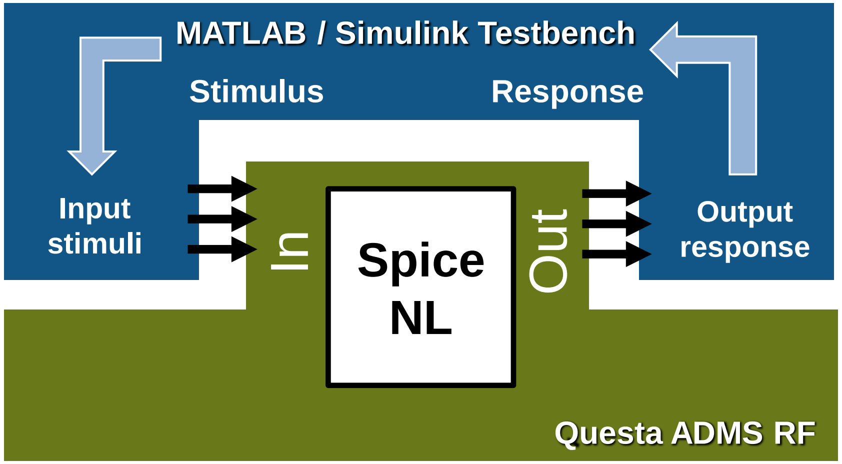
```
%% Create OFDM like waveform
Nbins = 1024;            % IFFT size (numb
h = modem.qammod(64);    % 64-QAM for each
u = zeros(Nbins*20,1);   % 20 OFDM symbols
for i = 1:20
    x = randint(Nbins-1,1,64);
    y = [0; modulate(h,x)];
    u((i-1)*Nbins+(1:Nbins)) = ifft(y);

end
x = repmat(u, 4, 1); % repeat the wavefo
                     % after pulse shapi
DataL = length(x);
```



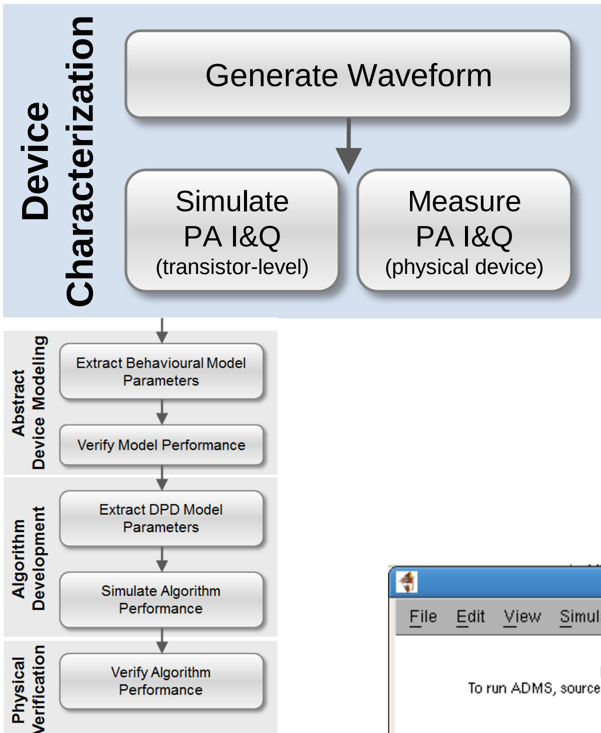
Interface to Transistor-Level Simulators

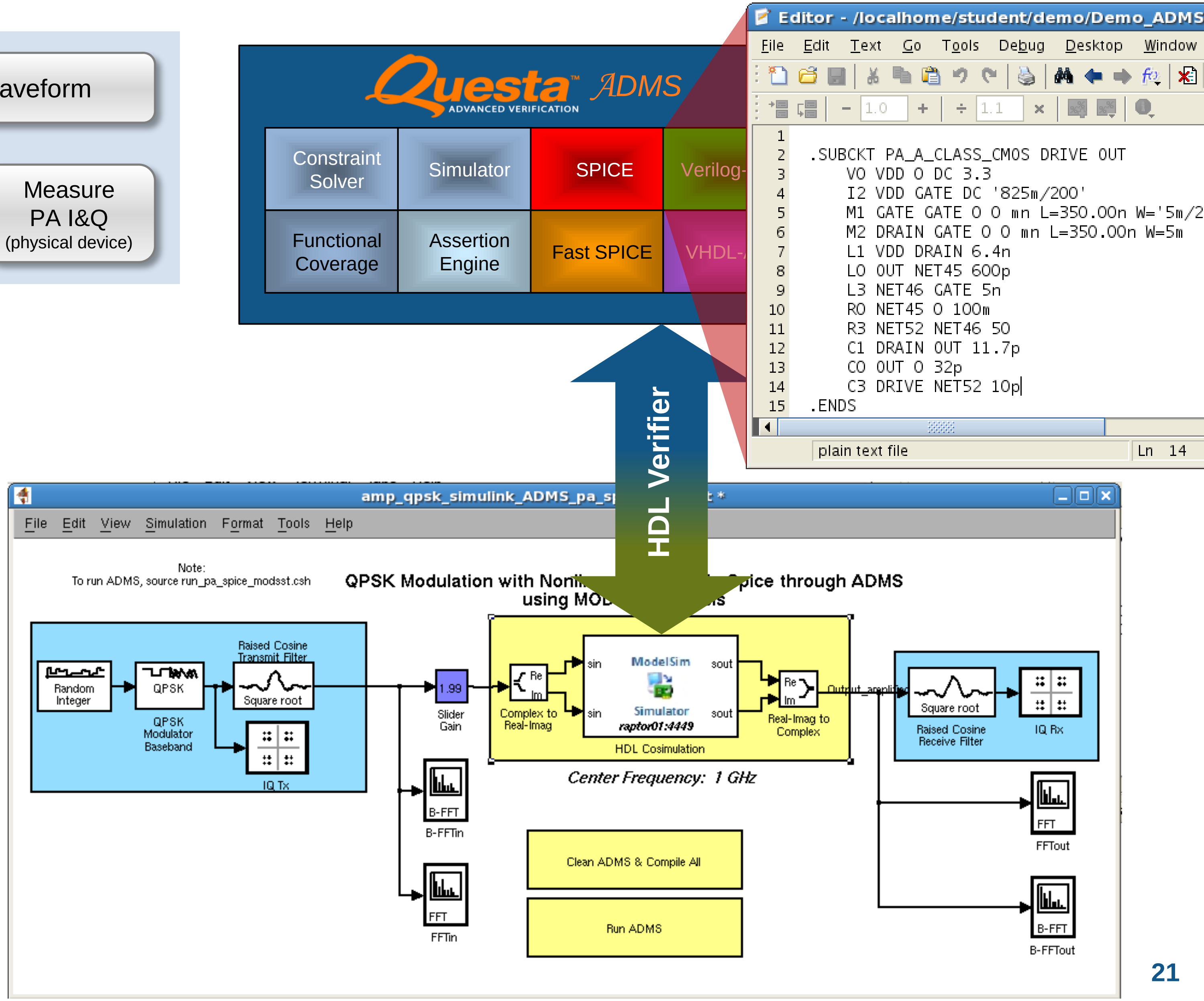


- Integration of Spice-level transistor netlist simulation in system-level testbench
- Stimuli generation and result analysis in MATLAB/Simulink

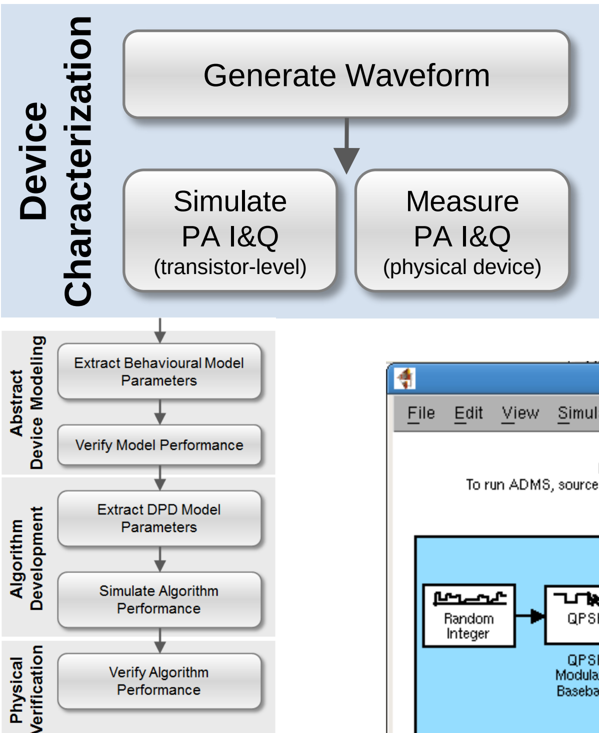


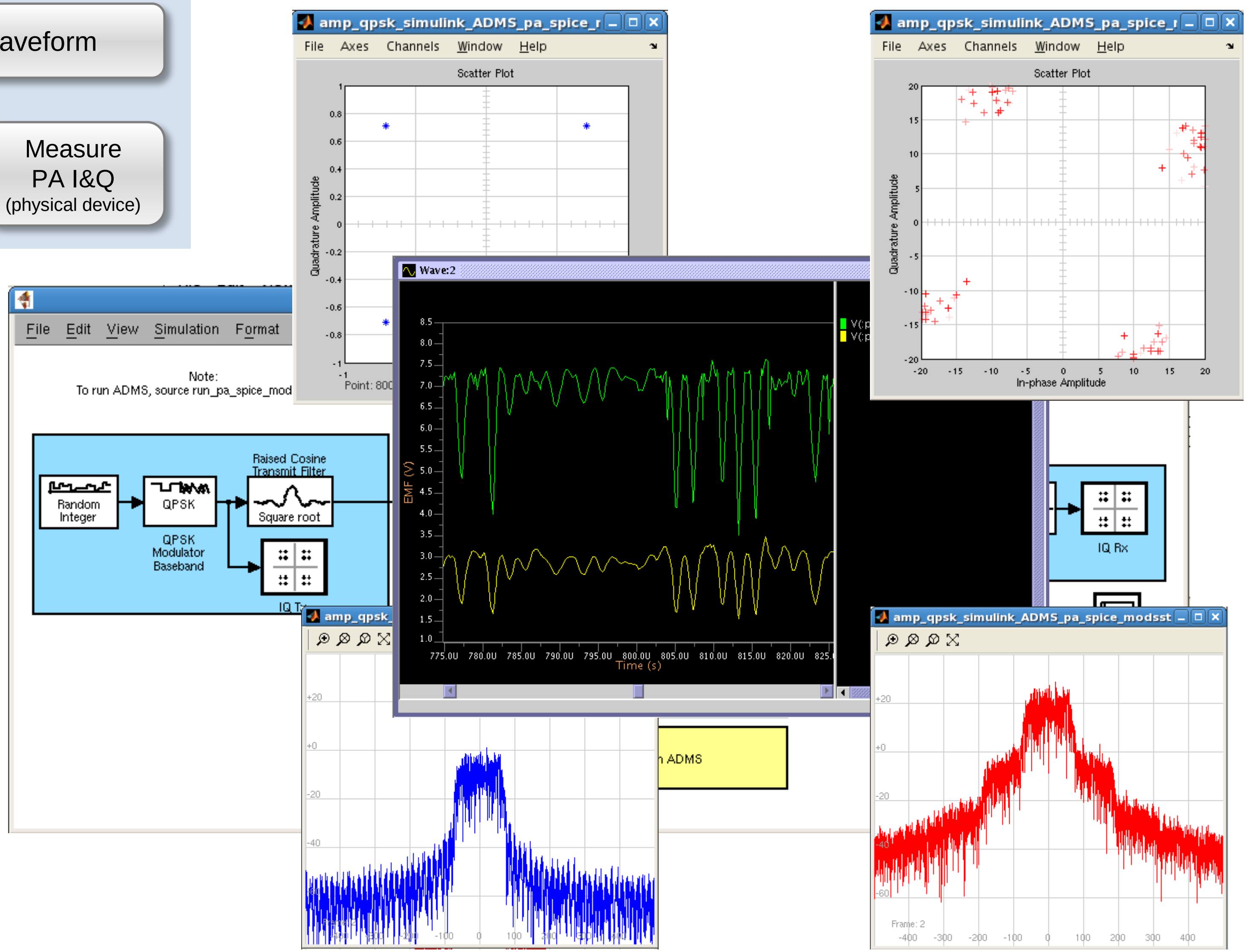
Example: Interface to Transistor-Level Simulators





Interface to Transistor-Level Simulators

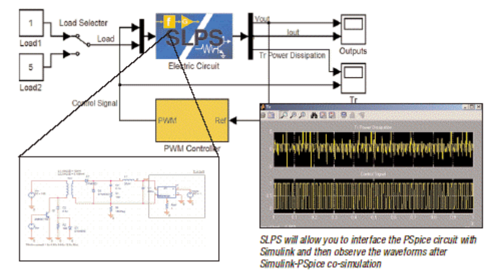


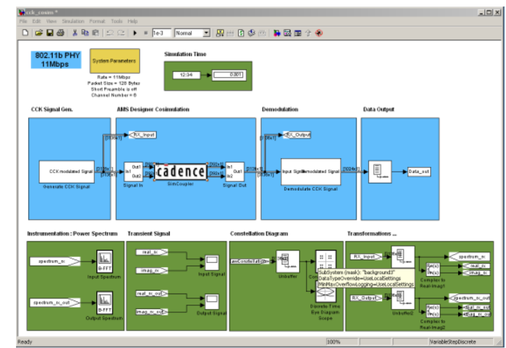


Co-Simulation with Analog Simulators

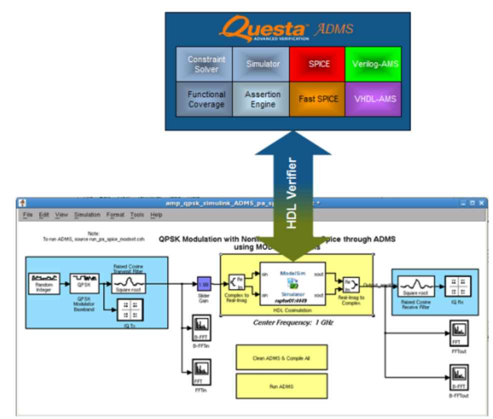
via 3rd party solution:

- Cadence
  - OrCAD SLPS
  - Virtuoso AMS Designer Simulink Integrator

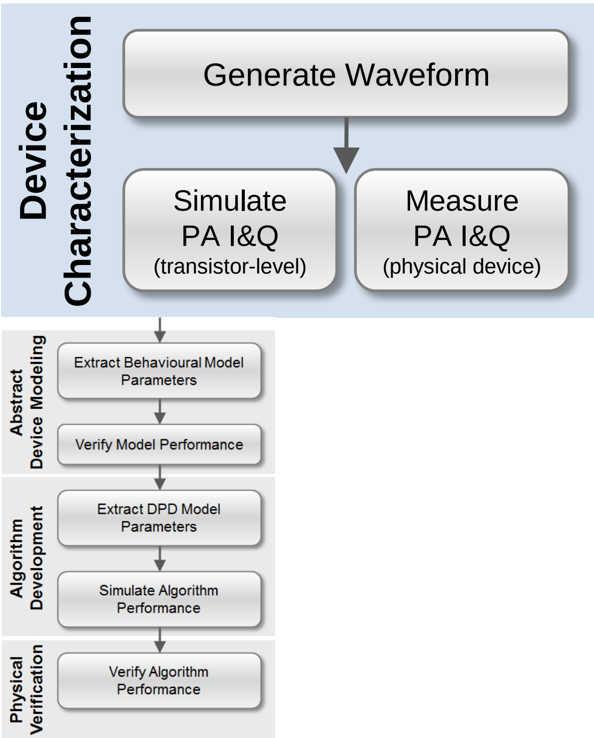




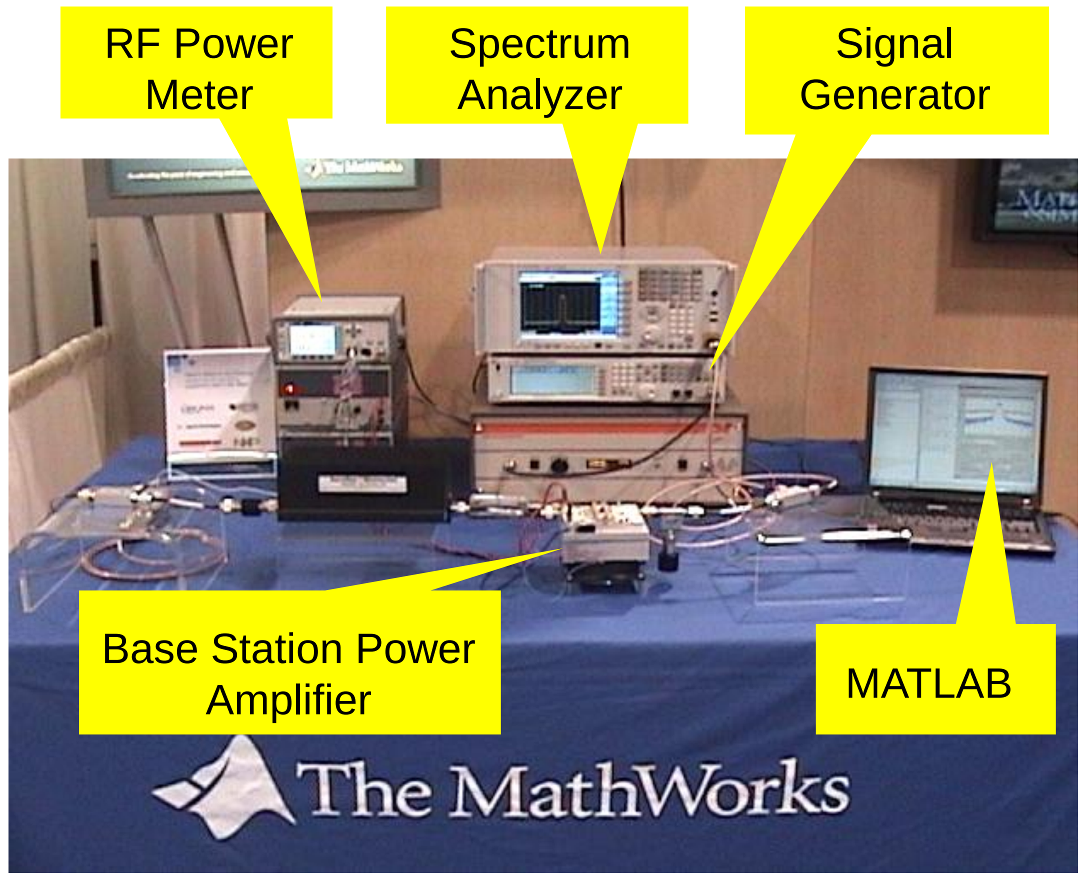
- Mentor Graphics
  - Questa ADMS



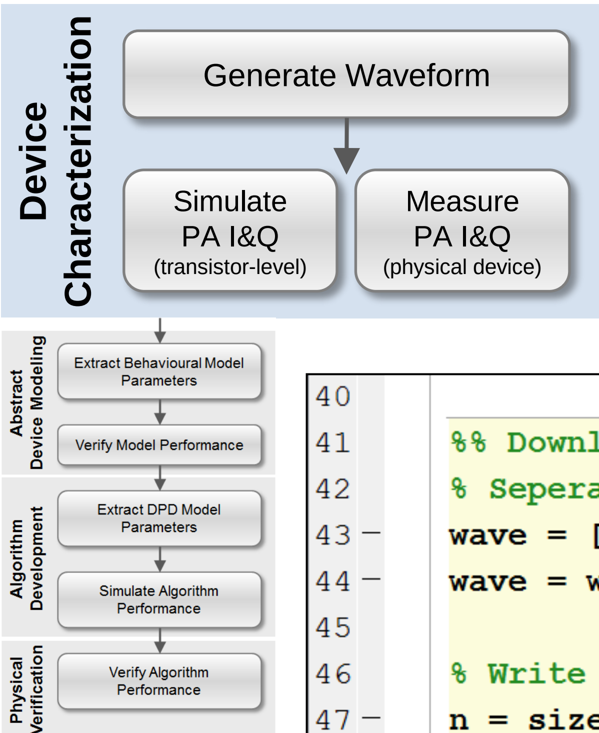
Interfacing to Test & Measurement Equipment



- Typical lab setup for device characterization

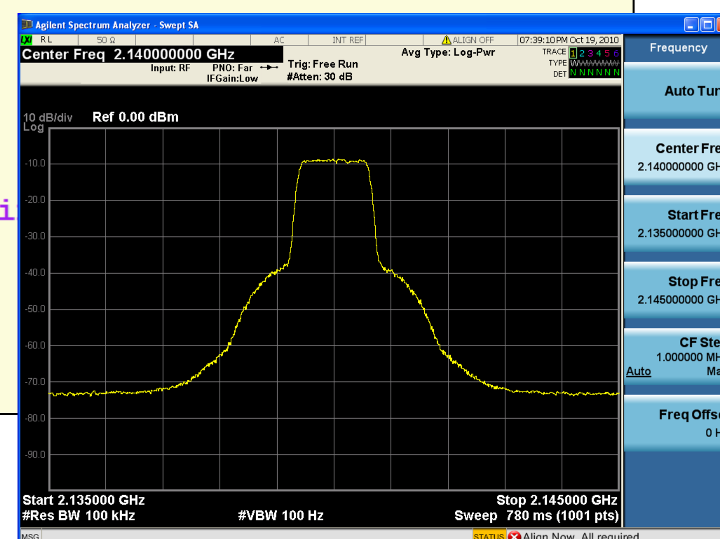


Interfacing to Test & Measurement Equipment

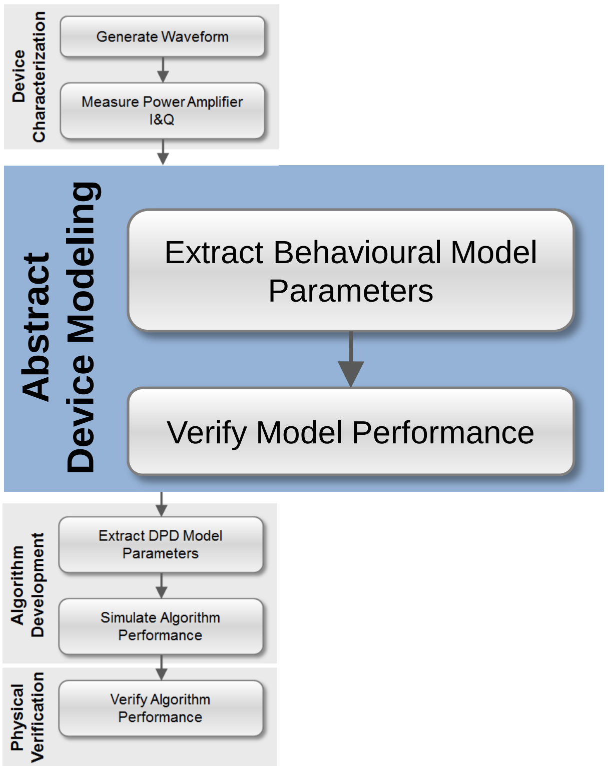


- Equipment setup, e.g. waveform download to signal generator
- Execution control
- Upload of measurent results

```
%% Download signal
% Seperate out the real and imaginary data in the IQ Waveform
wave = [real(IQData);imag(IQData)];
wave = wave(:)';     % transpose the waveform

% Write the data to the instrument
n = size(wave);
disp(sprintf('Starting Download of
binblockwrite(deviceObject,wave,'ui

fprintf(deviceObject,'');
disp('...done!');

```

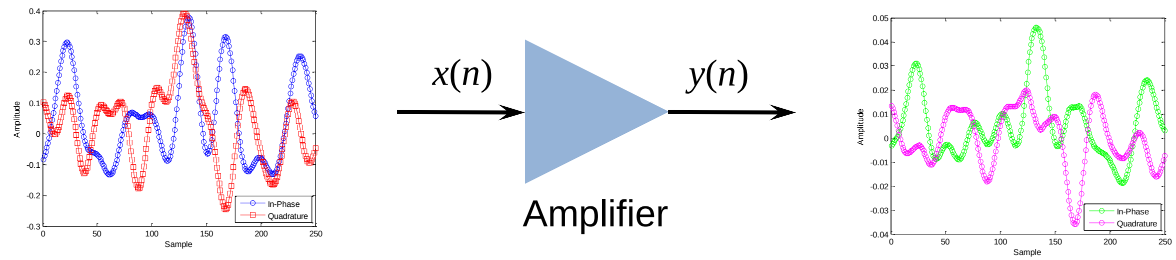


Behavioural Modeling of RF Amplifiers



- Memory polynomial model[1] used

$$y_{MP}(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} a_{km}\, x(n-m) \left| x(n-m) \right|^{k}$$

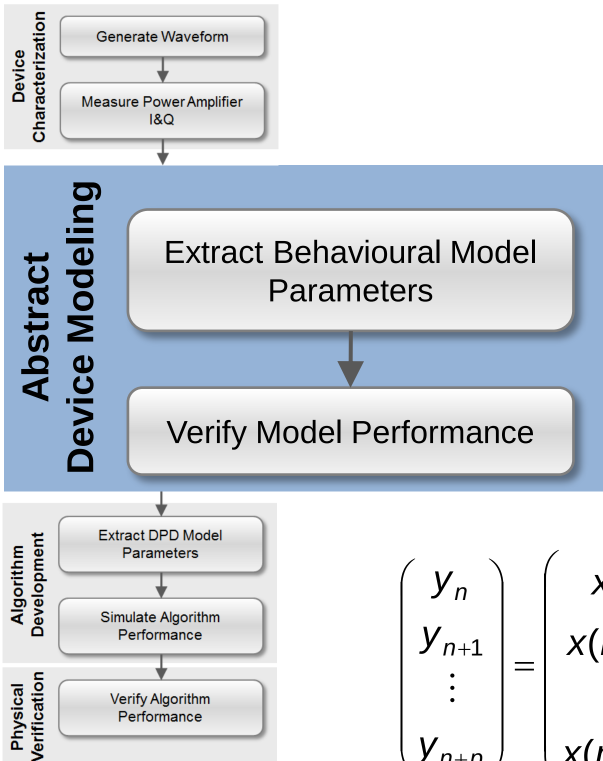


  – K = order of the model, M = memory depth

- Only diagonal terms considered

1) Morgan, Ma, Kim, Zierdt, and Pastalan, “A Generalized Memory Polynomial Model for Digital Predistortion of RF Power Amplifiers”, IEEE Trans. on Signal Processing, Vol. 54, No. 10, Oct. 2006

Behavioural Modeling of RF Amplifiers



$$y_{MP}(n)=\sum_{k=0}^{K-1}\sum_{m=0}^{M-1}a_{km}\,x(n-m)\left|x(n-m)\right|^{k}$$

Rearragned into vector form

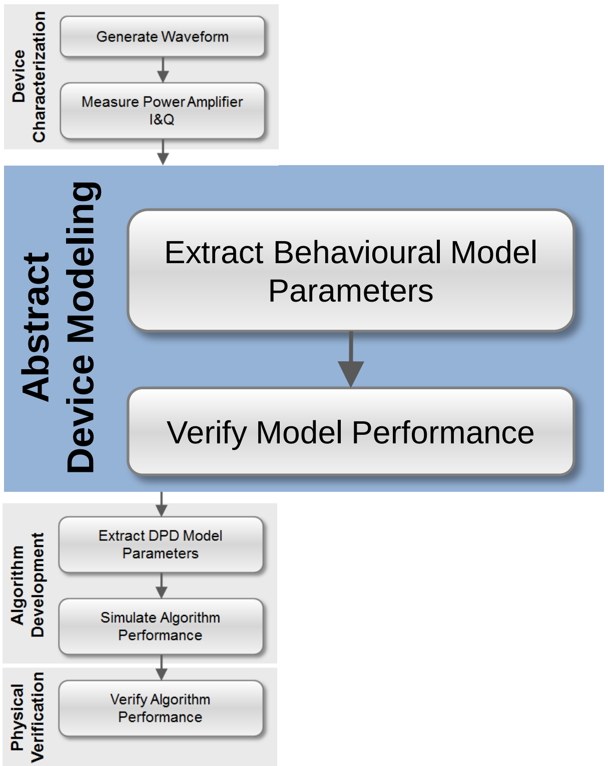
$$\begin{pmatrix} y_n \\ y_{n+1} \\ \vdots \\ y_{n+p} \end{pmatrix} = \begin{pmatrix} x(n) & x(n-1) & \cdots & x(n-M+1)\left|x(n-M+1)\right|^{K-1} \\ x(n+1) & x(n+1-1) & \cdots & x(n-M+2)\left|x(n-M+2)\right|^{K-1} \\ \vdots & \vdots & \vdots & \vdots \\ x(n+p) & x(n-1+p) & \cdots & x(n-M+1+p)\left|x(n-M+1+p)\right|^{K-1} \end{pmatrix} \begin{pmatrix} a_{00} \\ a_{01} \\ \vdots \\ a_{K-1,M-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_n \\ \varepsilon_{n+1} \\ \vdots \\ \varepsilon_{n+p} \end{pmatrix}$$

- MATLAB code for solving for a:

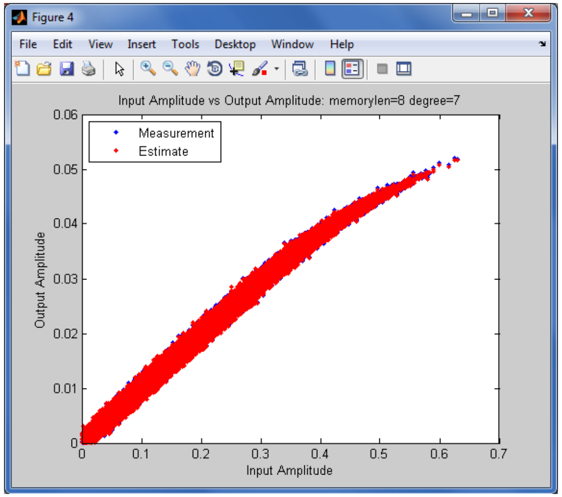
```
>> a_coef = x_terms \ y;
```

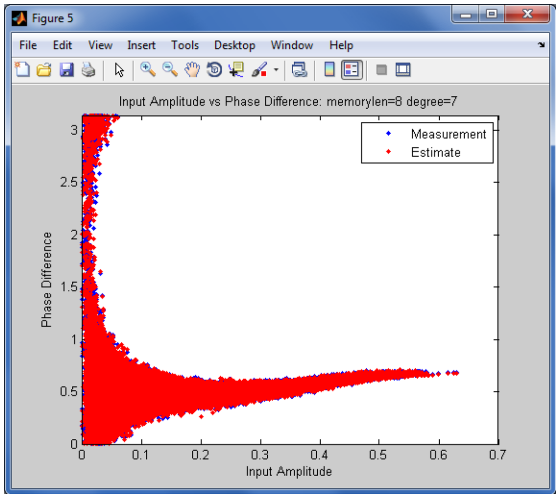
- “\” operator calculates LMS solution.

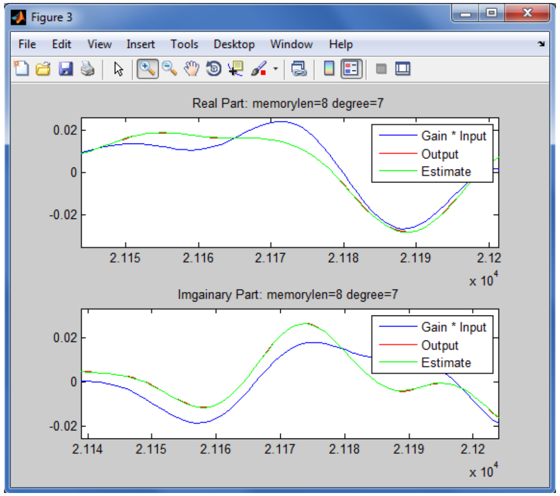
Behavioural Modeling of RF Amplifiers



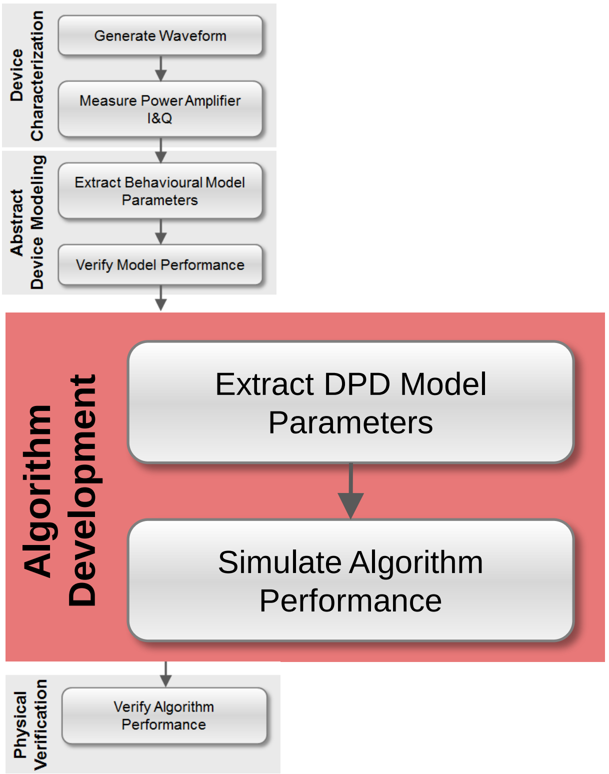
- Verifying match between measured data and model response







DPD Algorithm Development & Verification



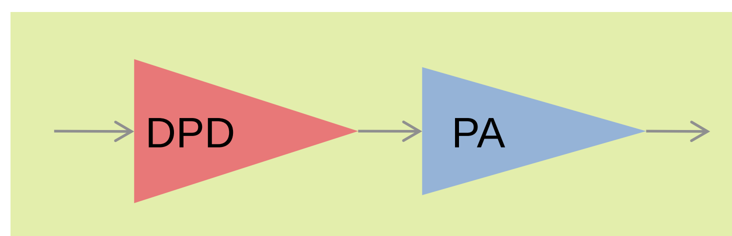
- Power amplifier model is:

$$y_{MP}(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} a_{km} x(n-m) \left| x(n-m) \right|^k$$

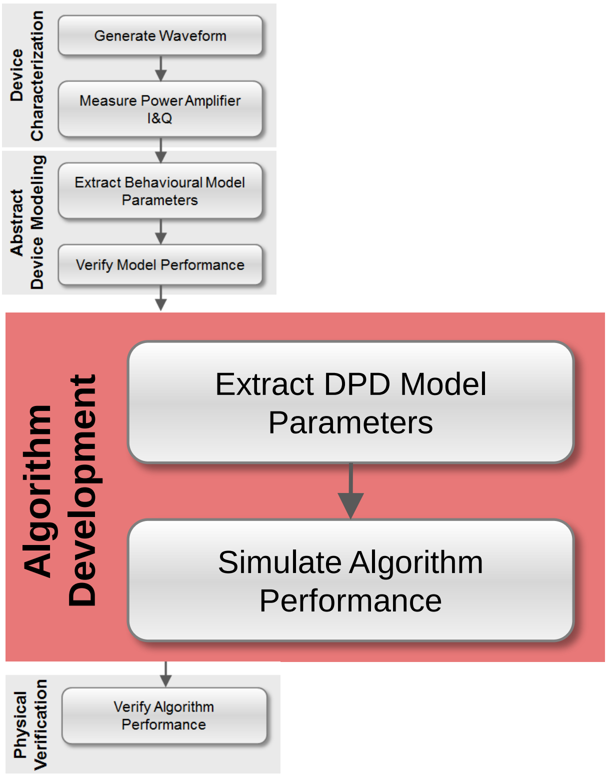
- We want the reverse, which is:

$$x(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} a_{km} y(n-m) \left| y(n-m) \right|^k$$

- DPD + PA = Ideal



DPD Algorithm Development & Verification



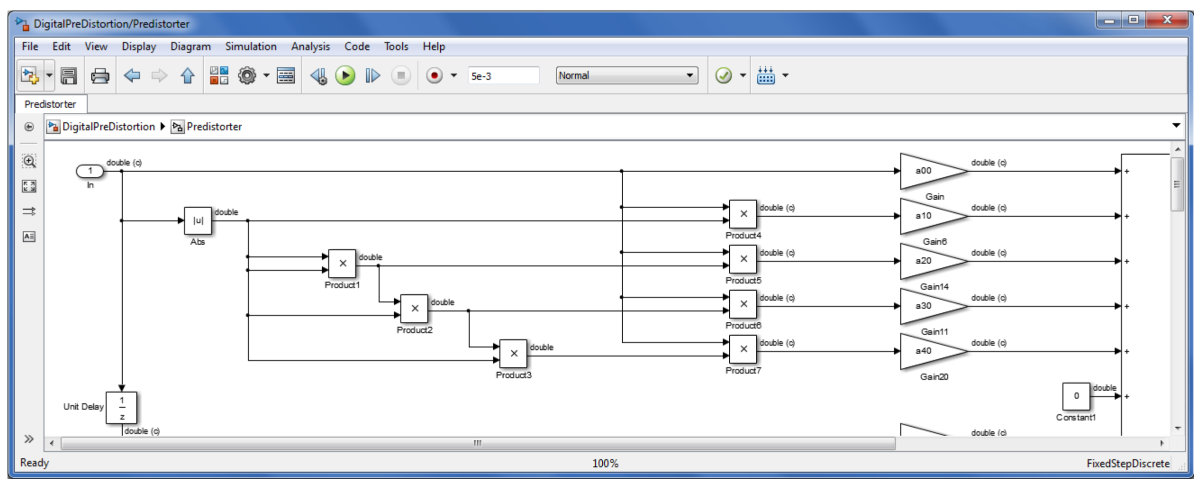
Same MATLAB code as before:

- Parameters fit by:

```
>> a_coef = x_terms \ y;
```

- Model results given by:

```
>> y = x_terms * a;
```



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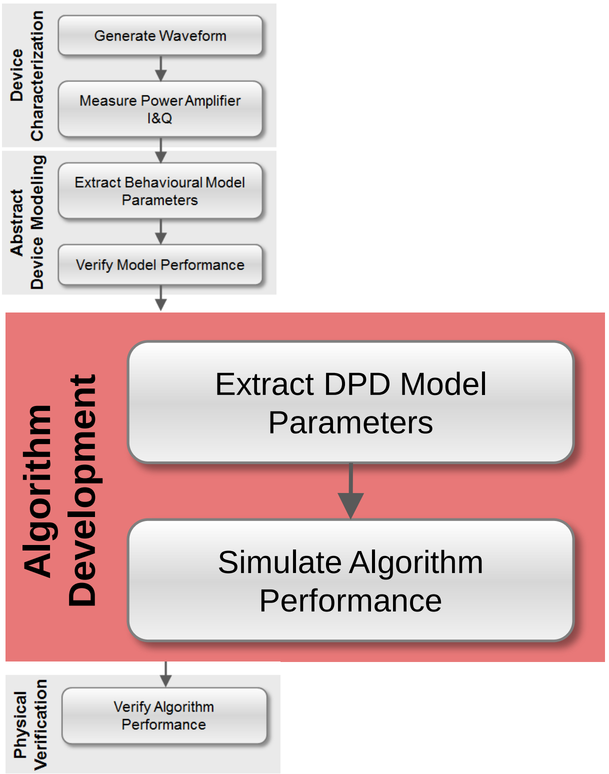
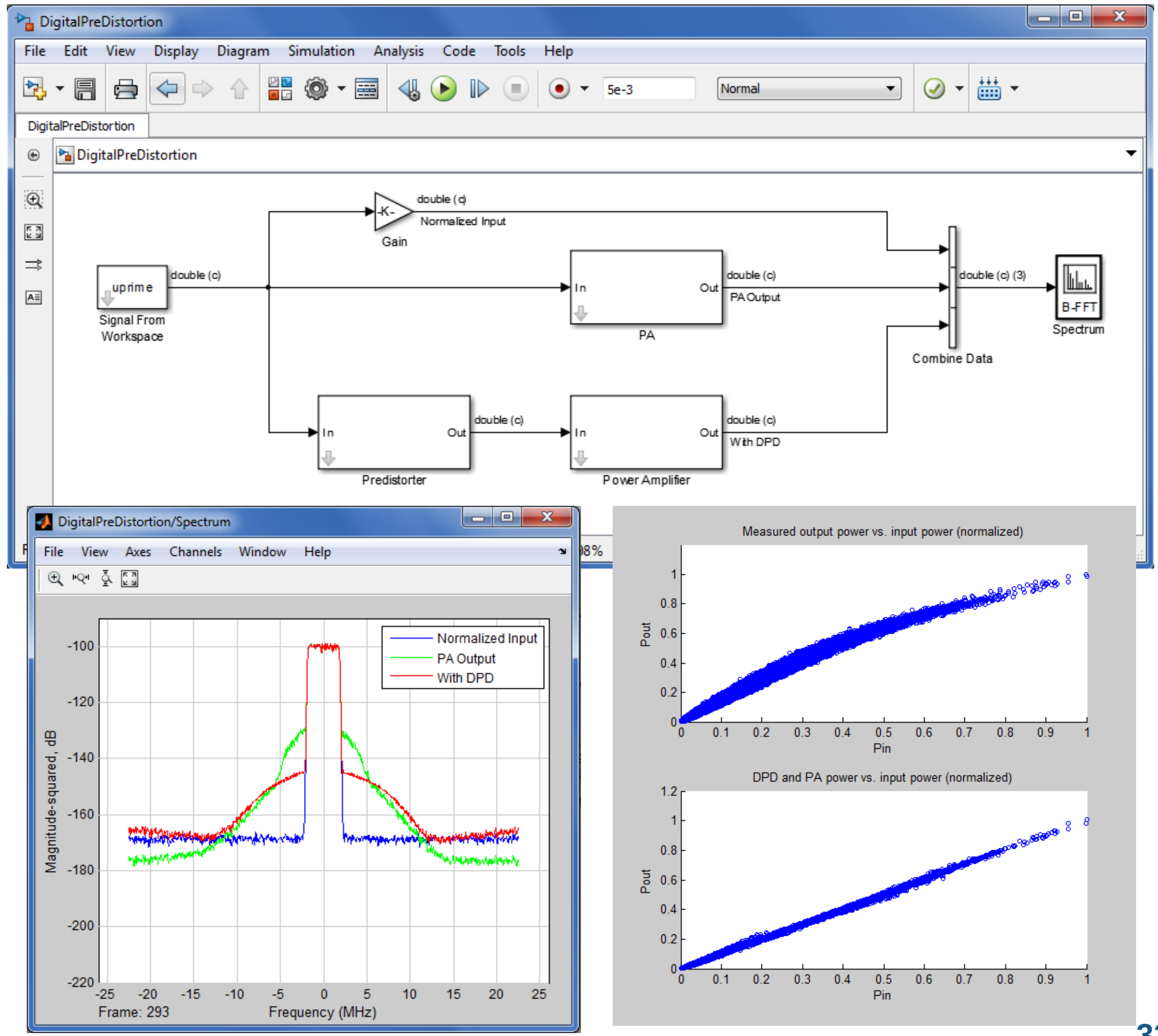
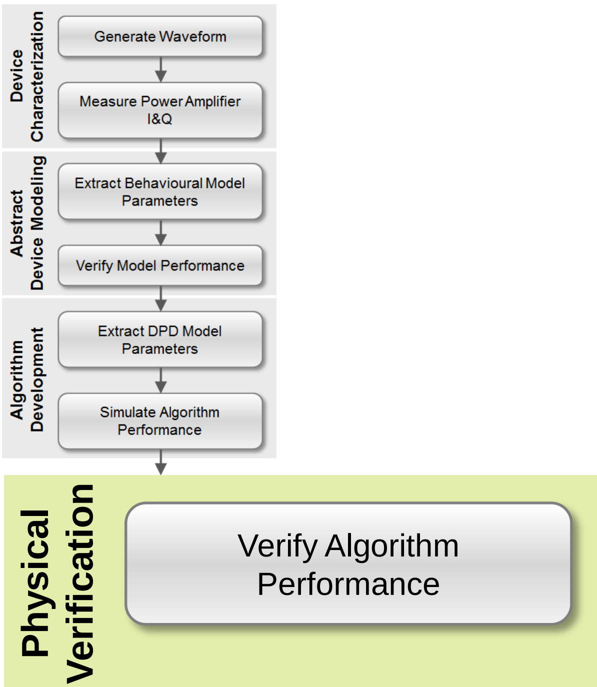
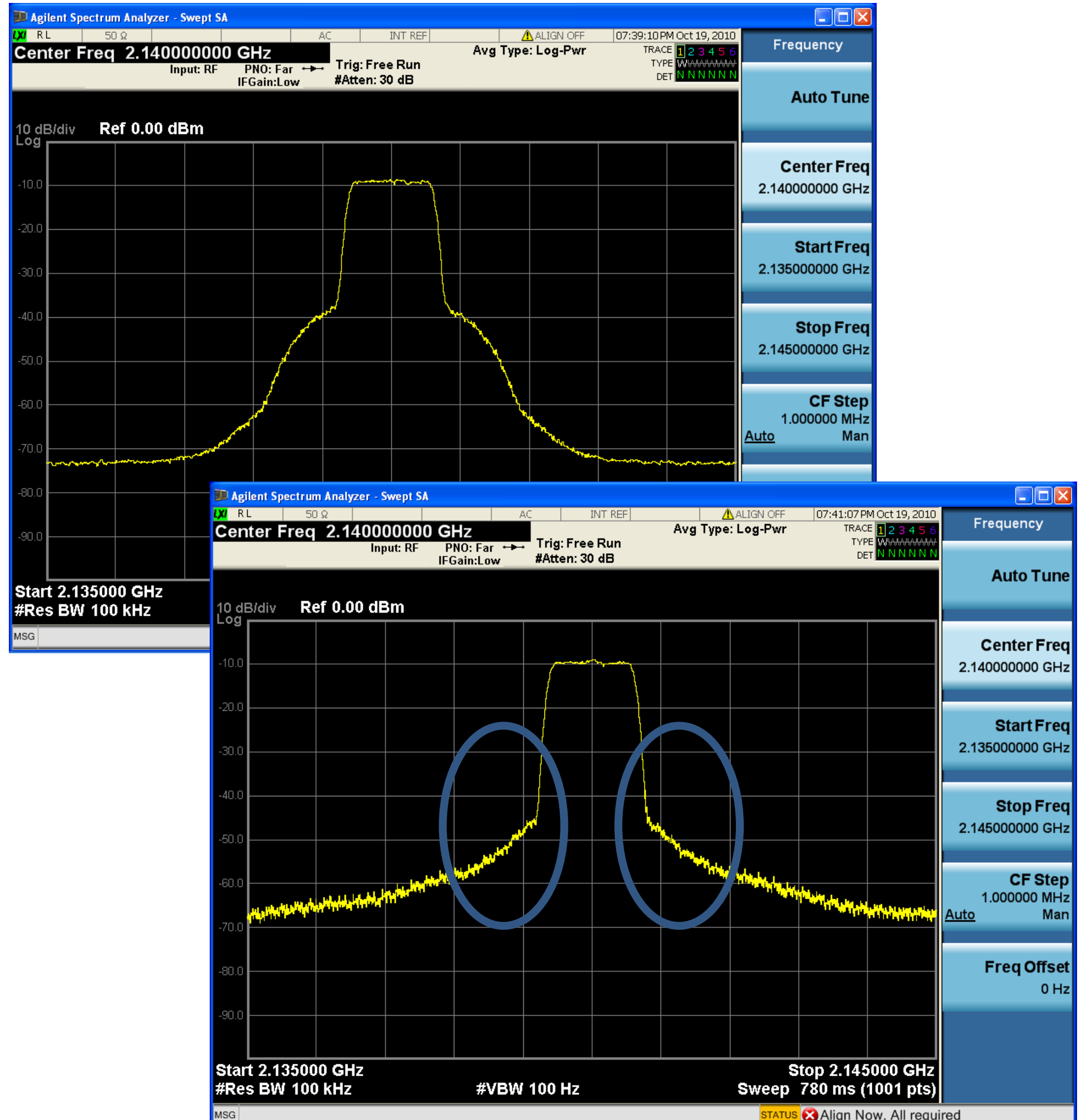


- Time-based simulation model



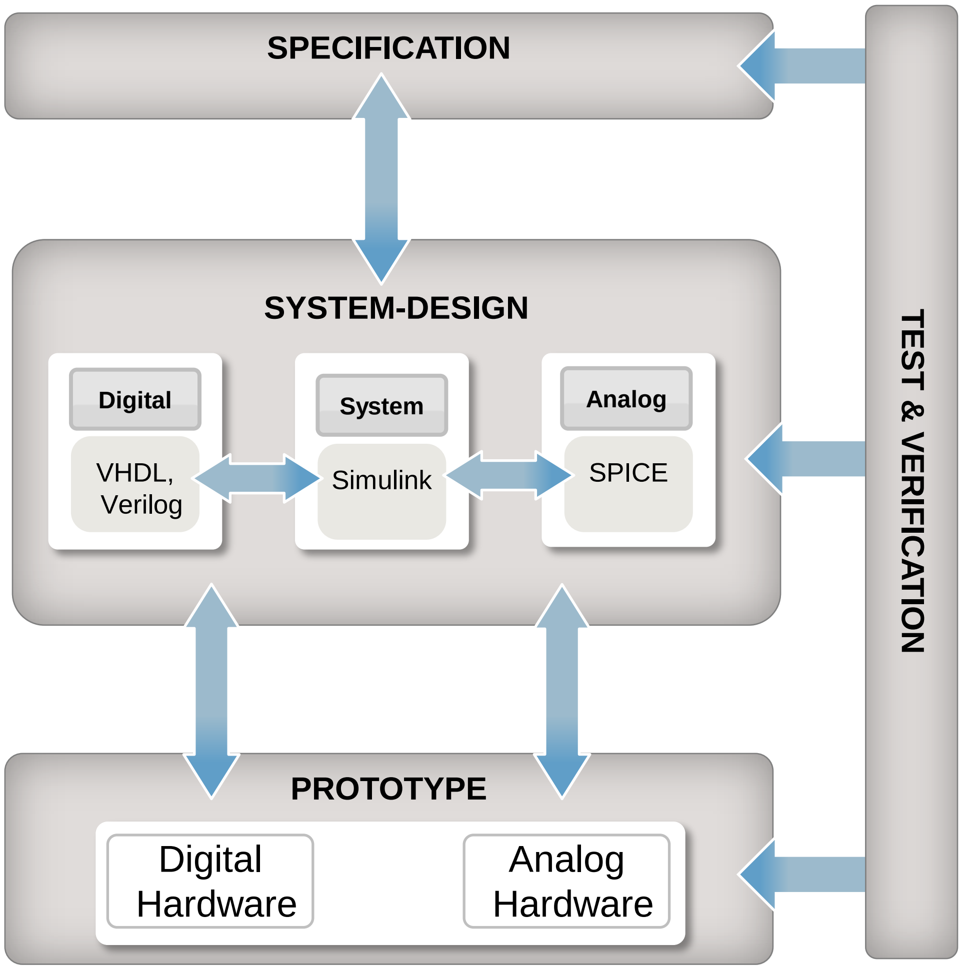
HW-based Algorithm Verification





Summary

Model-Based Mixed-Signal Design



- Design & simulation speed
  - rapid construction
  - design abstractions
- Design links
  - multiple domains (analog, digital, …)
  - multiple tools (ModelSim, Spectre…)
  - specification and verification
  - system-level and test equipment

Products mentioned

Product name	What it does
MATLAB	Algorithms, analysis, visualization
Simulink	System simulation and design
SimPowerSystems	Behavioral circuit models
Instrument Control Toolbox	Linking behavioral models to test & measurement
HDL Verifier	Co-simulation link to 3rd party HDL simulators (e.g. Mentor Graphics ModelSim, Questa ADMS, Cadence Incisive)

Some customers…

Customer	Use case
Atmel	RF Front End for DVB Analog-digital co-design and verification
IDT-Newave	Audio chipset Rapid simulation of PLLs
Realtek	Voiceband codec Analog-digital design
RFMD	Video transceiver System-level/SPICE cosimulation
Fujitsu	40 Gbit/s Serdes Rapid system simulation

More Information

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- Mixed-Signal Library:
  http://www.mathworks.de/programs/mixed-signal/
- Contact us:
  - contact@MathWorks.de
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Questions?

Thank you!