MathWorks

MATLAB&SIMULINK

# Signal Processing and Communications with MATLAB and Simulink

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# Key Takeaways

- Quickly analyze and develop new algorithms with MATLAB
- Accurate system-level multi-domain analysis with Simulink
- With MATLAB and Simulink you can quickly design entire systems with better performance

# Motivations

- Quickly analyze and develop new algorithms with MATLAB

**>> Evaluating innovative ideas is time-consuming**

- Accurate system-level multi-domain analysis with Simulink

**>> Modeling implementation constraints requires specific knowledge**

- With MATLAB and Simulink you can quickly design entire systems with better performance

**>> Optimizing the tradeoff between reuse and innovation is challenging**

# MATLAB for Signal Processing

- Digital Filter Design
- Fixed-point in MATLAB
- … and more

# MATLAB for Signal Processing: What's New

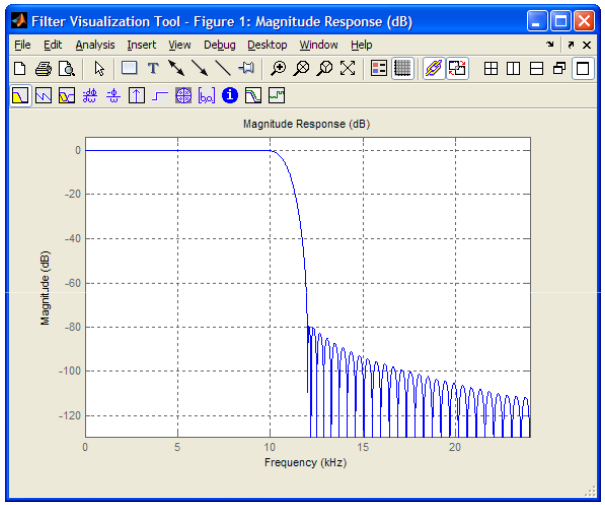
- **Multirate** Digital Filter Design
- Fixed-point in MATLAB **for streaming applications**
- **… and more**

# Challenges: Digital Filter Design

- During design:
  - Is it meeting the specs?
- During implementation:
  - How can I minimize cost?
  - Which filter structure will be optimal?
  - Will it work correctly on the target hardware?
  - What can I trade off?

# Digital Filter Design in MATLAB

- Design FIR and IIR filters
  - Many frequency responses
  - Optimized design methods
- Implement filters using various filter architectures
- Visualize filter response
- Export MATLAB filters into Simulink for system-level simulation



# Digital Filter Design Tradeoffs

DEMO

- Example: high speed, low pass decimation filter

**Specifications:**

Input sampling freq = 88.4kHz

Output sampling freq = 11.05kHz

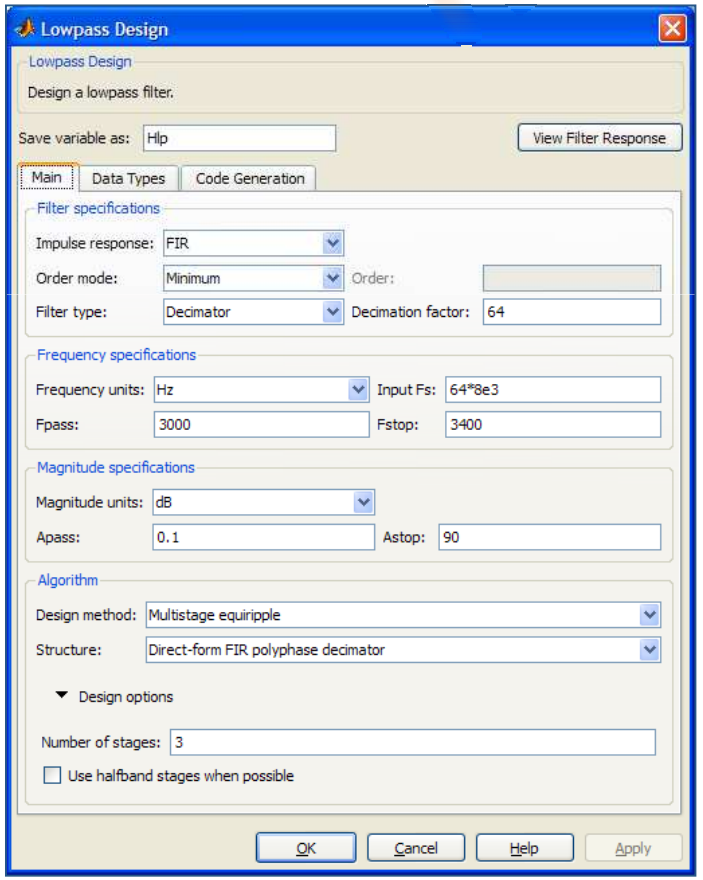
Decimation factor = 8

Passband ripple = 0.1dB

Stopband attenuation = 90dB

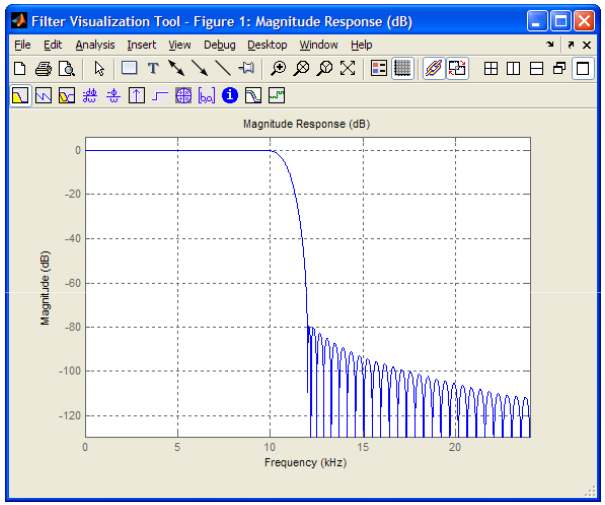
Passband = 3000Hz

Stopband = 3200Hz



# Takeaways: Digital Filter Design in MATLAB

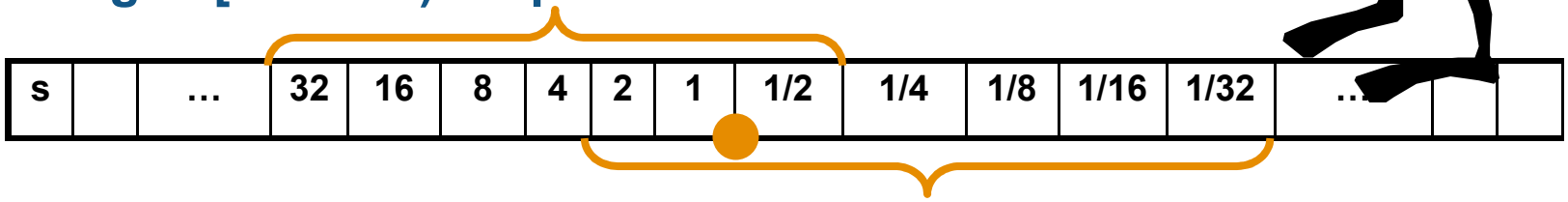
- Different filter responses
- Many optimized design methods
- Control of the filter architecture
- Evaluation of tradeoffs between performances, costs and specs
- Automation of the design process
- Rapid design iterations
- Visualization of filter characteristics



# Challenges: Fixed-Point Design

- Dynamic analysis of data range
- Finite word length = quantization error
  - Overflow (overload distortion)
  - Underflow (granular noise)
- Algorithms supporting fixed-point data type

**7+1=8 bit: 7 word length & 1 fractional bit**
**Range =[-64 63.5) Step =1/2**




**7+1=8: 7 bit word length & 5 fractional bits Range =[-4 3.9688) Step = 1/32**

# MATLAB for Fixed-Point

- Represent fixed-point data type
- Analyze quantization effects
  - Built-in logging and visualizations
- Accelerate execution of fixed-point code
- System objects for more fixed-point functions

# New in R2010a: System Objects

- MATLAB objects that represent time-based and data-driven algorithms, sources, and sinks
- System objects enable streaming in MATLAB
- Support of fixed-point data type and automatic C code generation

- Made available by:
  - Signal Processing Blockset
  - Video and Image Processing Blockset
  - Communication Blockset

# MATLAB is Best at Batch Processing

*All the data*

*Work on all the data at once…*

*Deliver all at once*

# Many Systems Demand Stream Processing


*Incremental delivery*

- All the data is not available at once
  - Limited memory footprint
  - Real-time requirements
- Typical applications
  - Communications simulation
  - Audio / video processing
  - Data acquisition

# Example: Filtering of an Audio Stream

```
filename = 'dspafxf_8000.wav';
[audio Fs] = wavread(filename);
filt = fir1(40, 0.8, 'high');
audiofilt = filter(filt,1,audio);
wavplay(audiofilt,Fs);
```

# Filtering in MATLAB

```
filename = 'music.wav';
[audio Fs] = wavread(filename);
filt = fir1(40, 0.8, 'high');
audiofilt = filter(filt,1,audio);
wavplay(audiofilt,Fs);
```

Loads entire dataset into workspace

"audio" data uses more space than needed (double vs. uint16)

Must wait for all data to be processed before listening to results

Overall, code uses several copies of the audio dataset in memory

# Stream Processing in MATLAB Today

```
%% Streaming the MATLAB way
% set up initializations
filename = 'music.wav';
Fs = 8000;
info = mmfileinfo(filename);
num_samples = info.Duration*Fs;
frame_size = 40;
bLP = fir1(12, 0.8, 'low');
zLP = zeros(1,numel(bLP)-1);
output = zeros(1,num_samples);

%% Processing in the loop
index= 1;
while index < (num_samples-frame_size+1)
    data = wavread(filename,[index index+frame_size-1]);
    [datafilt, zLP] = filter(bLP,1,data,zLP);
    output(index:index+frame_size-1) = datafilt;
    index = index + frame_size;
end
wavplay(output,Fs);
```

Explicit state management requires programmer to manage details that should be implicit

Indexing is tedious and error prone

Need to maintain output buffer because `wavplay` requires all data before being called

# Stream Filtering with System Objects

```
%% Streaming with System Objects
% set up initializations
filename = 'music.wav';
hFilter = dsp.DigitalFilter;
hFilter.TransferFunction = 'FIR (all zeros)';
hFilter.Numerator = fir1(12, 0.8, 'low');
hAudioSource = dsp.AudioFileReader(filename,  ...
        'SamplesPerFrame',40, 'OutputDataType','double');
hAudioOut = dsp.AudioPlayer('SampleRate', 11050);

%% Processing in the loop
while ~isDone(hAudioSource)
    data     = step(hAudioSource);
    datafilt = step(hFilter, data);
    step(hAudioOut, datafilt);
end
```

Initialize objects before use

Many ways to set object properties

Source and FIR filter states are implicit

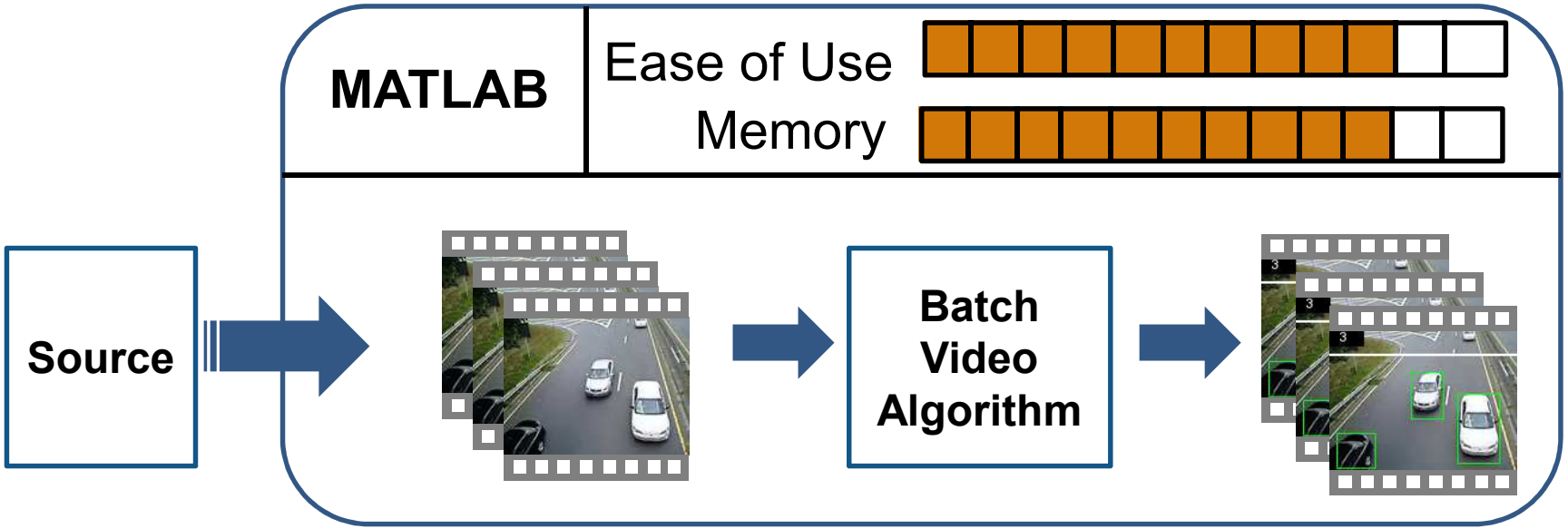
Audio player runs in-the-loop with the current frame, avoiding lengthy buffer

No management of indexing

"In-the-loop" code is much simpler

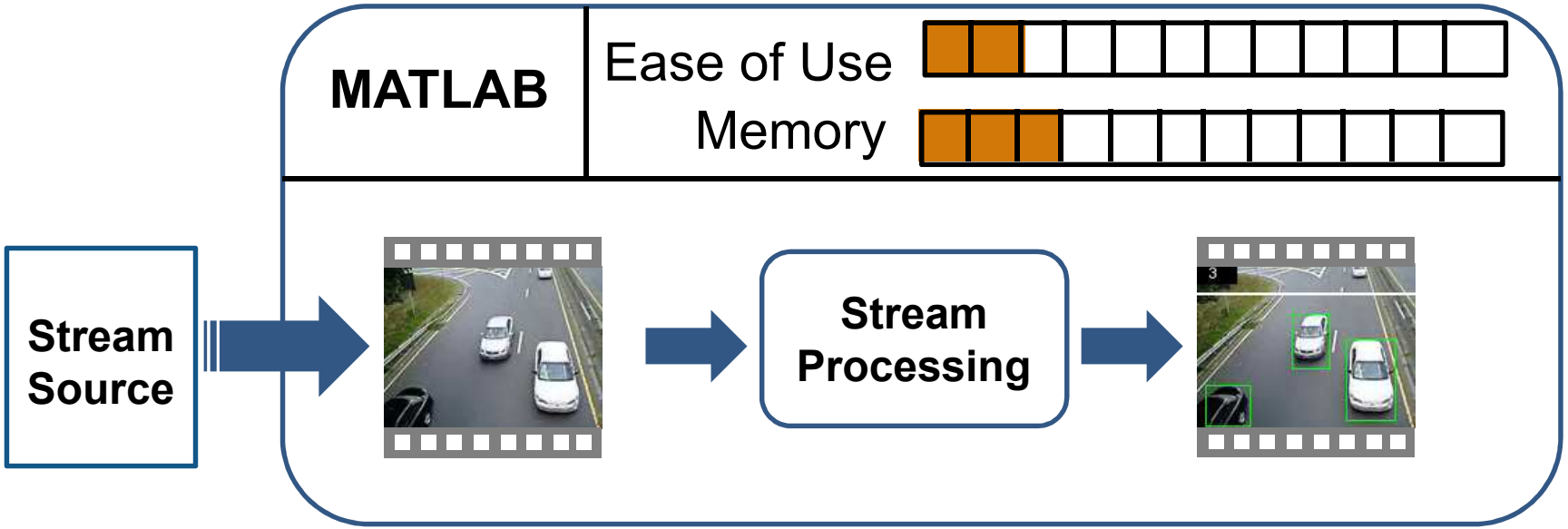
# Batch Processing

- Load the entire video file and process it all at once



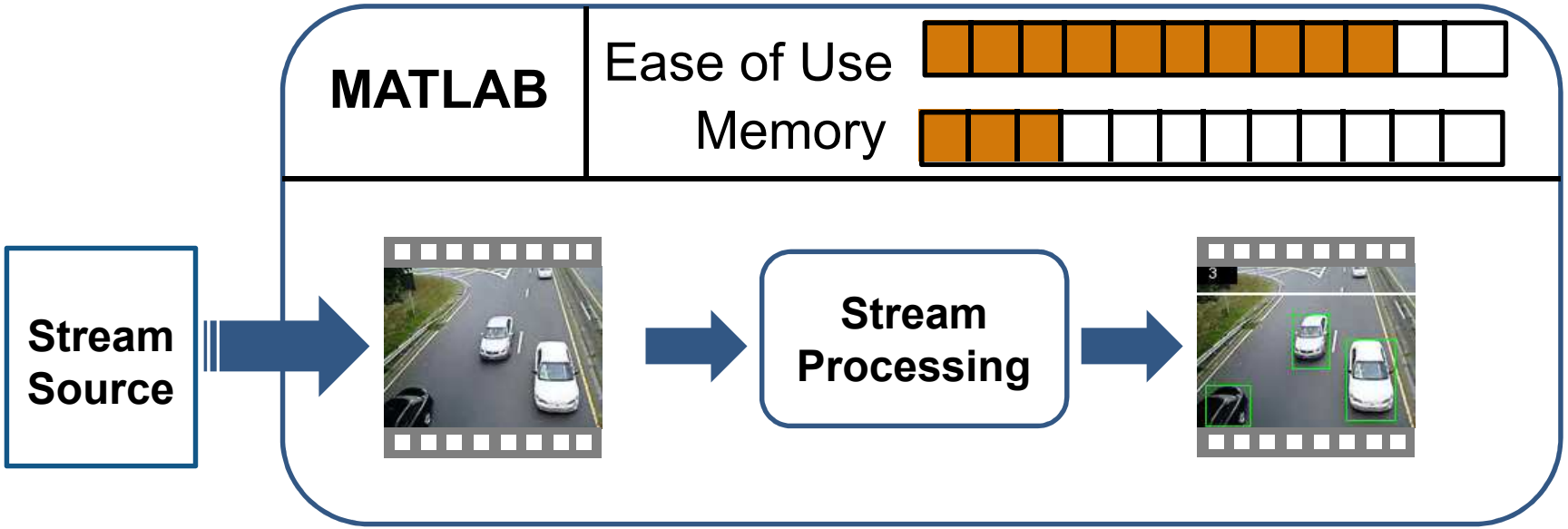
# Traditional Stream Processing in MATLAB

- Load a video frame and process it before moving on to the next frame
- Manually maintain indexing, buffering, states



# Stream Processing with System Objects

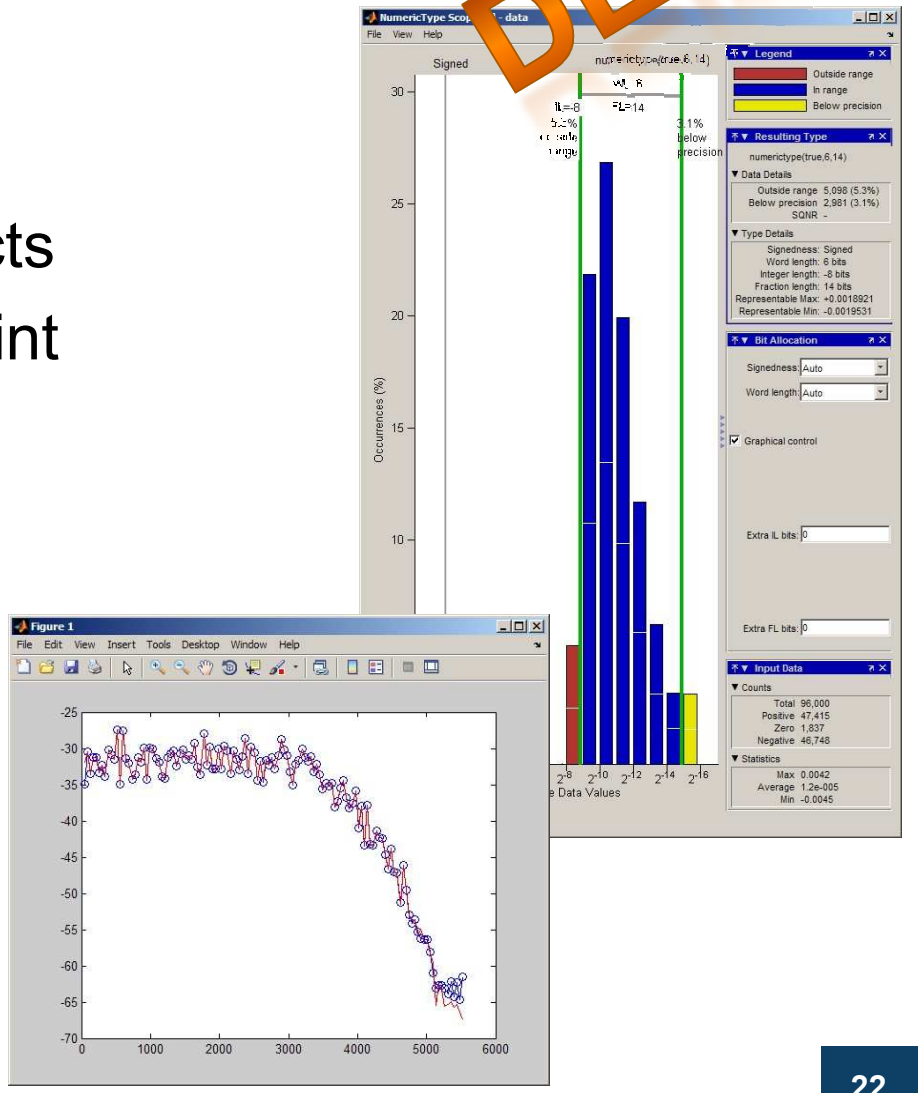
- Load a video frame and process it before moving on to the next frame
- Implicit indexing, buffering, handling of states



# Fixed-Point Algorithms in MATLAB

DEMO

- Represent fixed-point data types in MATLAB as ‘fi’ objects
- Run simulation in floating-point or fixed-point modes using data type override
- Log min, max and overflow



# Takeaways: Fixed-Point System Objects

- Stream processing in MATLAB
  - Easier to write and be correct the first time
  - Improves handling of large data sets
- Fixed-point modeling
  - All relevant objects support fixed-point data types
  - Compatible with Fixed-Point Toolbox
- C-code generation
  - Most objects support code generation using EMLC
  - Compatible with Embedded MATLAB

# Simulink for Signal Processing

- Systems with complex timing
- System-level simulation
- … and more

# Simulink for Signal Processing: What's New

- **Mixed-signal** systems with complex timing
- System-level simulation **including RF**
- **… and more**

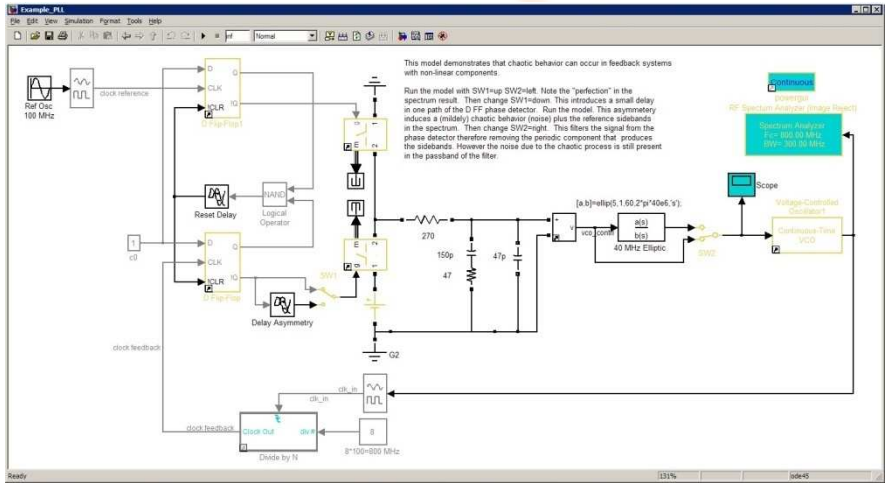
# Challenges: Mixed-Signal Systems

- Anticipate physical constraints
  - Analog and digital electronics
- Complex timing:
  - Continuous and discrete timing
  - Feedback loops
  - Threshold crossing
  - Asynchronous behavior
  - Concurrent paths

# Mixed-Signal Modeling with Simulink

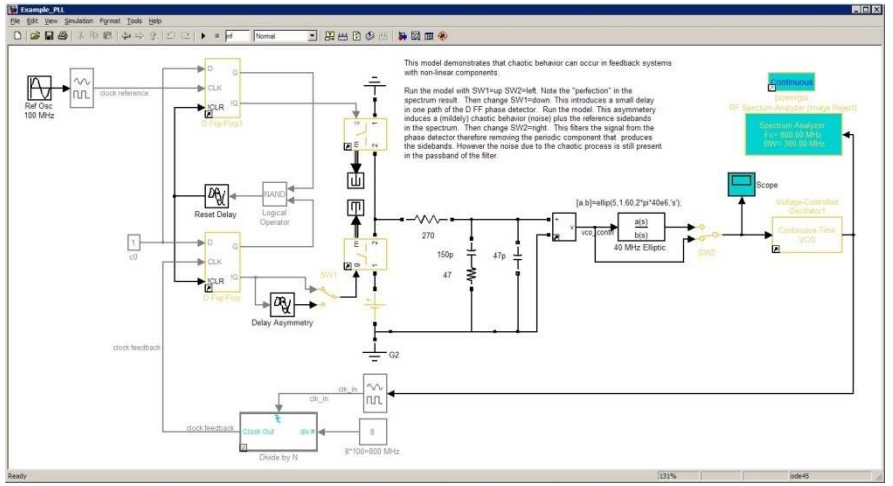
DEMO

- Design embedded systems:
  - Use the most suitable modeling approach
  - Anticipate physical impairments (mixed-signal)
  - Define the system architecture
- Verify embedded systems:
  - Analyze close-loop behavior



# Takeaways: Mixed-Signal Simulation

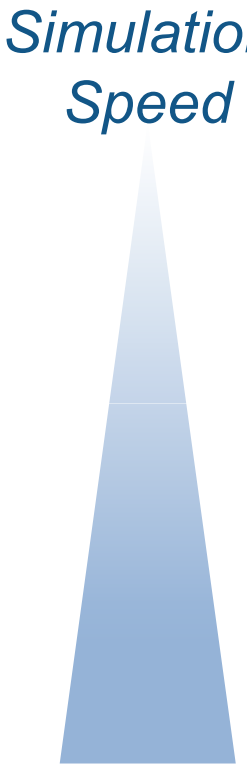
- Simulation of continuous and discrete signals
- Multi-rate digital signals with arbitrary sample rates
- Complex timing
  - Built-in notion of concurrency
  - Detect zero-crossings and discontinuities
  - Enable feedback loops
  - Asynchronously triggered blocks
- Share the MATLAB workspace

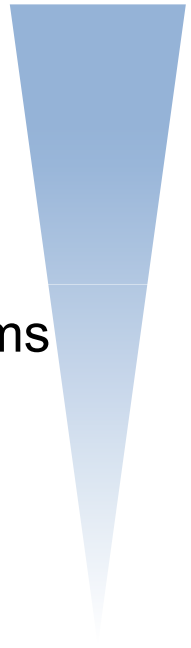


# Challenges: RF System-Level Simulation

- Model RF front-ends:
  - Without being an expert
  - With acceptable simulation speed
- Integrate baseband and RF simulation
  - Develop a system-level view

# New in R2010b: SimRF




- Circuit envelope analysis
  - Multi-carrier systems and arbitrary architectures
- Equivalent baseband models
  - Single carrier super-heterodyne cascaded systems (former RF Blockset technology)
- Complex baseband models
  - Mathematical analytical models

# Former RF Blockset Technology

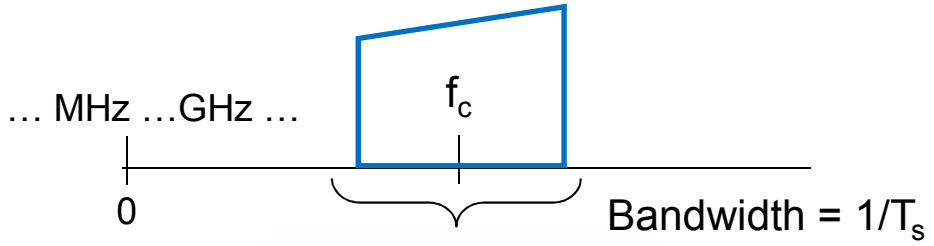
## Single carrier simulation of cascaded RF systems

- Linear elements are modeled with baseband-complex equivalent descriptions
- Nonlinear elements are described by means of (static) AM/AM – AM/PM characteristics
- Elements are cascaded for **fast single carrier simulations** in the time domain

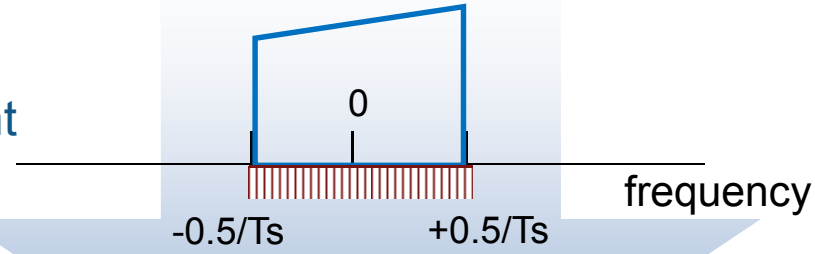
# Modeling Paradigm: RF Blockset

## From passband-real signal to baseband-complex equivalent signal

Pass-band transfer function

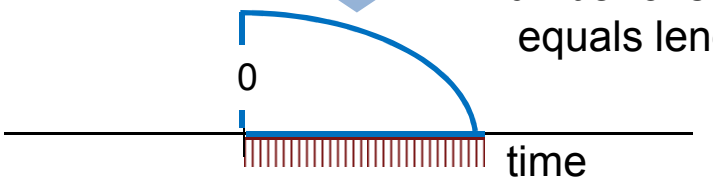



Baseband-complex equivalent transfer function




RF Blockset

Baseband equivalent time-domain impulse response




Number of sub bands (freq. resolution) equals length of impulse response

# New SimRF Technology

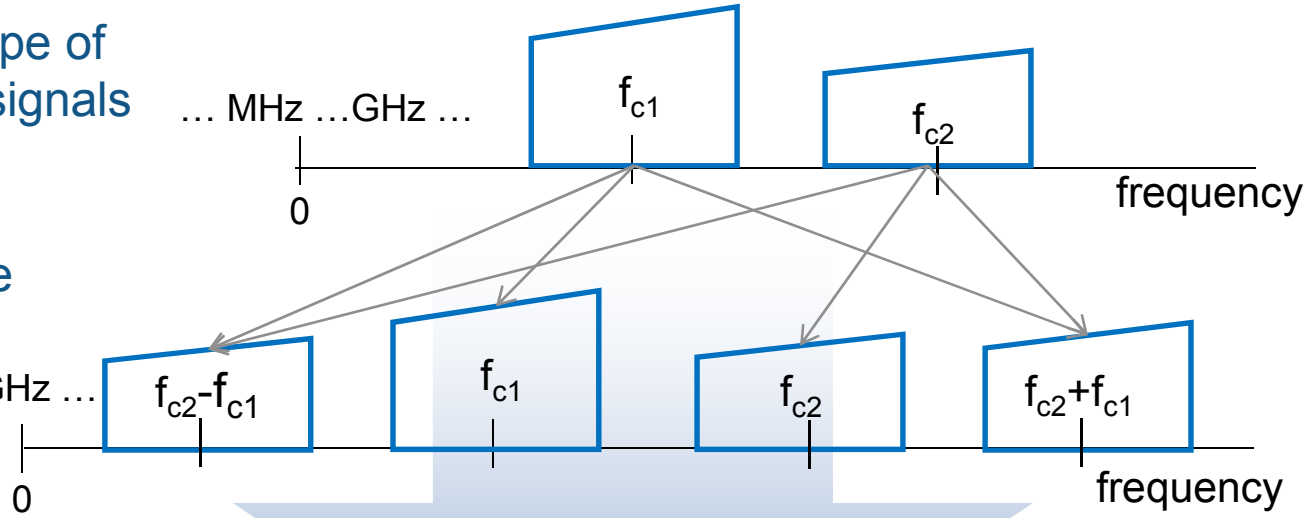
## Multi-carrier simulation for arbitrary topology of RF systems

- Use circuit-envelope analysis for multi-carrier linear and non-linear elements
  - Extend in band analysis to multiple bands
- Based on Simscape to model networks of physical components
  - Possibility to build arbitrary topologies
  - Possibility to probe within the network
- Enables extended **interferers and spurs analysis** at system-level

# Simulation Paradigm: SimRF

## Envelope analysis of the modulations centered on multiple carriers

Complex envelope of modulated input signals

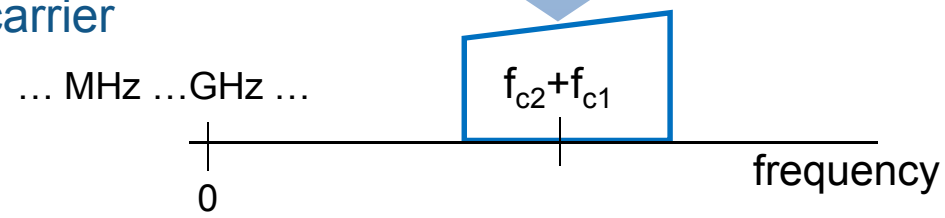



Circuit-envelope analysis




SimRF

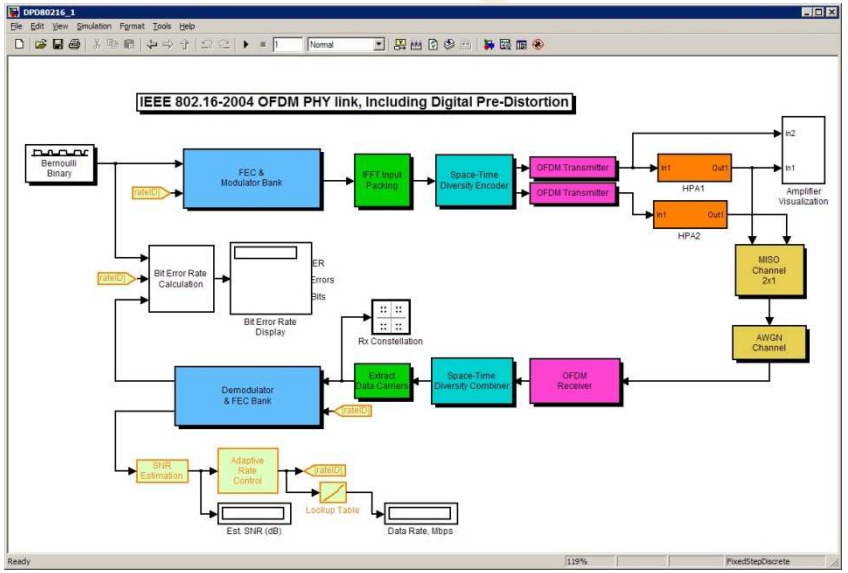
Complex envelope response around selected carrier



# RF Modeling with Simulink

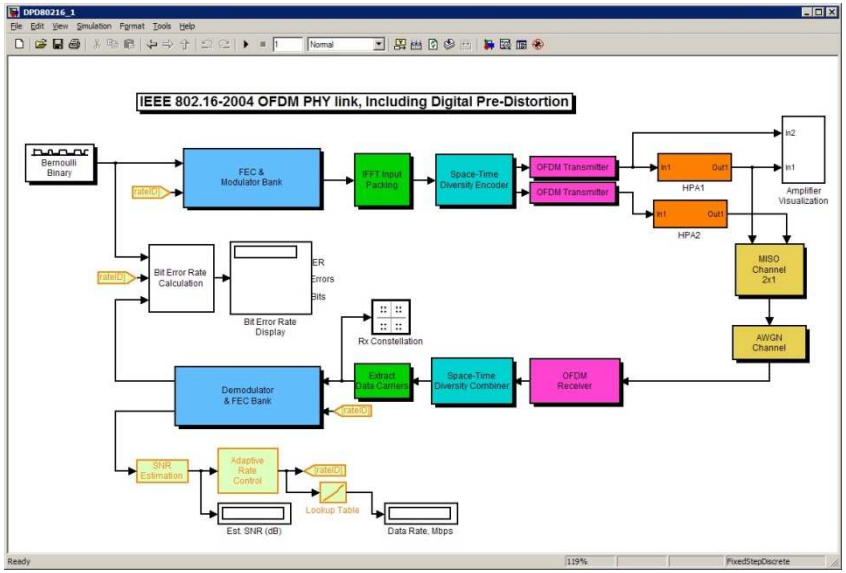
DEMO

- Design embedded systems:
  - Use the best modeling approach
  - Anticipate physical impairments (RF)
  - Define the system hierarchy
- Verify embedded systems:
  - Analyze results in streaming conditions
  - Evaluate system-level performances



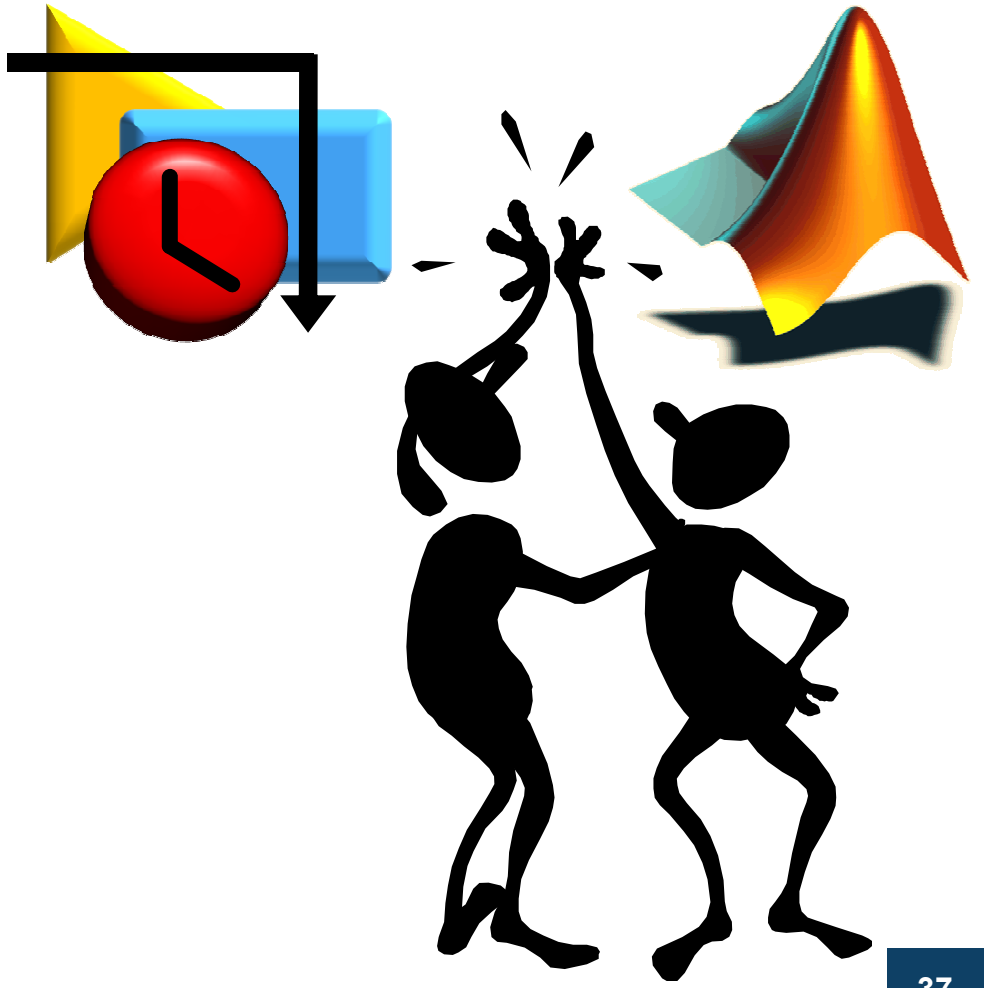
# Takeaways: RF Modeling with Simulink

- Complex hierarchical model description
- Streaming capabilities with frame-based processing
  - Make use of MATLAB for matrix processing
- Use Embedded MATLAB
  - Increase expressivity
  - Use of legacy-code



# Design and Implement Signal Processing Systems with MATLAB and Simulink

- Algorithm design
- Fast simulation
- Architecture exploration
- Targeting implementation
- Verification and testing
- Rapid prototyping



# Conclusions

- Quickly analyze and develop new algorithms with MATLAB
- Accurate system-level multi-domain analysis with Simulink
- With MATLAB and Simulink you can quickly design entire systems with better performance