Memory Effects in RF Circuits

Manifestation and Simulation

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June 7, 2011
Agenda

Opening Comments
Definition of Memory Effects
Manifestations of Memory Effects in Circuits
Simulation Challenges Posed by Circuit Memory
Simulation Techniques for Modulated Waveforms
Circuit Simulation Examples
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  • Receiver
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Memory Effects Defined

Memory effects are non-noise circuit characteristics which cannot be described by the steady-state nonlinear transfer function of the circuit.

- Filtering effects
- Delay effects
- Hysteretic effects

Memory effects make it difficult to predict circuit response to modulated waveforms based upon steady-state characteristics.

We will group memory effects by time-constant magnitude:

- “Baseband” memory effects tend to have long time constants
- “Inband” memory effects tend to have short time constants
Manifestations of Memory Effects in Circuits

Some examples

• Multiple time-constant memory effects

- Thermal effects
- Trapping effects
- Biasing circuits
- AGC loops
- DC offset correction
- Matching networks (group delay)
- Band filtering
- Transistors (transit time)
- Long time-constant memory ~µs to ms
- Short time-constant memory ~ns

Baseband Memory Effects

Inband Memory Effects

Nonlinear Coupling
Manifestations of Memory Effects in Circuits
Low Noise Amplifiers

Many Low Noise Amplifiers (LNAs) are typically wideband structures having little or no memory effects. However, some LNAs will exhibit strong memory effects.

- Automatic Gain-Control (AGC) circuitry can have important memory characteristics.
- Some LNA circuits use complex biasing schemes which add memory effects to the function of the LNA.
Power amplifiers are often intentionally DESIGNED to have strong memory effects in order to improve output power and linearity and limit out-of-band emissions.

- Matching networks can perform functions at harmonic frequencies which result in memory effects.
- Baseband circuits are typically strongly band-limited to minimize intermodulation distortion.
Manifestations of Memory Effects in Circuits Receivers

Receivers typically include baseband circuitry which produce strong memory effects.

- DC offset correction (DCOC) circuitry are used in zero- and low-IF structures to help take full advantage of the dynamic range of the A/D converter. This circuit has strong memory effects.
- Baseband filtering often strongly limits the bandwidth of the baseband circuits.
- Automatic Gain- and/or Level-Control (AGC and/or ALC) circuitry can also have important memory characteristics.
Manifestations of Memory Effects in Circuits
Transmitters

With the exception of the PA portion, many transmitters do not contain strong memory effects. However, some do:

- Baseband filtering is included in some transmitters to reduce the emission of noise or other spurious signals.
- Automatic Level-Control (ALC) circuitry may introduce memory effects.
Manifestations of Memory Effects in Circuits
How can you detect them with a steady-state solver?

- You typically need to sweep frequency to see these effects.
- Here is an example of what you might see for an amplifier:

**Some inband effects can be seen by sweeping a single tone in a steady-state simulation**

**Some baseband effects can be seen by sweeping the difference between two tones in a steady-state simulation**

Input power (dBm) vs. Gain (dB)

- Wrapping

Output C/IM3 ratio (dB) vs. Tone spacing (MHz)

- Resonance
Simulation Challenges Posed by Circuit Memory
Why are we here?

Most radio circuit design analysis today is performed using sinusoidal or other steady-state stimuli.

- Measurement equipment also often uses periodic waveforms to characterize circuitry.

Communication is not possible using steady-state signals.

- Most modern radios use complex digitally-modulated waveforms to carry information.
Transient simulation techniques can be used to analyze any circuit with any type of modulation.

- Transient simulation times are too long for this approach to be useful except for the simplest cases.
  - Amplifiers? Maybe
  - Receivers? Not likely

- Improving accuracy in transient simulation often entails a significant slowdown in performance.

Envelope transient techniques can offer significant speedups over transient.

- Through an approach which combines transient and harmonic balance techniques, envelop transient can greatly speed simulation with modulated waveforms.
Simulation Techniques for Modulated Waveforms
Some Target Figures-of-Merit for Envelope Transient

Prediction of ACPR

EVM

Trajectories / Constellations

And more…

Eye Diagram
Bit Error Rate
Simulation Techniques for Modulated Waveforms
But there are STILL a couple of problems…

Envelope transient, though faster than transient, is still often too slow to meet the needs of designers.

- Fast envelope transient techniques have been developed in order to help resolve this situation.
  - These techniques typically involve characterizing the entire circuit using a steady-state solver.
  - This characterization is then used to quickly analyze the circuit with modulated waveforms.

Sometimes it is necessary to use behavioral models for portions of the circuit.

- Parts of the circuit may come from a third party who is unwilling or unable to share design details.
- Various parts of the circuit may be described using incompatible formats.
- The circuit may be too large to fit on a computer using transistor-level views of all components.

But circuit memory effects make creation of accurate models using steady-state analysis VERY DIFFICULT!
Simulation Techniques for Modulated Waveforms
Two Main Types of Envelope Behavioral Models

Memoryless model:

- Use a steady-state solver to calculate AM-AM and AM-PM characteristics for the circuit for the fundamental and harmonics at the center of the band and at various power levels.
- Interpolate within this result to estimate the response of the circuit to a time-varying stimulus.

Model with memory effects:

- Modeling memory effects requires more and different types of characterization of the circuit than creating a memoryless model.
- Inband and baseband effects are handled differently due to the fact that they are quite different phenomena.
Simulation Techniques for Modulated Waveforms
Memoryless Fast Envelope Limitation

- Each AM/AM AM/PM is identified at the center $f_{CENTER}$ of the modulation bandwidth

Memory effects not taken into account.

Please note that MANY circuits CAN be accurately modeled without memory!!

Pass-band Filter

Real Behavior

Interpretation made by memoryless models

Memoryless models will provide a signal which did not have undergone any filtering effects
Circuit Simulation Examples
Power Amplifier

Circuit Description:
- 20 MOS devices
- Contains 25-port S-parameter block
- Linear gain: 31 dB
Circuit Simulation Examples
power Amplifier - “Memory Effects Map”

Inband Memory Effects Plot

Baseband Memory Effects Plot
Circuit Simulation Examples
Power Amplifier – Output Spectrum Comparison

RED – Normal Envelop Transient  GREEN – Memoryless Model  BLUE – Model with Memory
Circuit Simulation Examples
Power Amplifier – Power Gain Comparison

RED – Normal Envelop Transient  GREEN – Memoryless Model  BLUE – Model with Memory
Circuit Simulation Examples
Power Amplifier – ACPR Comparison

RED – Normal Envelop Transient  GREEN – Memoryless Model  BLUE – Model with Memory
Circuit Simulation Examples
Power Amplifier – Performance Comparison

<table>
<thead>
<tr>
<th>Method Used</th>
<th>Accurate?</th>
<th>Model Time</th>
<th>Sim Time</th>
<th>Sim Speedup</th>
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• For a memoryless circuits, ALL envelope transient approaches covered give correct results.
  – It is important to verify that the circuit is memoryless by verifying the results against normal envelope simulation.
• In this case, the memoryless model is the most efficient since it requires the fewest simulations to complete.
Circuit Simulation Examples
Receiver

Circuit Description:
- 946 MOS devices
- Contains 12-port S-parameter block
- Frequency: 2.4 GHz
- Output: Zero-IF
- Linear gain: 40 dB
Circuit Simulation Examples
Receiver “Memory Effects Map”

Inband Memory Effects Plot
Due to the fact that this is a zero-IF receiver, there is no map for the “Inband” response.

Baseband Memory Effects Plot

![Baseband Memory Effects Plot](image_url)
Circuit Simulation Examples
Receiver – Output Spectrum Comparison

RED – Normal Envelop Transient  GREEN – Memoryless Model  BLUE – Model with Memory
## Circuit Simulation Examples
### Receiver – Performance Comparison

<table>
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<th>Accurate?</th>
<th>Model Time</th>
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<th>Sim Speedup</th>
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- For circuits with memory, a memoryless model can give very poor results.
  - It is important to verify that the results using the model with memory using normal envelope simulation.
- In this case, the behavioral model with memory is accurate but it is slower than regular envelope transient simulation. In many cases, it will be faster. Many factors will impact the speed.
Summary and Conclusion

Memory effects are circuit behaviors that defy modeling through standard steady-state characterization techniques.

• Inband memory effects have been differentiated from baseband memory effects based on their widely-differing time constants.
  – Different modeling techniques are used to characterize these two effects.
• Several examples of memory effects for various types of circuitry have been presented.
• Techniques for spotting circuit memory effects using a steady-state solver have been provided.
• Example simulations showing the limitations of memoryless models in the presence of memory effects have been given.

Conclusion: Proper understanding of these behaviors can help designers to understand when memoryless models can or cannot be used to evaluate the response of circuitry to modulated stimuli.
Questions and Answers

Questions?
Where do you go from here?

• Visit GoldenGate on the Web to sign up for a demonstration or evaluation.

• Download the GoldenGate Workshop and go through the example based on this Webcast.

• Contact your local Agilent EEsof field representative or George Estep, RF-MS Application Specialist
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Attend other RFIC Webcasts from Agilent EEsof EDA:
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