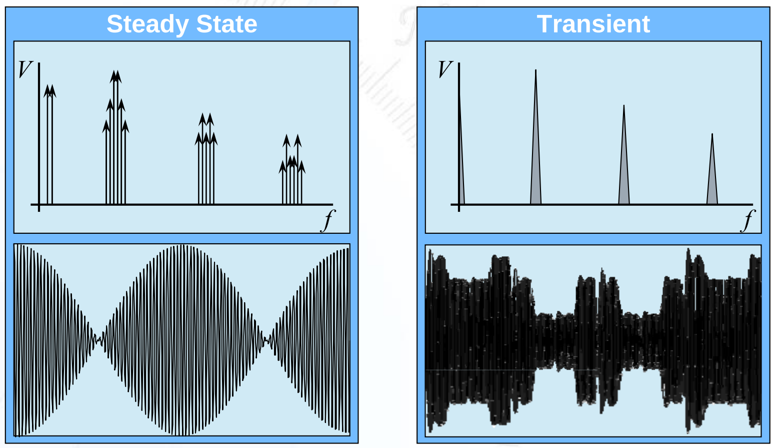
It has been 10 years since the first RF circuit simulator was released. It was SpectreRF, released in 1996, that was the first simulator to focus primarily on RF circuits (as evidenced by the name) and the first simulator to employ Krylov methods, which give it the capacity to handle RF circuits.

RF Simulators

- Exploit nature of RF circuits to run efficiently
  - Assume sparse spectrum, few harmonics



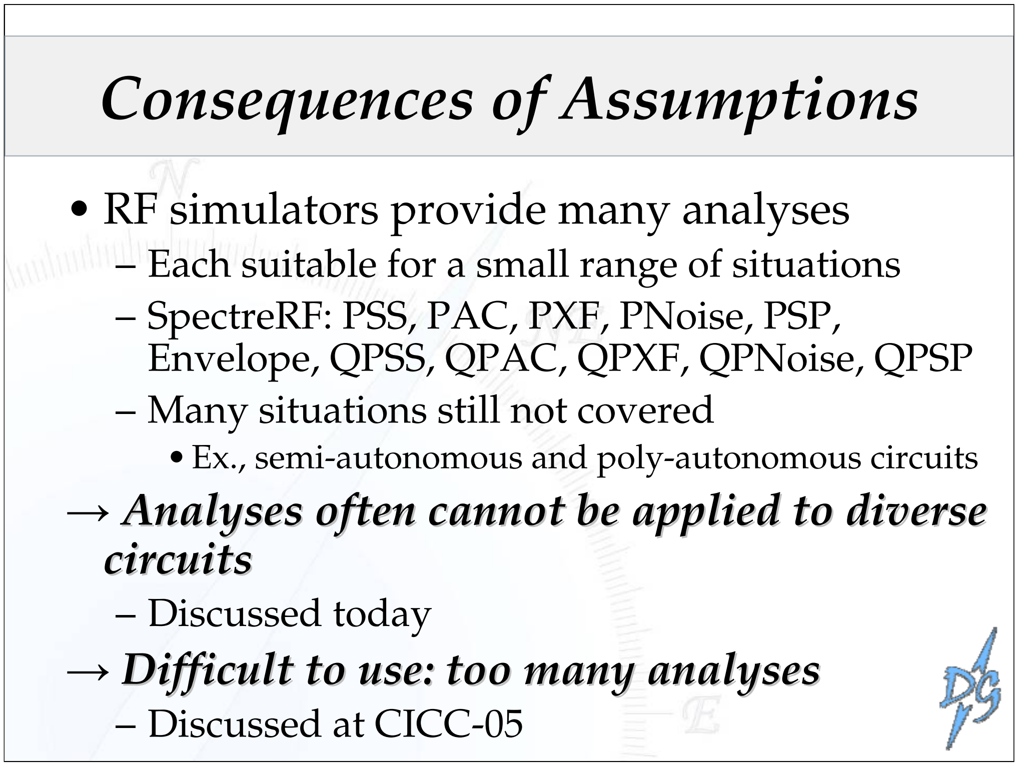
RF simulators answer questions that are either not practical or not possible to answer with general purpose simulators. They do this by exploiting certain characteristics of RF circuits, the most important being the relative sparsity in the spectrum of RF signals. However, these signals have markedly different characteristics, and so require different simulation techniques to produce results efficiently.

Assumptions of RF Simulators

- Only one type of signal present
  - Quasiperiodic with few fundamentals (≤ 3),
  - Or slowly modulated periodic carrier
- Small number of harmonics
- Small number of oscillator modes (≤ 1)
- Near-linear signal path
- No Verilog or VHDL
  - Purely transistor level
  - Verilog-A okay if no hidden state

Here are more details on the types of assumptions that must be satisfied for RF simulators to be efficient.

The point is that these assumptions are typically not satisfied by non-RF circuits. Some are mutually exclusive, so multiple analyses must be provided. Putting it another way, each analysis is only suitable for a subset of RF circuits.



As a natural consequence of these assumptions or constraints, an RF simulator must provide a collection of analyses, each of which would be applied in particular situations. SpectreRF, which certainly went a bit overboard, has 11 RF analyses at last count. But even if similar analyses were combined, there would still be at least 5 or 6.

This need for multiple analyses has two undesirable consequences.

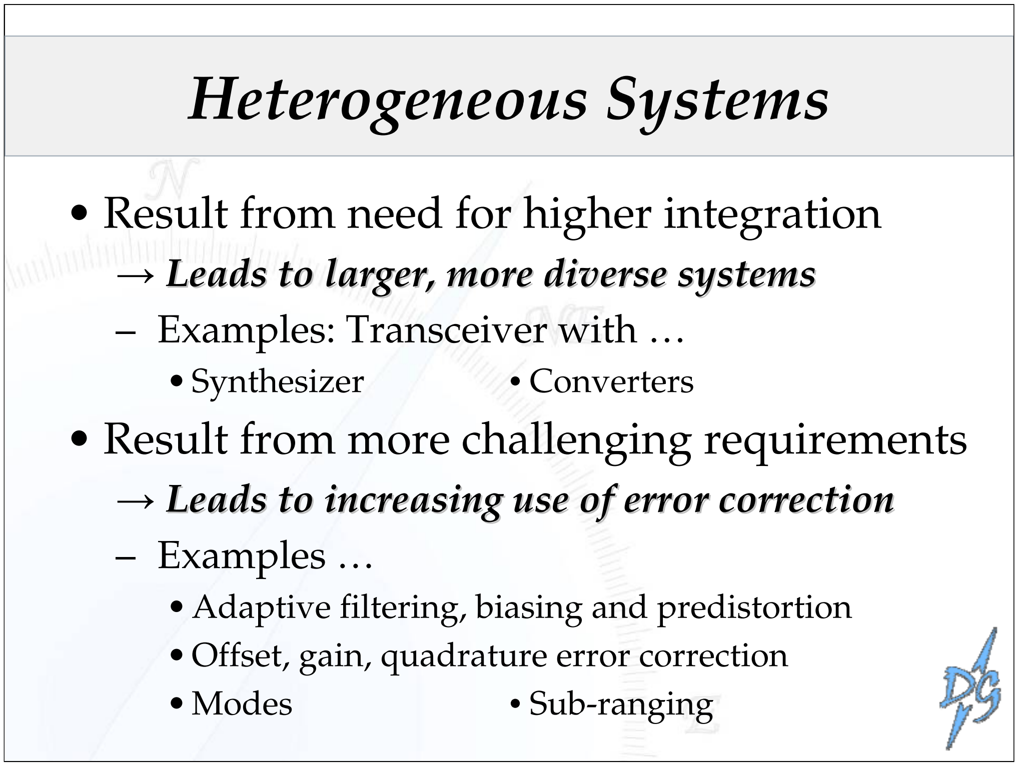
1. As circuits become larger and more diverse, it becomes more and more likely that a circuit cannot be analyzed by any RF analysis because for every analysis there is some part of the circuit that violates its assumptions.
2. Each analysis has an associated learning curve, and having a large number of analyses would cause the simulator to be hard to use. In fact, the more analyses, the more likely it is that a user is using an analysis poorly or not at all because they not as familiar with it as they should be.

This first topic is the issue that will be discussed today. The second topic will be discussed in an invited paper at CICC this year.

RF Simulators

- ✔ Work well on individual functional blocks
  - Amplifiers, mixers, oscillators, filters, etc.
  - Segments of RF signal path
- ✘ Work poorly on algorithmic blocks
  - ADC, DAC, PLL (frequency synthesizer)
  - Anything ΔΣ
- ✘ Work poorly on heterogeneous systems
  - Full transmitter or receiver
  - Digital calibration or adaptation

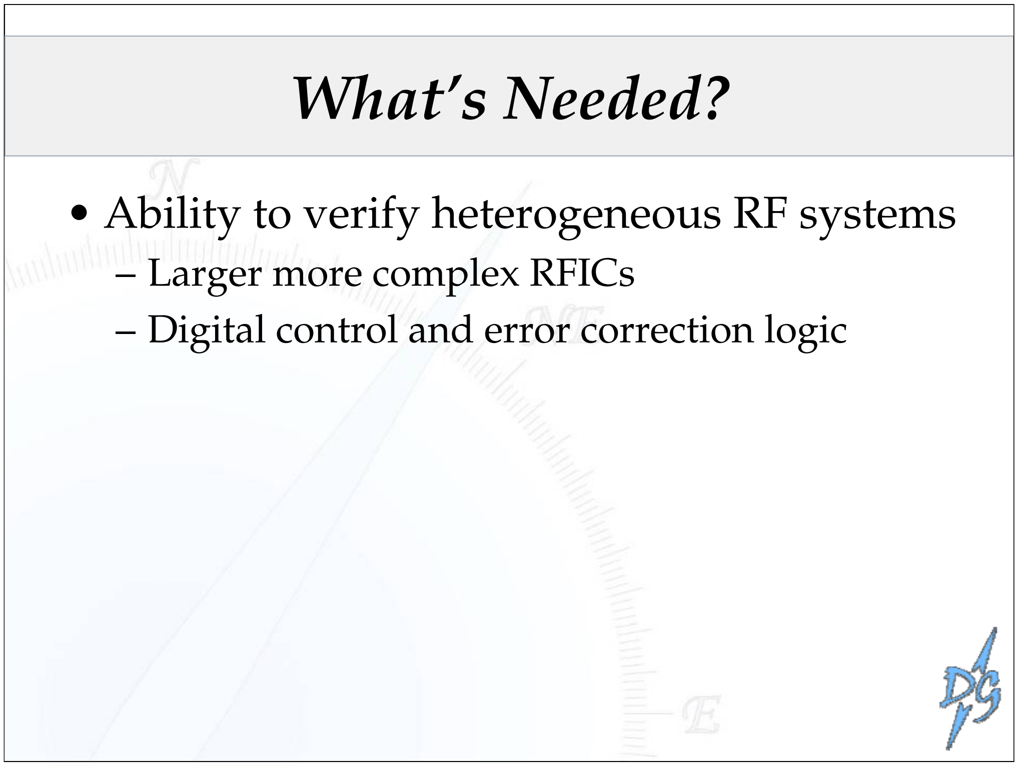
The conclusion of all this is that RF simulators can be expected to work well on individual functional blocks (amplifiers, mixers, oscillators, filters, etc.), or perhaps simple combinations of such blocks, such as fragments of an RF signal path. However, they do not work well on algorithmic blocks such as data converters, PLLs, or anything that involves delta-sigma modulation. They also do not work well on heterogeneous systems. Such systems are generally large, and include algorithmic blocks. Examples include a full transmitter or receiver, as it includes the frequency synthesizer and perhaps the data converters. It also includes circuits that incorporate digital calibration or adaptation as such circuits generally contain significant amounts of digital control logic.



The fact that RF simulators cannot be applied to heterogeneous systems is a huge bummer because such systems are becoming much more common.

Competitive pressures are driving the trend toward larger more integrated transceivers, which in turn is drives the need to analyze the larger, more diverse systems.

Advances in standards (3-G, 802.11g/n, etc.) are placing higher and higher demands on the performance of RF systems in order to provide the end users more features, capabilities and capacity. Designers are coming up with more sophisticated approaches to delivering that performance by exploiting relatively inexpensive digital transistors. A broad variety of techniques are being used, including adaptive filtering, biasing, gain and predistortion; offset, gain, quadrature and matching correction; sub-ranging, and increasing use of specialized modes, etc.



Going forward, there is a strong need to be able to simulate heterogeneous RF systems.

Given this need, what are our options?

•We can revert back to using SPICE class simulators, or their higher capacity cousins, the timing (or fast-SPICE) simulators. Unfortunately, timing simulators are marginal at best on RF circuits, and both types of simulator are simply too slow for verifying large complex RF circuits. In addition, many of the more interesting characteristics of RF circuits, such as noise, cannot be predicted using SPICE-like simulators.

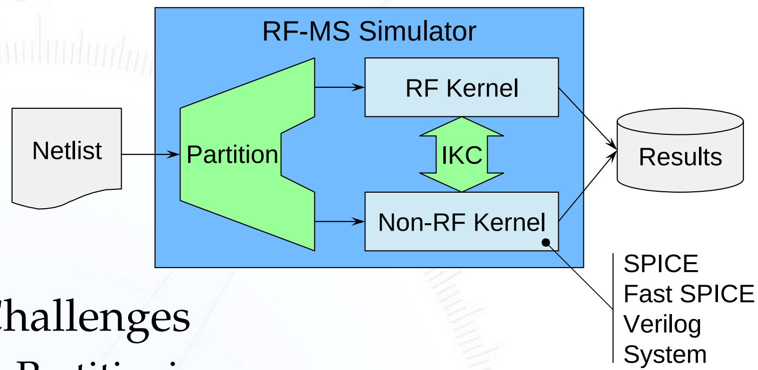
•We could develop more general RF algorithms, algorithms that can both provide the efficiency on RF circuits of the current RF simulators while also being able to efficiently handle a wide variety of other types of circuits. Unfortunately, there seems to be little to no effort being expended to develop such simulators, and there is nothing that will be available in the foreseeable future.

•There is co-simulation, where RF simulators are linked to other more flexible simulators, such as SPICE or AMS simulators. There are some very early version currently on the market, such as Ptolomy-ADS. However, such simulators will be difficult to develop, and even more difficult to make broadly applicable. Progress here is expected to be slow.

•The last option is macromodeling. Here designers develop models for the RF blocks, and then simulate those models along with high-level models of the rest of the system. Such models tend to be very hard to develop, limited, and fragile.

In summary, here are no satisfying options available.

Co-Simulation



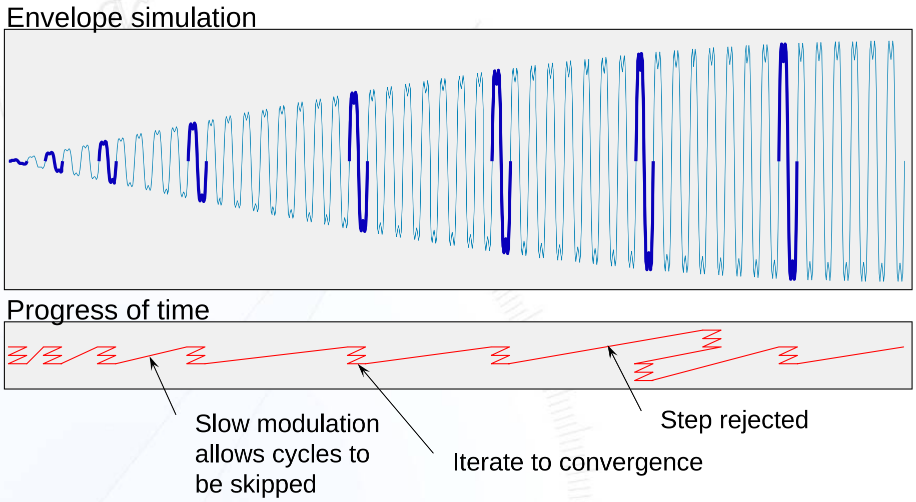
- Challenges
  - Partitioning
  - Synchronization & Inter-Kernel Communication (IKC)

A bit more on co-simulation …

Co-simulation is characterized by having an RF simulation kernel linked to another simulation kernel. This assumes that the circuit can be easily partitioned between the kernels, and that the kernels communicate in order to coordinate the simulation.

Any type of automatic partition would be very difficult if not impossible. And the synchronization and inter-kernel communication puts constraints on what kinds of simulations can be performed and how efficient they can be. They might also place requirements on the kernels that would be practically very difficult to achieve.

Envelope Simulation

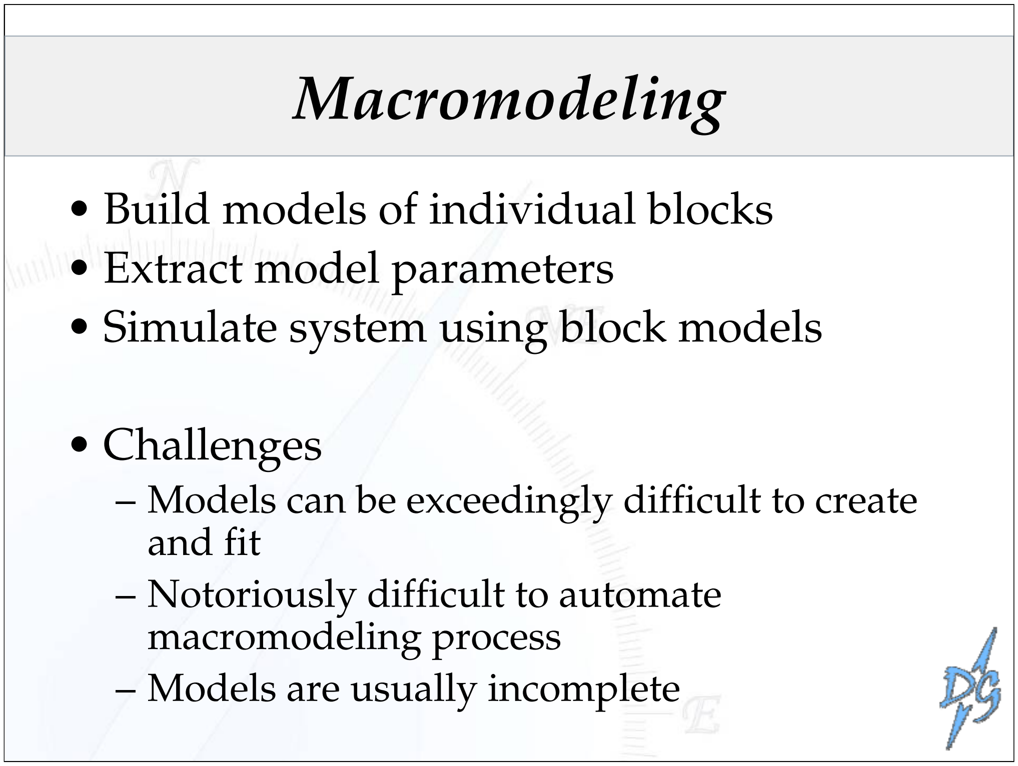


- Non-RF kernel must be able to back up one or more cycles
- What happens to ITC when envelope is skipping cycles

Envelope simulation would typically be used with co-simulation. Envelope simulation presents some difficult challenges for co-simulation.

One example is the need to back up. SPICE class simulators need the ability to try a time point, and reject it if the resulting error would be too large. RF simulators take this issue to another level. With envelope simulations, it is common to reject not just a single time point, but they often also reject a complete period's worth of time steps. Thus, the non-RF kernel would also need the ability to roll back time to a relatively distant point in the past. Many non-RF kernels are not equipped to do that or cannot do it efficiently.

Another issue is the inter-kernel communication (IKC) that occurs while the envelope simulators are skipping cycles. It might occur on every cycle if the non-RF kernel is providing the clock signal for the RF kernel. Thus, the effect of this IKC must be taken into account, but it also must done is such a way that the RF kernel is still able to skip cycles.



Macromodeling, if anything, is even more difficult to do than co-simulation. Here you would build models of individual blocks, either using an automatic process if it existed, or more likely, doing it by hand. Building the model by hand would involve pursuing complex and often laborious or fragile fitting procedures. Effective automated approaches are available for very specific types of block types whereas automated approaches that try to be very general are usually fragile or impractical.

The difficulty of building and extracting macromodels generally results in the model being incomplete or single-purpose.

Outlook

- Co-simulation and macromodeling are …
  - Promising but immature
  - Very difficult to generalize
  - Unlikely to be a general solution
- EDA will likely not solve your problem
  - In the foreseeable future

Currently the likelihood that EDA will develop a solution that addresses the problem of simulating heterogeneous RF systems anytime soon is low. The co-simulation and macromodeling problems are notoriously difficult, and unlikely to yield a general solution. In addition, progress is expected to be quite slow.

What is One to Do?

- Must change your design methodology
  - Top-down verification
    See *Principles of top-down mixed-signal design* from *www.designers-guide.com/documents.html*
  - Careful verification planning
  - Judicious use of co-simulation and macromodeling
  - Consider use of dedicated verification engineers

Instead, as it often does, the problem shifts onto the design team. When effective verification tools do not exist, the design team must adjust by employing a methodology that minimizes the risk of failure. This is generally done by careful verification planning and judicious use of the tools that are available. Consider adding to the design team a dedicated verification engineer that is responsible for developing and implementing a verification strategy.

Thank You

Look for part 2,

"A Measurement Description Language"

at CICC 2005

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The remainder of this talk was to be on using the concept of user definable measurements to make RF simulators both more powerful and easier to use. Unfortunately I was not able to cover both of these topics in the time allotted. Instead, I will be discussing measurements in more depth at CICC in September.

Of course I will take any questions you may have now, but you may also send them to be or post them on my website.