RF High-level Behavioral Models With Transient Noise

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Abstract:

High-level behavioral Verilog-AMS models of an RF receiver front end are presented. The models of LNA, passive mixer, filter, and ADC include non-idealities such as gain and dc offset error, IP3, and time-domain noise. They are intended for system level transient simulations, to see the effect of non-idealities on performance, and to serve as executable specifications in a top-down design methodology. The modelling of IP3, gain and dc offset error are known, but modelling of transient noise in Verilog-AMS is rarely discussed.

Modelling Transient Noise

The issue of noise-folding in sampling receivers prompted the decision to model transient noise in system level simulations. Frequency-domain noise analysis in Spectre or Spice is prone to error when simulating non-linear and time-varying systems such as sampling receivers using switch-capacitor circuits. Modelling noise in time domain with Verilog-AMS settles the matter and shows its system-level impact. To model each noise source, a noise-like sequence of numbers is generated using Verilog-AMS code, then smoothed into a continuous-time voltage signal and inserted into the circuit.

Wideband noise is created for resistors and switches. Since the simulation is in fact a sampled system, we can only discriminate frequencies up to fs/2, where fs is the sampling rate of the noise generator. The desired rms value of the resistor noise is set to $\sqrt{4kTRfs/2}$. For a target 2 GHz system, the simulation sampling rate fs is chosen to be 40 GHz, i.e. 20 times of the system frequency. Thus, a 50-Ohm resistor would give an rms noise voltage of 124 uV (when T = 300). The random noise voltage inserted into the circuits is generated with a random sample sequence with sample time ts = 1/fs with the following code segment:

```
@timer(0,ts)  vn = rms_desired * $rdist_normal(seed,0,sqrt(2))
```

Narrowband noise, as seen at the output of a narrow-band LNA, is modeled by wideband noise source with a band-pass filter. Because the bandpass filtering effect of the LNA does not have an ideal 'brick-wall' shape, it required iterations to obtain final parameters of the band-pass filter in the model. A 4th-order Butterworth bandpass filter is used in the simulation, and the filter gain is adjusted for a specified LNA noise figure.

Presentation

The full text of the models is presented in an appendix. A schematic test bench incorporates all the models and includes the ability to adjust non-ideal parameters and turn transient noise generators on or off individually. Results of several runs and analyses are presented.

Summary

These modeling techniques are useful to evaluate noise contributions in a sampling receiver and system trade-offs.