Measuring the Impact of RF Impairments on an LTE System

- Perform dynamic simulations of RF impairments within an LTE system
- Use off-the-shelf capabilities for the LTE baseband subsystem
- Use a single environment for baseband and RF simulation

Communication systems performance places a high demand on RF components such as low noise amplifiers (LNAs), power amplifiers (PAs), or mixers. The constraints dictated by these RF components directly affect baseband design. Two famous examples include the choice of GMSK modulation for GSM or, more recently, SC-FDMA for the uplink of LTE. Therefore, it is desirable to assess the impact of such RF components on a complete system early in the design process. This requires setting up a simulation with both accurate baseband modeling and realistic RF effects.

LTE System Toolbox™ offers easy access to detailed baseband modeling and standard measurements such as EVM and ACLR. It also integrates with SimRF™ (Figure 1), which provides fast simulation of RF systems and insight into intermodulation distortion, image rejection, and phase noise, among other effects.
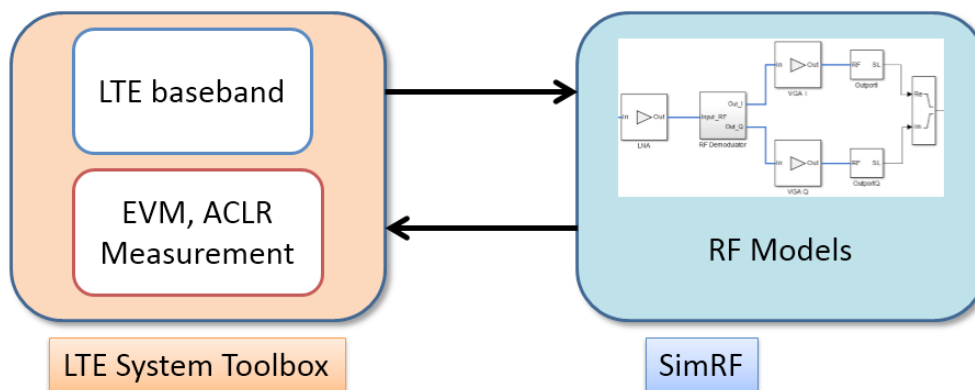

Figure 1. Simulation set up with LTE System Toolbox and SimRF.

This example shows how to assess the impact on EVM of an RF front end. A partial list of the imperfections we want to take into account includes

- LNA: Nonlinearity (IP3), frequency-dependent response (S-parameters), noise
- Mixer/demodulator: I/Q imbalance, phase noise, input isolation, nonlinearity (IP2), LO leakage
- VGAs: Nonlinearity (IP3, 1dB compression point)

RF Receiver Set Up

Figure 2 shows the model of the RF receiver. The input signal goes through an LNA, and then it travels through a direct-conversion demodulator and down to baseband. The I/Q components are amplified with a VGA and combined into a complex output signal for further processing and analysis
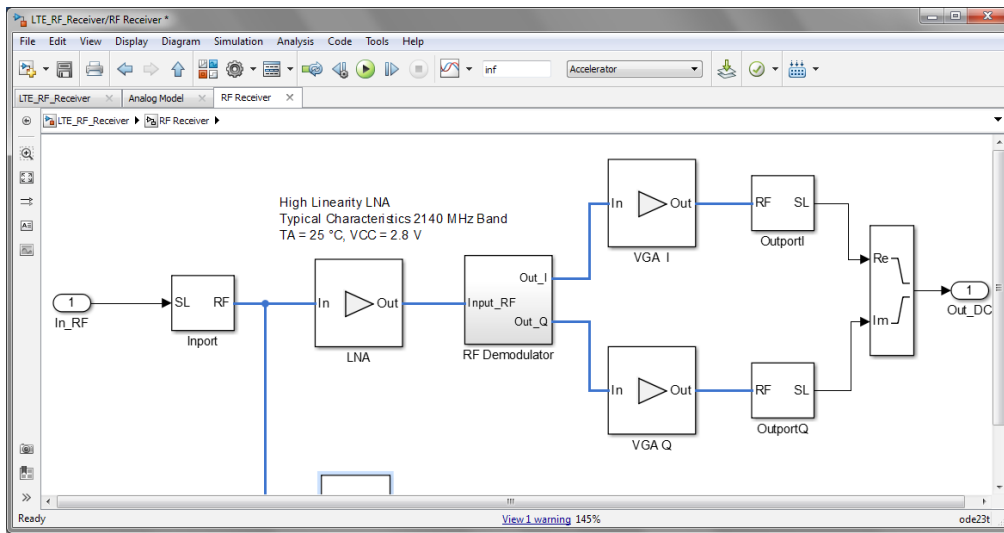
Figure 2. RF Receiver implemented with SimRF in Simulink.

Simulation Results

Figure 3 compares the measured RMS EVM for an ideal RF front end with a realistic RF front end with impairments. This figure clearly shows the influence of impairments in the RF front end. By leveraging such simulations early in the design, we can fine tune RF component parameters to verify that an EVM target is satisfied.
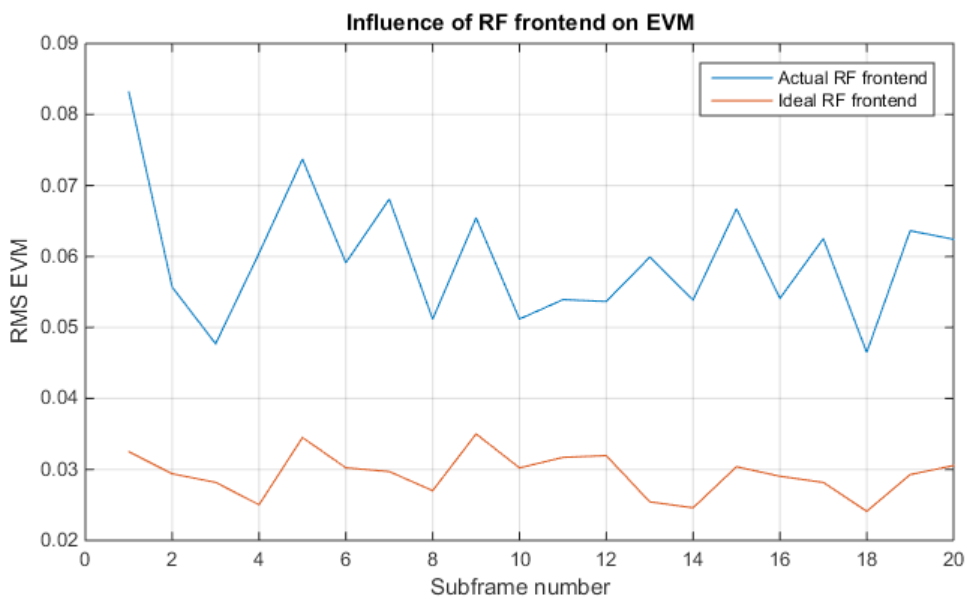

Figure 3. Measured EVM with and without RF impairments.

Details of the Transmit/Receive Chain

We use LTE System Toolbox in MATLAB® to generate a subframe of standard-compliant LTE data. The output variable, `tx`, represents the baseband output of the OFDM modulator after cyclic prefix insertion. As shown below, LTE System Toolbox includes functions such as `lteRMCDLTool` that generate standard-compliant test signals [1].

```
% Create eNodeB transmission with fixed PDSCH data
rmc = lteRMCDL('R.6');
data = randi([0 1], sum(rmc.PDSCH.TrBlkSizes),1);
[tx, ~, info] = lteRMCDLTool(rmc, data);
```

Using the `sim` command, the signal generated with LTE System Toolbox is imported into Simulink®.

```
% SimRF testbench
sim(model, time(end));
xInitial = xFinal;
```

As illustrated in Figure 4, the imported signal (orange) undergoes filtering, free-space propagation, and enters the receiver, where white Gaussian noise is added. The received signal then enters the RF front end shown in blue in Figure 4 and discussed in Figure 2. This is where the RF simulation engine from SimRF comes into play.
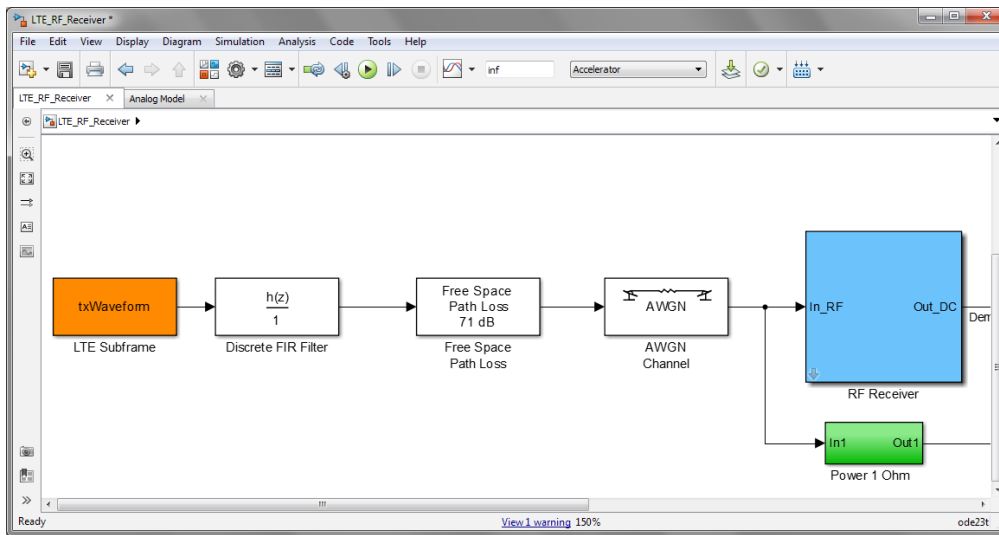

Figure 4. Transmit and receive chain in Simulink.

As an example of RF impairment, the mixer includes phase noise. Figure 5 shows the profile of the phase noise around the LO used in the mixer in dB versus a log of the frequency offset.
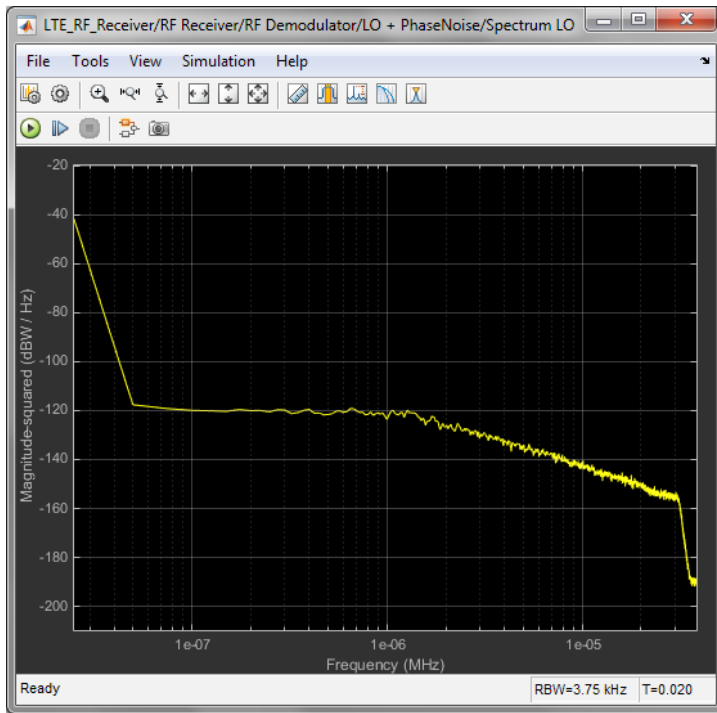
Figure 5. Phase noise profile measured in the demodulator.

Other effects include nonlinearities, which result in a DC offset at the output of the RF front end due to harmonics mixed back to DC through the direct-conversion process. To compensate for this DC offset, the signal is passed to an ADC and a DC offset compensation algorithm (not shown).

SimRF uses circuit envelope technology to achieve fast simulation of the RF signals without loss of accuracy. Circuit envelope technology enables easy integration of the RF model with digital baseband algorithms, and it provides a natural framework where RF effects and imperfections can be easily described.

Figure 6 shows the spectrum of the signal at different stages of the chain:

- At the output of the transmitter (yellow)
- At the input of the receiver (blue), after attenuation and noise addition
- At the output of the RF front-end (red), with an increased power but a DC offset
- At the output of the DC offset compensator (green)

The DC offset compensation algorithm successfully removed the DC offset, represented by the red peak at the center frequency.
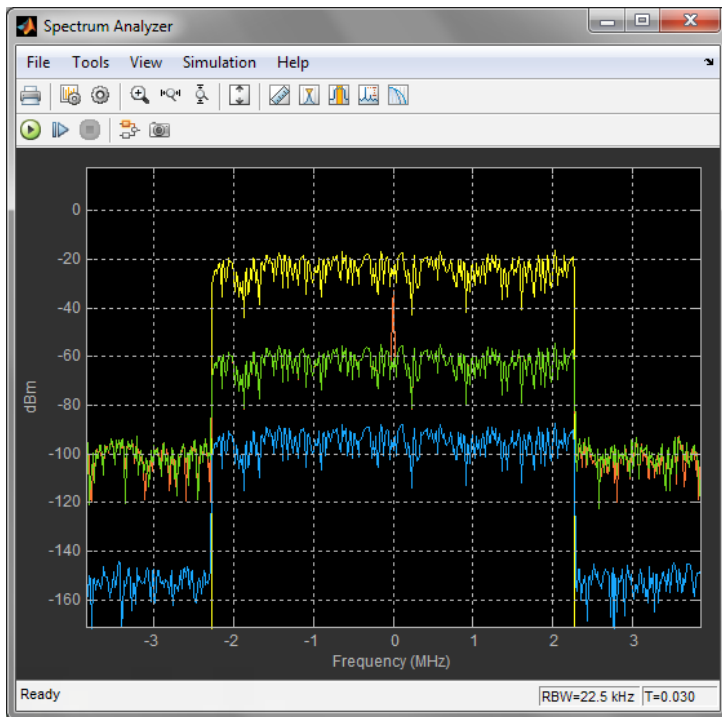
Figure 6. Spectrum of the signal at various points in the chain.

Finally, we measure EVM signals in MATLAB with LTE System Toolbox providing the EVM as per 3GPP TS 36.101 [2].

```
% Compute EVM measurements
evmmeas = hPDSCHEVM(rmc, struct('PilotAverage','TestEVM'),rx);
evmpeak(n)  = evmmeas.Peak;
evmrms(n)   = evmmeas.RMS;
```

Conclusion

LTE System Toolbox integrates with SimRF to simulate RF components in the context of an LTE system. LTE System Toolbox provides accurate LTE baseband modeling while SimRF, with its available RF components and core simulator, lets you simulate the RF section of the design transparently.

By assessing the performance and influence of RF components early in the design process with LTE System Toolbox and SimRF, we can reduce risk and issues that might appear at a later stage.

Products Used

MATLAB

Simulink

LTE System Toolbox

SimRF

References

[1] *Generating LTE Waveforms*,
mathworks.com/tagteam/81244_80711v00_LTEWaveformGeneration.pdf

[2] 3GPP TS 36.101 – Base Station Radio Transmission and Reception

[3] *PDSCH Error Vector Magnitude (EVM) Measurement*,
mathworks.com/help/releases/R2014b/lte/examples/pdsch-error-vector-magnitude-evm-measurement.html

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