Systems Simulation

Simulation of complex electronic systems

- Complex electronic systems are circuits composed by a huge number of electronic components. Conceptually, they are the combination of sub-circuits, each realizing a specific task

- The electrical analysis of these systems is very demanding in term of computing resources. Moreover it is possible only once the system has been designed

- During the design, more flexible tools are needed, suitable to test the functional behavior if the sub-system components (less accurate than electrical analysis but much faster)

- These tools are called ***Systems Simulators***

Behavioral vs. Electrical Model

Electrical model

Solution requires to know the circuit topology.

- Excitation and response are represented by voltages/currents
- To get V_{out} vs. V_{in} the solution of the internal circuit must be carried out
- Analysis carried out in frequency domain (time domain is some cases)
- Very demanding in term of computing resources.
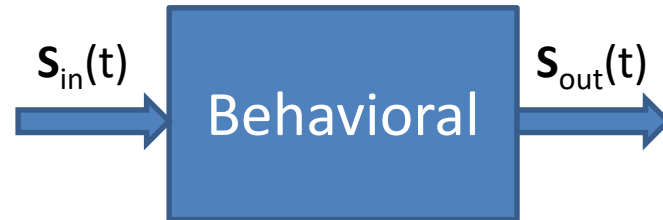
Behavioral model

It is defined by the task the sub-system must perform.

- Excitation and response are in the time domain (streams of numerical samples)
- The functional behavior is defined mathematically or through specific procedures
- It is not necessary to specify the actual sub-system structure
- Computing is much faster (especially for very complex systems)

Examples of behavioral models

Real (circuit)   **Behaviorial**

RF Amplifier

$S_{in}(t)$ $S_{out}(t)$
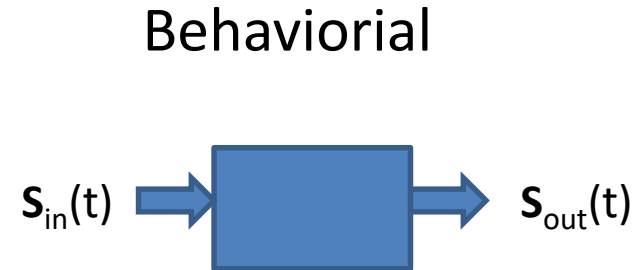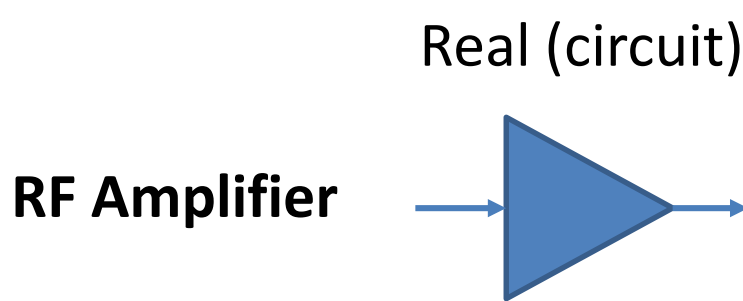
Ideal (gain block): $S_{out}=G \cdot S_{in}$
Linear (Gain, Noise, frequency Band)
General (Non-linear effects)

Mixer

$S_{in}(t)$ $S_{out}(t)$

$S_{LO}(t)$
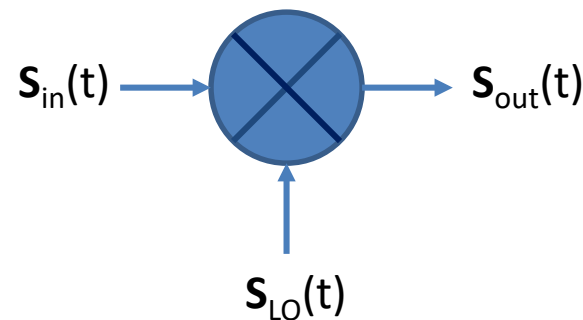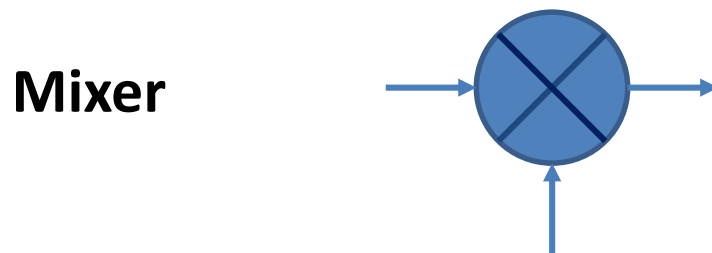
Ideal (Multiplier): $S_{out}=k \cdot V_{in} \cdot V_{LO}$
Linear (Conv. loss, Noise, Image Band)
General (Non-linear effects)

Time simulation of generic systems

- The system is intended as the interconnection of blocks, defined by functional relationships between input and output
- Time is assumed as independent variable
- The blocks are unidirectional
- Analysis is performed by sampling the variables in time
- Variables may be real or complex. In the latter case they represent modulated signals (envelope notation)
- System simulation differs from circuit simulation being electrical quantities and circuit constraints not directly involved in the modelling

Analysis with Sampled Signals

- From sampling theorem the sampling frequency fs must be larger than twice the maximum frequency of signal spectrum (B). In practice, the <u>oversampling factor</u> (i.e. the ratio fs/B) must be much larger than 2 (typically 8 or higher) to avoid the inaccuracies due to the reconstruction filters
- If we want to observe the time response in systems simulators, we need many points per period otherwise the signal representation is bad (although the analysis of the system is correct as far as the sampling theorem is satisfied)

Spectrum with Sampled Signals

- In case of real signals the analysis spectrum spans from 0 to fs/2. The spectrum resolution depends on the time window T_W used for the analysis ($\Delta f = 1/T_W$). The larger is T_w, the larger is the number of time points and the longer is the simulation time
- In case of complex envelope signals, the analysis spectrum is fc±fs/2 (fc carrier frequency). Note that the sampling frequency cannot exceed 2fc (to avoid negative frequencies folding). Also the signal band cannot exceed fs/2

VSS (Visual System Simulator)

- VSS is a software tool included in AWR Design Environment (commercially available from Cadence)

- It includes a wide library of RF and baseband models of real components for analysis and evaluation of complex communication systems

- A temporary license can be obtained following the instructions in this document on Beep (documents and media folder): https://beep.metid.polimi.it/documents/181798 379/6d2b8ba5-3457-4628-803d-a8d6c7f0db52

Specific parameters in VSS

- The time analysis is regulated by three fundamental parameters:
  - Sampling frequency (_SMPFRQ)
  - Data Rate (_DRATE)
  - Samples per symbol/oversampling factor (_SMPSYM)
- The meaning and the impact they have on simulations depends on the type of signals they refer to.

Signal Types:

- **Digital** (base band). Are characterized by a base M (M is the number of possible levels, including zero). Each digital sample represents a digital symbol and the data rate (_DRATE) is the transmission speed.

- **Real**. They represent an signals in time domain. The sampling frequency (_SMPFRQ) must be larger than 2B. Note that when B is defined, _SMPFRQ is computed automatically from the oversampling factor: _SMPFRQ =B*_ SMPSYM.
  When the analog signal is derived from a digital stream, the sampling frequency (_SMPFRQ) is related to the data rate (_DRATE) as follows:

  _SMPFRQ=_DRATE * _ SMPSYM
- **Complex** (RF signals). They refer to the complex envelope of the signal (also a tag is added to specify the carrier frequency). The sample rate is referred to both I and Q components. Note that this value is much smaller that that required for sampling the corresponding real signal ($f_s > 2f_c$)

Example: Real vs. Complex signals

- AM modulated signal
Carrier: fc=1 GHz, modulation: fm=10 MHz (single tone), modulation index: 0.85
Signal band: 20 MHz (max frequency: 1.02 GHz)
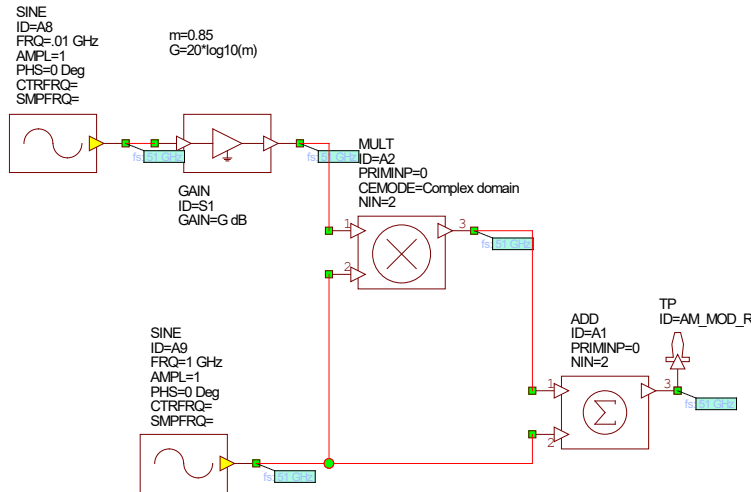
$$s_{out}(t)=s_{carrier}(t)*(1+m*s_{mod}(t))$$

- Real signals
fs=50*1.02=51 GHz (to get a good reproduction of the carrier)
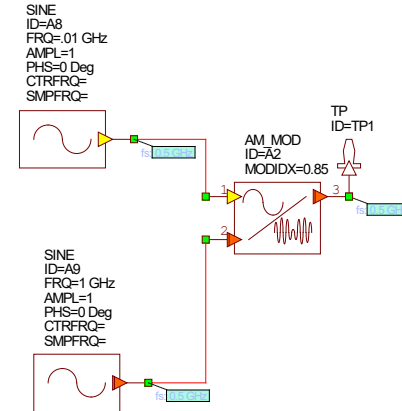Simulation time (3 period of the envelope): 300 nsec number of samples: 300*51=15300

- Complex signal
  fs=50*0.01=0.5 GHz (to get a good reproduction of the envelop)
  Simulation time (3 period of envelop): 300 nsec
  number of samples: 300*0.5=150

Real signal Diagram:

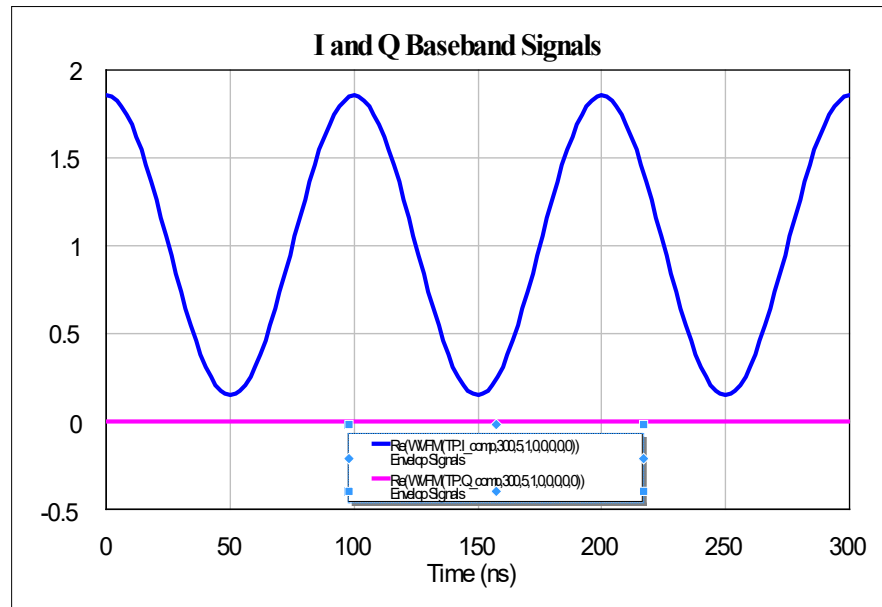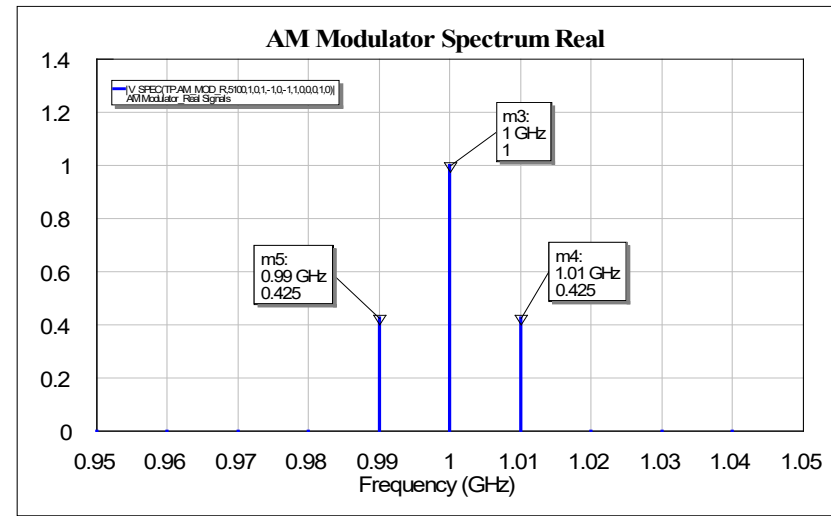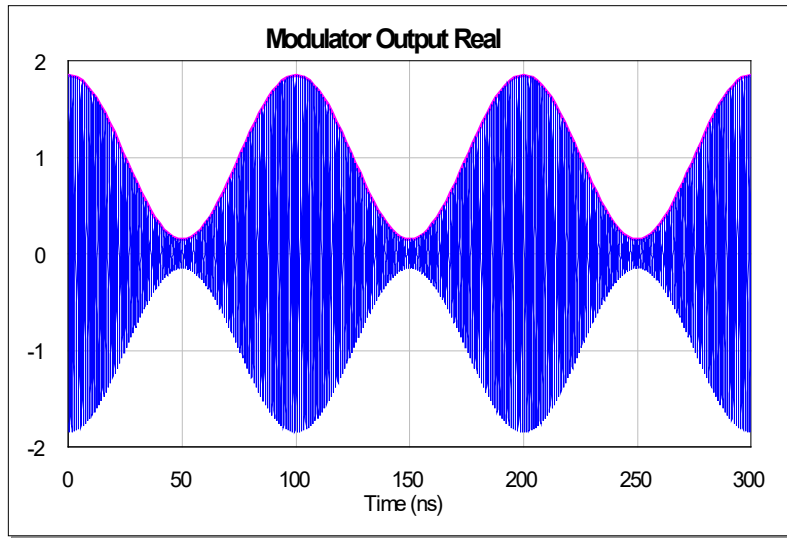Complex signal Diagram:

$$S_{out}(t) = \cos(\omega_c t)(1 + m \cdot \cos \omega_m t) = \cos(\omega_c t) + m \cos(\omega_c t)\cos(\omega_m t) =$$

$$= \cos(\omega_c t) + \frac{m}{2}\cos((\omega_c - \omega_m)t) + \frac{m}{2}\cos((\omega_c + \omega_m)t)$$

Simulation results

Real vs. Complex with mixing

- Consider two signals with CE:
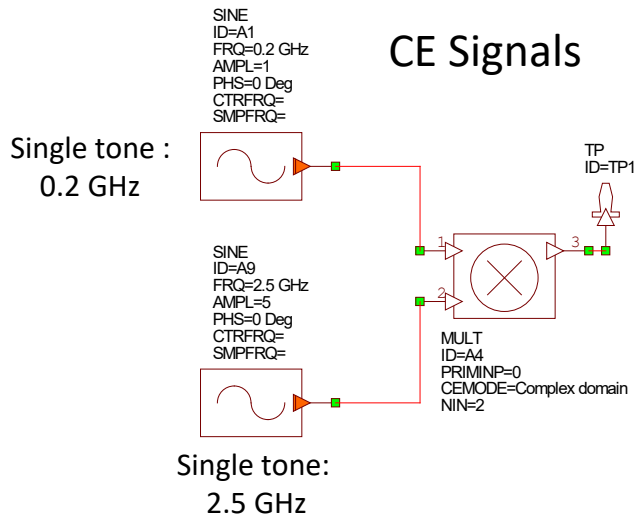$$S_1 = A_1 * \exp(j\omega_1 t), \quad S_2 = A_2 * \exp(j\omega_2 t)$$

- Assume ω_{c1} and ω_{c2} the two carrier frequencies

- If the two signal are multiplied, attention must be paid to the meaning of the output signal:

  – Multiplication of real signals generates an output composed by two RF signals (no complex envelopes:
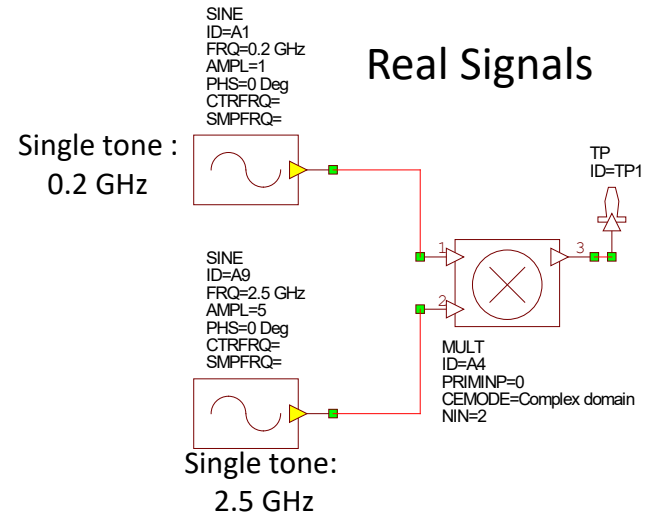
  $$s_3(t) = A'_1 \cos((\omega_{c1}+\omega_1+\omega_{c2}+\omega_2)t) + A'_2 \cos((\omega_{c1}+\omega_1-\omega_{c2}-\omega_2)t)$$

  – Multiplying the two envelopes, only the first of the above signals is obtained (carrier $\omega_{c1}+\omega_{c2}$)

- Behavioral model of mixers select one of these RF signals, so it is still possible to consider the complex envelope at output

Verification by simulation (fs=50 GHz):

CE Signals

SINE
ID=A1
FRQ=0.2 GHz
AMPL=1
PHS=0 Deg
CTRFRQ=
SMPFRQ=

Single tone :
0.2 GHz

SINE
ID=A9
FRQ=2.5 GHz
AMPL=5
PHS=0 Deg
CTRFRQ=
SMPFRQ=

Single tone:
2.5 GHz

TP
ID=TP1

MULT
ID=A4
PRIMINP=0
CEMODE=Complex domain
NIN=2

$V(t)=Re(5 \cdot 1 \cdot exp(j2\pi \cdot 2.7GHz))=5 \cdot cos(2\pi 2 \cdot 7GHz)$

Real Signals

SINE
ID=A1
FRQ=0.2 GHz
AMPL=1
PHS=0 Deg
CTRFRQ=
SMPFRQ=

Single tone :
0.2 GHz

SINE
ID=A9
FRQ=2.5 GHz
AMPL=5
PHS=0 Deg
CTRFRQ=
SMPFRQ=

Single tone:
2.5 GHz

TP
ID=TP1

MULT
ID=A4
PRIMINP=0
CEMODE=Complex domain
NIN=2

$V(t)=Re(1 \cdot exp(j2\pi \cdot 0.2GHz)) \cdot Re(5 \cdot exp(j2\pi \cdot 2.5GHz))=$
$2.5 \cdot cos(2\pi \cdot 2.3GHz)+2.5 \cdot cos(2\pi \cdot 2.7GHz)$

Complex Signals (plus added carrier)

Real Signals