RF MEMS for Radar Tutorial Exercises

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The exercises require the open-source software packages Qucs (an ADS look-a-like) and wxMaxima (a Maple / Mathematica look-a-like). MacOS X, Ubuntu, and Windows executables can be downloaded[1] from:
http://qucs.sourceforge.net
http://wxmaxima.sourceforge.net

The Qucs project, containing data displays, sub circuits and test benches, the wxMaxima notebooks, as well as background material, can be downloaded from: http://www-personal.umich.edu/~vcaeken/RADAR2010.zip. The attendee is encouraged to explore the content of the RADAR2010.zip package, scroll through the Qucs and wxMaxima getting started manuals, simulate the Qucs test benches, such as for example TESTBENCH_DA_SP and TESTBENCH_DA_HB with SUBCIRCUIT_MOSFET_DA, or evaluate the wxMaxima notebooks.

Note that the Qucs harmonic balance (HB) solver is still in beta, and only works with "lumped components" and "verilog-a devices". If the HB simulation results are not satisfying, then the attendee is encouraged to increase the number of harmonics or the number of iterations.

Exercise 1: Design of a capacitive fixed-fixed RF MEMS single pole single throw (SPST) switch

The purpose of the exercise is to become familiar with the electromechanical and RF model parameters, and to investigate how design choices (material selection, dimensions) affect the figures of merit of the RF MEMS SPST switch. More specifically, the attendee is encouraged to evaluate RFMEMS.wxm with wxMaxima to investigate the effect of a change in beam dimensions or beam material (replace the mass density, Poisson ration, Young's modulus of Au, with the one of UNCD (slide 39/80 of the tutorial) on the electromechanical (pull-in voltage, hold-down voltage, switching time) and RF figures of merit (capacitance ratio). The RF figures of merit of an ohmic cantilever RF MEMS SPST switch can be simulated using TESTBENCH_SPST_SP with SUBCIRCUIT_RFMEMS_SPST in Qucs,

The attendee is also encouraged to evaluate RFCMOS.wxm with wxMaxima and simulate TESTBENCH_SPST_SP with SUBCIRCUIT_MOSFET_SPST in Qucs, which describe the performance of a 0.13 micron NMOS SPST switch. The NMOS SPST switch is a common gate (CG) transistor stage, biased in the linear region.

Finally, the attendee is encouraged to simulate TESTBENCH_SPST_SP with SUBCIRCUIT_MESFET_SPST in Qucs, which describes the performance of a 0.5 micron GaAs MESFET SPST switch.

Some questions worth discussing are:

- Is a high spring constant (stiff beam) a good thing or a bad thing? The analytical expression for the spring constant consists of two terms. Which one would you want to dominate the equation?
- Is a high pull-in voltage a good thing or a bad thing if you consider linearity? What if you consider reliability?
- What material would you choose for your RF MEMS beam if you would like to minimize the switching time?
- How do the MESFET, MOSFET, and RF MEMS SPST switches compare in terms of bandwidth, insertion loss, linearity, power consumption, supply voltage? What are the advantages and disadvantages of each RF technology?

Exercise 2: Design of an S-band 4 bit switched resistive network attenuator using ohmic cantilever RF MEMS single pole double throw (SPDT) switches

The purpose of the exercise is to design an RF MEMS attenuator using TESTBENCH_ATTENUATOR in Qucs. Prior to designing a 1.25 dB attenuator bit, the attendee is encouraged to get acquainted with the concept of constant-k sections, using the built-in Qucs attenuator synthesis tool.

Some questions worth discussing are:

- What limits the bandwidth of an attenuator based on resistive constant-k sections?
- Why is the P1dB compression point obtained with TESTBENCH_ATTENUATOR_HB infinity? Is SUBCIRCUIT_RFMEMS_SPDT valid for large-signal simulations?
- Why use an attenuator and not a variable gain amplifier (VGA)?

Exercise 3: Design of an S-band 4-bit switched LC network phase shifter using ohmic cantilever RF MEMS SPDT switches

1 On Debian/Ubuntu systems, the packages can be installed using the command: "sudo apt-get install qucs wxmaxima".

The purpose of the exercise is to design an RF MEMS phase shifter at 3 GHz (not at 10 GHz). Unfortunately, Qucs does not have a built-in phase shifter synthesis tool, capable of calculating the inductance and capacitance of pi and T networks with a specified phase shift (180 deg, 90 deg, 45 deg, 22.5 deg) at a specified frequency (3 GHz). The attendee will have to resort to a trial and error approach, use the Elsie tool, or the Exercise2.wxm notebook. However, the attendee is encouraged to first understand why there is a phase error between the S21 obtained with TESTBENCH_CONSTANTK and TESTBENCH_PHASESHIFTER.

Some questions worth discussing are:

- How to choose between LC pi and T-networks?
- Is a switched LC network phase shifter a phase shifter or a true-time-delay phase shifter (time delay unit)?
- What is the effect of RMS amplitude and phase errors of the phase shifter on the electronically scanned array figures of merit? (Qucs has a built-in RMS function)

Exercise 4: Optimization of S- and X-band T/R module architecture using previously designed 4-bit RF MEMS attenuator and phase shifter

The purpose of the exercise is to investigate how the RF technology affects optimal T/R module architecture. An introduction for the exercise is taken from [1]:

Active phased array radars have power and low noise amplification distributed at the antenna aperture, reducing the effect of losses in the distribution network for both transmit and receive. To take full advantage of this property, T/R module performance must be optimized in several key areas. In transmit, efficiency, output power and power gain are particularly important. In receive, gain, noise figure, third order intercept, dynamic range, and amplitude and phase accuracy are significant design drivers. Requirements on these parameters flow from antenna requirements and architectural considerations.

Because the central transmitter has been eliminated, the T/R module must have sufficient transmit gain to allow a reasonably low input power for a given output power. In receive, a high gain first stage LNA reduces the noise contribution from secondary stages. In the same way, high module gain reduces the noise impact of the down stream corporate feeds, time delay units, and receivers. At the same time, the modules must provide a high TOI to meet dynamic range requirements and maintain radar performance in a high interference environment. The module must also supply low error, high precision phase and amplitude control for low side lobe beam steering, usually with multi-bit MMIC phase shifters and digital attenuators or variable gain amplifiers. The selected module architecture must simultaneously satisfy these requirements, some of which conflict.

In particular, the trade-off between receive gain, noise figure (NF), and TOI will drive most of the module architecture choices. The high first stage gain desired for NF minimization directly conflicts with the need for high TOI. Function blocks must be distributed prudently in the T/R module to optimize all of these parameters.

Three possible module architectures are considered. The first features completely separate transmit and receive chains. The second shares only a few components between chains. The third, the common-leg approach, shares major functional groups between transmit and receive. For this discussion, the receive gain is held to 30 dB, and the same receiver protection and T/R duplexing is used in each case.

The attendee is encouraged to simulate TESTBENCH_TRMODULE_SP and TESTBENCH_TRMODULE_HB in Qucs. The attendee is further encouraged to mix and match amplifiers (SUBCIRCUIT_MESFET_DA, SUBCIRCUIT_MOSFET_DA) with previously designed attenuators and phase shifters in order to optimize overall T/R module specifications (gain, NF, P1dB).

Some questions worth discussing are:

- Which RF switch technology do you favor for UWB T/R module design?
- What is the optimal T/R module architecture for the RF technology of your choice, in the light of a trade-off between linearity and noise figure of the Rx leg?
- How will the choice of the RF switch technologies affect a pulse-Doppler waveform?

Exercise 5: Simulation of an UWB differential reflect array brick

The purpose of the exercise is to investigate how a cascade of differential RF MEMS reflect-type phase and a wideband differential antenna, may yield a wideband reflect array brick. The attendee is encouraged to simulate

TESTBENCH_REFLECTARRAY_BRICK in Qucs.

Some questions worth discussing are:

- Which other types of phase shifters and antennas can be mixed and matched to yield a wideband lens or reflect array brick? Would the design work with antennas, other than traveling-wave antennas?
- What should dB(S11) be for a matched and lossless reflect array brick? Does dB(S11) vary with phase state? If so, make an estimation of the RMS amplitude error.
- Why would anyone want wideband passive electronically scanned arrays?

References:

1) A. Agrawal, R. Clark and J. Komiak: T/R module architecture tradeoffs for phased array antennas, IEEE MTT-S International Microwave Symposium Digest, 17-21 June 1996, San Francisco, CA, USA, vol. 2, pp. 995-998.