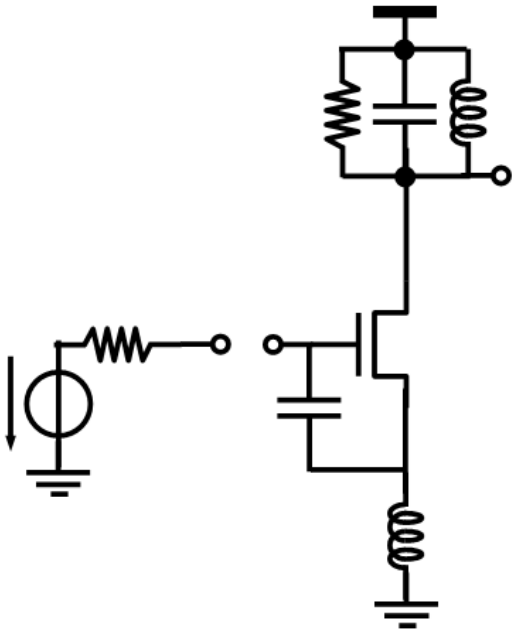
Common source LNA

We are designing an LNA in the license-free, 26MHz wide, 915MHz-centered ISM (industrial, scientific, and medical) band.

The LNA should be matched to the 50Ω antenna and be designed for maximum gain using the topology sketched below.

Capacitors could be ideal; inductors should be chosen from the Coilcraft 0402dc series 0402dc.pdf (coilcraft.com). Self-resonance and Q @900MHz are given so no need to do a lot of calculations.



Question 4) Derivation of the LNA input Z and gain

We want to achieve a reasonable power gain in our LNA while trading off the power consumption and achieve 50Ω input matching to the antenna. We will use the structure sketched above with inductive degeneration and a capacitor placed between the gate and source of the gain transistor (part of it is actually made by the transistor itself). Neglect the substrate body effect (gm=gms) and all components which are not shown on the schematic. We choose to have a resonant load but you should adjust the Q to fit our BW. All elements are discrete components but inductors are limited to the mentioned series.

In calculations we consider ideal L components unless noted explicitly!

a) Calculate the input impedance of the circuit Vin/Iin after writing the Kirchhoff equations to determine the conditions for impedance matching to Rs=50Ω (observe the equations first to avoid unnecessary and complex calculations !). Write the conditions clearly and re-use them later for simplification.
b) Sketch on a Smith chart normalized to 50Ω the input impedance when varying slightly the frequency (this will be re-used later).
c) Calculate the transistor source voltage vs Iin, this will be useful for the overall gain calculation; now you may get the VGS voltage as a function of Iin; what do you conclude?
d) Calculate the parametric maximum in-band voltage and power gains of the LNA from the antenna to the output; some of our design parameters are linked by the 50 Ohm matching condition; compute the range of gm and equivalent sub-threshold currents over the design space imposed by the inductors range and discuss shortly the results.
e) Select the two sets of L and C components, gm and limit the Q of the output stage so that it fits our BW; they are multiple solutions! Get a numerical expression for the voltage and power gain
f) Calculate the Q of the antenna & input stage and comment shortly
g) Sketch the small circuit equivalent of the LNA adding controlled current sources modeling the transistor and its main noise source (1/f noise is neglected)

Question 5) Output impedance and noise factor calculations

h) Now you need to connect Rs to the input! Note that we should add e.g. a 100pF ideal cap as a DC block to isolate the voltage source from the LNA bias. We neglect this cap as its reactance is low but it would be needed in simulations or when injecting a signal from a generator.
i) Determine the output impedance of the LNA (why is it so simple ? justify with the equations (you do not need to solve the system!)
j) The noise factor calculation of the LNA is a bit tricky; we will consider only the MOS transistor noise and neglect that of the output loss first; the relevant noise source is between the output node and the intermediate L-degenerated one and is thus 100% correlated on the way it acts on both nodes. We would need to write all 3 equations and use "-in" as the output node noise current and "+in" at the other node before solving Vout("in") noise. Rather we consider only the first two nodes equations and calculate the transfer function VIN("in") before computing the equivalent voltage noise source PSD $vn^2(in^2)$; with impedance matching it is straightforward to compute the equivalent noise of the input resistor and get F; show your calculation and then do not forget to do all the simplifications and you will be surprised how simple is the result!

k) Using the proper voltage gain from VIN to VOUT get the equivalent output noise including the noise due to the load loss (Rp) and comment your result
l) knowing that Thevenin, Norton equivalents hold, match the LNA output impedance so that it may be used as the filter input impedance? Give the components values and check the matching network Q! How is the power gain affected? Our overall Q is not that easy to calculate since it is a combo of that of the LNA output stage and matching network ones!
m) We need additional gain in our system, what block could you place at the output of the filter to implement the output impedance of the filter, how do you modify that block?