EE-426 RF Circuits Design Techniques Fall 23 Examination

26.01.24, 3:15-6:15PM

Indicative timing, 30’ for part A and 30’ for each of part B questions

Part A: warm up, system-oriented questions

Question A1

Our receiver operates 3dB above its minimum sensitivity level. Describe as many perturbation mechanisms linked to interferers that could lead to a large degradation of the bit error rate and which should be taken care of in the design of all blocks of the receiver.

Question A2

One of your colleagues is claiming that he designed a narrowband LNA thus he does not have to care with third order non-linearity as the H3 will largely be filtered by the load Q-factor. Is he right?

Question A3

Discuss the trade-off in a narrow-band receiver highlighting the linearity, gain, noise issue at various stages. Elaborate on where special attention should be taken care of.

Question A4

What key technology besides microelectronics is necessary to achieve co-existence of that many standards in our phones? Quickly explain the challenges from a system perspective.

Question A5

You have a 4G smartphone and Salt is trying to convince you to switch to their network as they have signed with Musk’s Starlink to provide high data rate via low earth orbiting satellites with a standard phone. Discuss the challenges and limits associated to getting the same service via SATCOM and terrestrial base stations with some scientific evidence. What is the challenge on the satellite side?

Part B: more in-depth questions

Question B1

We are willing to minimize the current consumption of a VCO using an external coil to cover the ISM 915MHz-centered 26MHz-wide band. The coil is to be chosen from the Coilcraft 0402dc series 0402dc.pdf (coilcraft.com). Note that the self-resonance and Q @900MHz are given so no need to do a lot of calculations.

a) With a varactor tuning ratio Cmax/Cmin of 2 and a fixed differential loading cap of 1pF representing the load of the VCO including its own transistors, the pads and PCB parasitic capacitance, calculate the varactor size so that we fully cover the band with 5% margin on each side. The varactor Q is 50 over the whole tuning range. The fixed cap Q is also 50.
b) Calculate the worst case current required to overcome the tank losses (critical current) assuming the transistors are biased in sub-threshold.
c) Demonstrate the formula for Phase noise of VCO. What is the phase noise at 1MHz offset assuming a noise factor for the active that is twice the noise of the resistor. Hint (assume half the noise is phase noise, half of the noise is amplitude noise thus not relevant)
d) How is the consumption affected if the Q of all the capacitors is reduced to 25?

Question B2

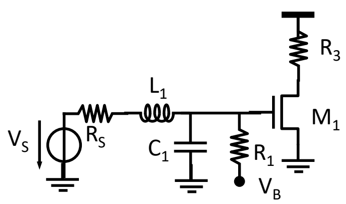
In a transceiver for an in-the-ear hearing aid application in the ISM 2.4-2.48GHz band, the 50Ω antenna is miniaturized and has a gain of -10dBi due to internal losses. The limited size of the battery yields a maximum output power of the TX of -6dBm when tested on a 50Ω power meter.

a) Knowing that the noise figure and the required SNR of the RX is 15dB, calculate the maximum data-rate if an additional potential path loss of 80dB between the two ears may occur.
b) After initial trials, the test engineer reported that his phone is desensitizing the receiver when transmitting at +17dBm in the neighboring 1.8-2GHz band. Knowing that the phone may transmit up to +30dBm and that we would like to get 6dB margin, design using tables an LC RX bandpass filter to be placed between the antenna and the LNA.

Question B3

We have seen in the course that when input matching the LNA with a 50Ω resistor, the noise figure is >3dB. However, when the input impedance of the LNA is made bigger, the NF is reduced at the expense of violating the power match condition.

a) How is the NF affected if we introduce a higher matching resistor together with the required impedance matching network to satisfy the optimal power transfer condition? Make a parametric study versus the Q of your matching network and discuss the high-Q limitations.



b) Design the output resonant load maximizing the voltage gain of the LNA so that within the 2.4 to 2.48GHz band, the attenuation is limited to 1.5dB while taking into account a +-3% variation for each of the LC tank components.

c) What is the benefit of the network with respect to the gate capacitance of M1

<u>Question B4</u>

During the course we have designed a common source LNA with inductive degeneration and a gate to source capacitance (you should use all results as a starting point, no need to recalculate everything).

a) Discuss why it would be beneficial to add an external series inductor between the antenna and the LNA input with supporting equations and how consumption, noise figure and gain are affected by the introduction of this new degree of freedom. Consider the case where C12 is kept constant and the other one where L2 is kept constant for comparison with the baseline LNA (there is no need to make a numerical example, we are interested in a parametric analysis when 50Ω matching is required).

b) Illustrate on a Smith chart the cases covered by a) highlighting the LNA impedance

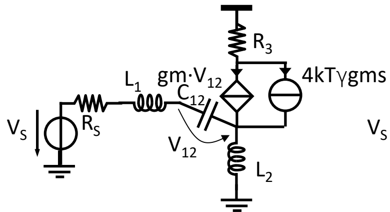
<u>Question B5</u> (follow-up of B4, similarities with B3)

We have neglected the pad input capacitance to ground in our LNA.

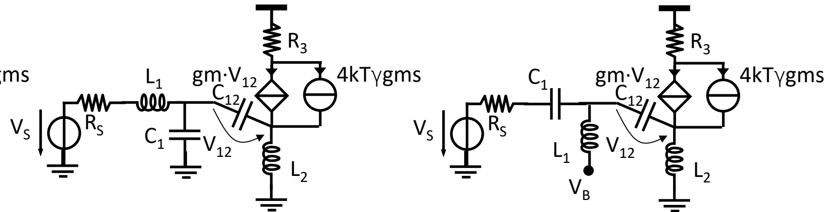
a) How does it modify the input impedance of the circuit? (reasoning only, no equation).

b) This shunt cap gives you an idea: Let’s try to increase the input impedance of the LNA using an LC or CL transformation network. Sketch the two cases on a Smith chart and discuss with supporting equations how the consumption, noise figure and gain is affected by the introduction of these new degrees of freedom. Consider first the case where the LNA still provides a real input impedance and then using the LC or CL to compensate as well for a reactive part in the LNA.

c) What do you conclude from your findings?



B4 illustration



B5 illustration with LC and CL Z-transformation L-shaped circuits