Indian Institute of Space Science and Technology
Department of Avionics
AVM 862 RF Integrated Circuits
Quiz 1

Time: 1 hour **Max. marks:** 15

Answer all the questions

1. Consider an RF frontend which consists of a band pass filter and 2 stages of low noise amplifiers. The band pass filter has a loss of 0.5 dB. The first low noise amplifier has a gain of 10 dB and a noise figure of 1.1 dB. The second LNA has a gain of 15 dB and a noise figure of 2.5 dB. Calculate the noise figure of the total system. *Hint: The numbers given in this question are in decibels. Convert them to normal power ratio quantities before proceeding with the calculations.* (3 marks) 1.85 dB

2. Design a low pass L-match network which can convert 50 Ω to 25 Ω at 10 GHz. Give the component values. (3 marks) 39.7 nH 0.318 pF

3. A receiver is required to have a sensitivity of -100 dBm for a QPSK modulation scheme at 100 kbps. The minimum SNR required is 10dB. The effective bandwidth of the receiver is 60 kHz. What should be the noise figure of the receiver at room temperature (300K) to support this requirement? (2 marks) 16.21 dB

4. An amplifier has a $\alpha_1 = 10$ and $\alpha_3 =$ -0.2 at 2.3 GHz. All the terminal impedances are at 50Ω. The amplifier is fed with an input of -10 dBm at 2.298 GHz and -5 dBm at 2.302 GHz. Derive the expression for the intermodulation terms. Calculate the power levels of the intermodulation terms at the output in dBm. (5 marks) -21.535 -16.575
Some formulae: $\cos 3\theta = 4\cos^3\theta - 3\cos\theta$; $\sin 3\theta = 3\sin\theta - 4\sin^3\theta$; $(a+b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$; $cos2\theta = 2\cos^2\theta - 1$;

5. Explain the origin and the phenomenon of AM-PM conversion in non-linear circuits. (2 marks)

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Quiz 2

Time: 1 hour **Max. marks:** 15

Answer all the questions

Some useful formulae:

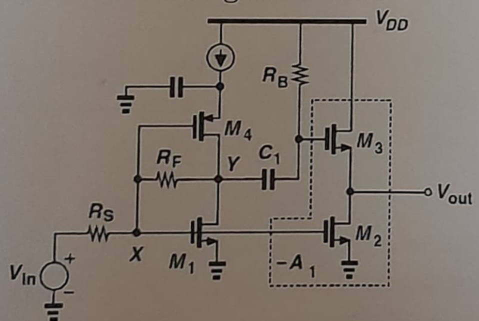
The fourier expansion of a square wave with 50% duty cycle toggling between -1 and +1 is:

$$s(t) = \frac{4}{\pi} \sum_{n=1,3,5..}^{\infty} \frac{1}{n} \frac{sin(n\pi t)}{T}$$

1. Consider an inductively degenerated common source LNA.
   (a) Derive the input impedance for this LNA. (1 mark)
   (b) A transistor with an f_T of 100 GHz is used to design an LNA at 5 GHz. Calculate the source inductance. (1 mark)
   (c) If the C_{gs} is 100 fF, calculate the gate inductor required to match this LNA. (1 mark)

2. Why is a cascode transistor used in a common gate LNA? Explain with derivations. (3 marks).

3. Consider the circuit given below.



Show how the noise phases and the signal phases align such that noise cancellation is possible. (3 marks)

4. Consider an active downconversion mixer. Draw its complete circuit with all biasing arrangements. You can assume a square wave LO. Derive the conversion gain. (3 marks)

5. Draw an up-conversion passive mixer. The mixer drives a driver amplifier whose input impedance can be taken as a parallel RC circuit ($R_{DA}||C_{DA}$). You can employ an inductor to tune at the frequency of interest. Assume the inductor has a quality factor of Q_{ind}. Derive the conversion gain at resonance. (3 marks)

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End Semester Examination - May 2024

Time: 3 hours **Max. marks:** 30

Note: Do not directly copy from the papers. Write in your own words. Direct copying will result in half credit. Use additional derivations, expressions, diagrams, figures apart from those which are provided in the paper. Some useful formulae are provided at the end of the paper.

Answer all the questions

1. In a single sideband (SSB) mixer where hard-switching is used, explain the mechanisms with suitable derivations to show how the intermodulation components $3\omega_{LO} - \omega_{BB}$ and $-\omega_{LO} + \omega_{BB}$ are generated (3 marks)

2. In the harmonic reject mixer, derive and show how the effect of the harmonics is removed. (3 marks)

3. Refer to the receiver paper (RFIC 2016). In receiver design section, 2 receivers are compared. The conventional receiver is said to have degraded matching, gain and noise performance at 3CC when compared to 1CC. Why is that? How is this problems alleviated in the proposed architecture? (3 marks)

4. Refer to the transmitter paper (ISSCC 2017). (3 marks)
   (a) How is the HRM implemented? (2 marks)
   (b) When the TX is configured in HR-disable mode, redraw the transmitter circuit showing only the paths that are active. (1 mark)

5. Refer to the transceiver paper (JSSC). Consider the receiver LNAs for LB, MHB and NR (UHB/LAA) bands in the IC. (3 marks)
   (a) How is the input matching achieved in each case? Explain with circuit and necessary expressions. (1 mark)
   (b) How is the output tuning achieved in each case? (1 mark)
   (c) How is the gain tuning achieved in each case? (1 mark)

6. A differential cross-coupled VCO is being designed. The inductor of the tank has a Q of 12 and a value of 2.5 nH. (4 marks)

   (a) If the targeted frequency of oscillation is 5 GHz, what should be the value of the capacitor? If a tuning range of $\pm 10\%$ is required, what is the range of capacitors required? (1 mark)

   (b) What is the gm required from the transistors for the circuit to oscillate? Derive and calculate the value. What is the current through the tail current source of the oscillator if the cross-coupled transistors have a W/L of $5\mu m$/ 60nm. (1.5 marks)

   (c) Show the behaviour of a MOS cap. Connect it to the oscillator in such a way that when the control voltage increases, the frequency of oscillation increases. (1.5 marks)

7. Consider a Class AB PA. (3 marks)

   (a) Draw the complete schematic of a fully differential PA, with a single-ended output. Provide the biasing arrangements as well. (1.5 marks)

   (b) For a Class AB PA, draw the typical drain voltage and drain current waveforms, input voltage with biasing information, output wavforms. (1.5 marks)

8. Phase Locked Loops (8 marks)

   (a) Consider a type-1 PLL. Provide the complete modelling of each block and derive the closed loop response (3 marks)

   (b) Show how a frequency step to the PLL results in a residual error (2 marks)

   (c) Provide the complete circuit diagram and the modelling for the PFD and charge pump. (3 marks)

Some useful formulae:

$$I_D = \frac{\mu C_{ox}}{2}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$g_m = \mu C_{ox}(W/L)(V_{GS} - V_{TH}) = \sqrt{2 I_D \mu C_{ox}(W/L)} = \frac{2 I_D}{(V_{GS} - V_{TH})}$$

Degrees	$0°$	$30°$	$45°$	$60°$	$90°$
sin	0	$\frac{1}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{\sqrt{3}}{2}$	1
cos	1	$\frac{\sqrt{3}}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{1}{2}$	0
tan	0	$\frac{\sqrt{3}}{3}$	1	$\sqrt{3}$	

$$\begin{aligned}
\sin x \sin y &= \frac{1}{2}\big[\cos(x-y) - \cos(x+y)\big] \\
\cos x \cos y &= \frac{1}{2}\big[\cos(x-y) + \cos(x+y)\big] \\
\sin x \cos y &= \frac{1}{2}\big[\sin(x+y) + \sin(x-y)\big] \\
\sin x + \sin y &= 2\sin\left(\frac{x+y}{2}\right)\cos\left(\frac{x-y}{2}\right) \\
\sin x - \sin y &= 2\cos\left(\frac{x+y}{2}\right)\sin\left(\frac{x-y}{2}\right) \\
\cos x + \cos y &= 2\cos\left(\frac{x+y}{2}\right)\cos\left(\frac{x-y}{2}\right) \\
\cos x - \cos y &= -2\sin\left(\frac{x+y}{2}\right)\sin\left(\frac{x-y}{2}\right)
\end{aligned}$$