Final Examination

Electronic Instrumentation (ET8017)

Monday, November 5, 2012, 14:00-17:00

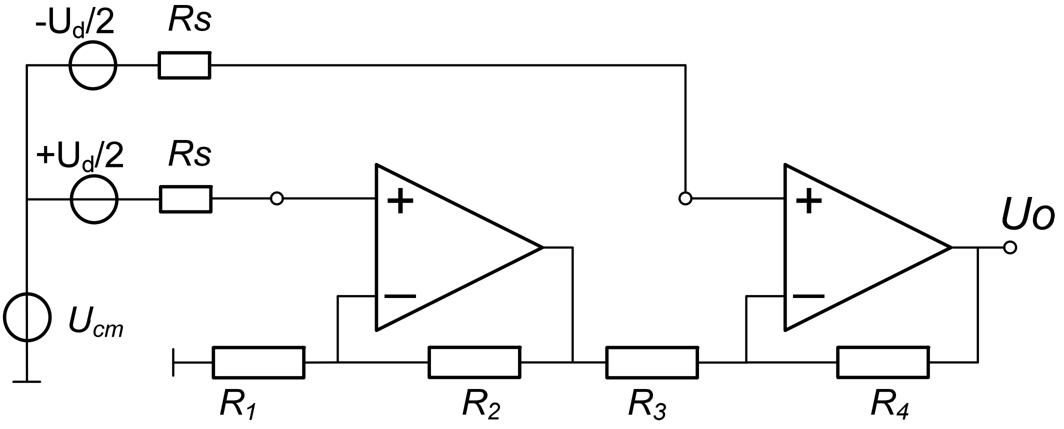
There are 5 questions in the exam
all of which should be attempted.

Please support your answers with the appropriate
explanations, drawings and circuit diagrams

Only the book and the slides
can be taken into the exam

— Good luck! —

1. Figure below shows an instrumentation amplifier (INA), built from two identical opamps, which is connected to a sensor with a source impedance $Rs = 10\ k\Omega$.



A) If the INA has a gain of 100 and $R_2 = R_3 = 10\ k\Omega$, what must the values of the other resistors R_2 and R_4 be?

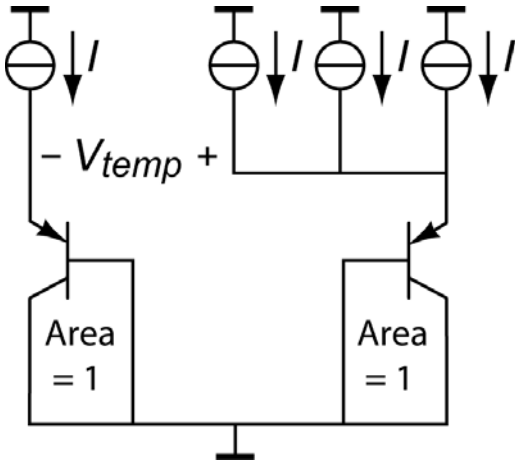
B) Calculate the detection limit due to offset and input bias current if each opamp has the following specifications:

Input offset voltage:	$V_{os} = 1mV$
Input offset current:	$I_{os} = 100nA$
Input bias current:	$I_b = 50nA$

C) If the amplifier's output Uo can swing from 0 to 5V and $U_{cm} = 2.5V$, calculate the maximum value of the differential input signal U_d for a distortion-free output.

D) If the various resistor ratios suffer from up to 1% mismatch, calculate the worst-case value of the INA's *CMRR*.

2. The following circuit employs two BJTs and four current sources to generate a voltage V_{temp} that is proportional to absolute temperature.



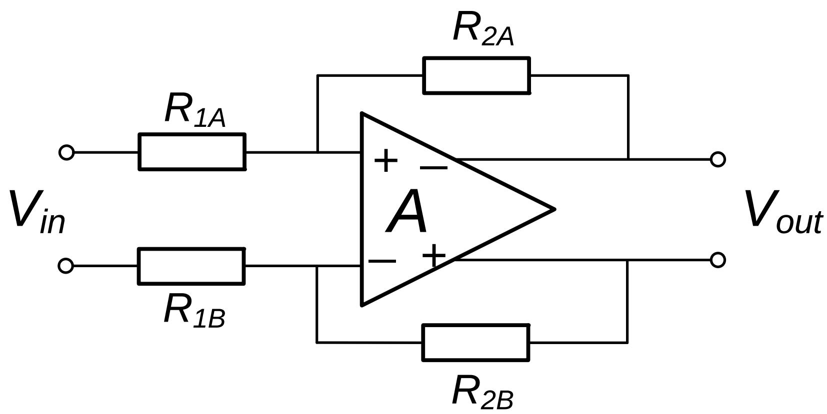
A) Derive an expression for V_{temp} in terms of the Boltzmann constant k and the electron charge q.

B) Assuming that one of the current sources suffers from 1% mismatch at room temperature (21°C), calculate the worst-case equivalent temperature error in V_{temp}.

C) Using a circuit diagram, describe how dynamic-element matching (DEM) can be used to mitigate the effects of the current source mismatch on the accuracy of V_{temp}. How many switches are required for your scheme?

D) After the application of this DEM scheme, compute the equivalent temperature error in the average value of V_{temp}.

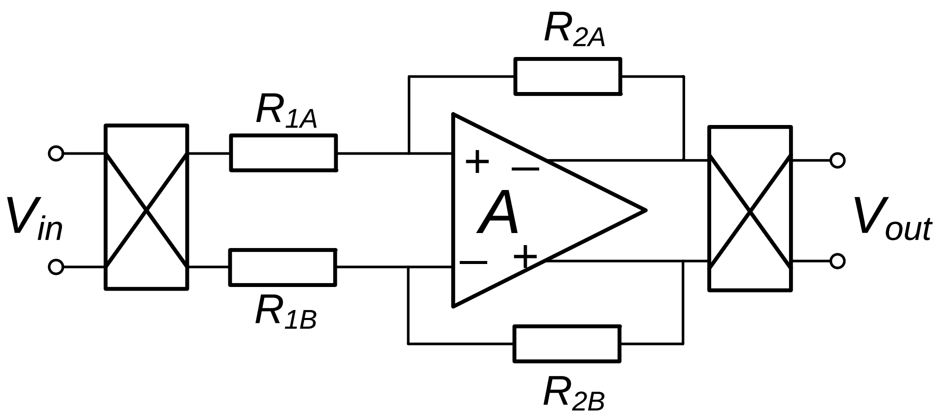
3. Figure below shows a fully differential amplifier based on a differential opamp with an input referred noise of 30 nV/√Hz and 10mV offset.



A) If the amplifier is to have a closed-loop gain of 100 and an input resistance of 100kΩ, calculate the corresponding values of $R_{2A} = R_{2B}$ and $R_{1A} = R_{1B}$.

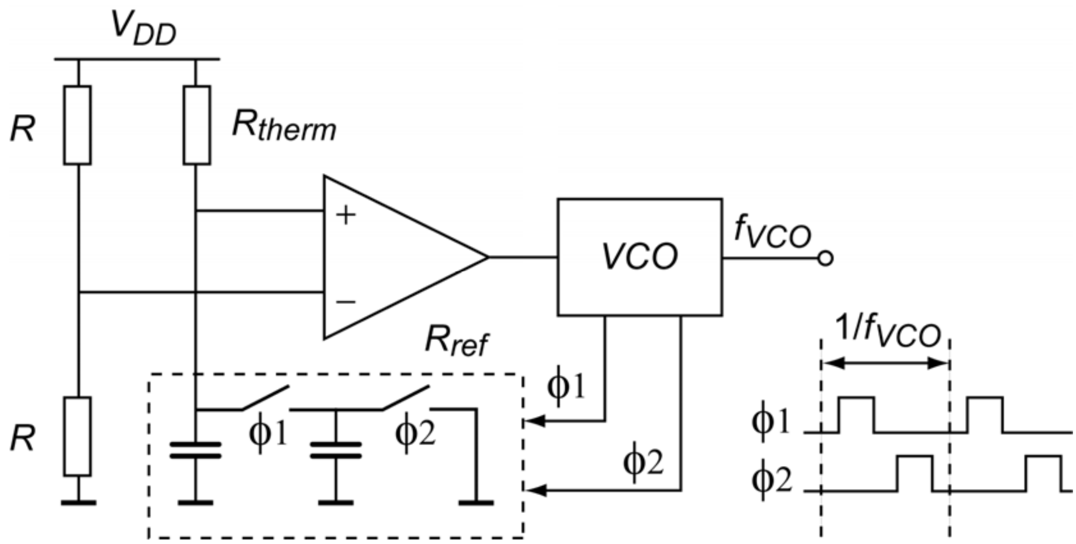
B) If the amplifier is to have a closed-loop gain of 100 and an input-referred noise is less than 50nV/√Hz, find the maximum (or minimum) value for the input resistors (R_{1A} and R_{1B}). Note: $4kT = 1.62 \times 10^{-20}$ (W/Hz).

C) To reduce the effect of the opamp's offset, the entire amplifier is chopped as shown below. Make a sketch of the output waveform assuming that the input signal has a common-mode voltage of 0V and a differential voltage of 10mV. What is the input-referred amplitude of the ripple?



D) To reduce the amplitude of the output ripple, the chopped amplifier is followed by a 1st order low-pass filter. Given that the amplifier's input-referred noise is 50 nV/√Hz and the chopping frequency is 10kHz, calculate the maximum cut-off frequency of the low-pass filter such that the input-referred amplitude of the ripple is less than the input-referred rms noise.

4. Consider the circuit below in which a thermistor R_{therm} is incorporated in a bridge circuit, which further consists of two fixed resistors and a variable reference resistance R_{ref}. This is implemented as a switched-capacitor network that periodically dumps charge to ground and whose effective resistance depends on the frequency f_{VCO} output by a voltage-controlled oscillator (VCO). Capacitor C_1 is much larger (100x) than C_2 and serves as a charge reservoir that reduces the ripple across R_{therm} to negligible levels. The bridge is embedded in a feedback loop, which adjusts f_{VCO} in such a way that the bridge is always balanced.



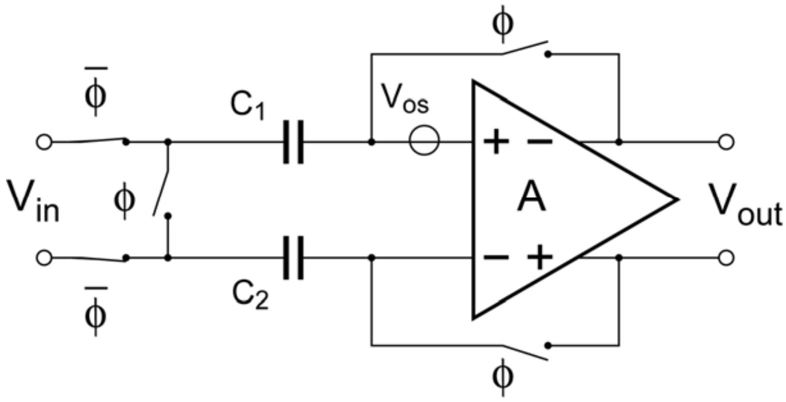
A) Derive an expression for R_{ref} in terms of f_{VCO}. Given that C_2 = 4pF and that R_{therm} = 6.6 kΩ at room temperature, what is the corresponding value of f_{VCO}?

B) Assuming that R_{therm} has a tempco of 0.3%/K, what change in f_{VCO} corresponds to a 1mK temperature change and how many bits of resolution are required to digitize this frequency change such that the resulting error is less than ½ an LSB.

C) If V_{DD} = 1.8V, what amount of opamp offset corresponds to an error of 0.1°C

D) DISCUSS the effect of the following non-idealities on the circuit: a non-linear VCO transfer function, VCO jitter, the charge injection associated with the two switches in the R_{ref} circuit..

5. Consider the auto-zeroed amplifier shown below:



A) If the amplifier's offset V_{os} = 10mV, determine the gain A of the basic amplifier such that the input-referred offset after auto-zeroing is less than 1μV.

B) If both the auto-zeroing and the amplification phases last 10μs, and given that all the switches have an on-resistance of 2kΩ, determine the worst-case value of C_1 (= C_2) such that settling errors are below 1μV (input-referred). Note: the opamp may be assumed to be ideal.

C) If both the auto-zeroing and the amplification phases last 10μs, determine the unity-gain bandwidth of the opamp such that all settling errors are below 1μV (input-referred). Note: the switches may be assumed to be ideal.

D) If the amplifier is assumed to be noise-free, what value of C_1 (= C_2) ensures that the residual input-referred noise after auto-zeroing is less than 1μV (rms).
Note: 4kT = 1.62×10^{-20} (W/Hz)