ECE 627

Midterm Examination

May 8, 2015

Open book

1. (10 %) In a flash ADC, each comparator has a dc offset error V_{os}. Assuming 8-bit resolution and V_{ref} = 5 V, what are the limits on these offsets, if

a. the condition |DNL| < ½ LSB must hold?

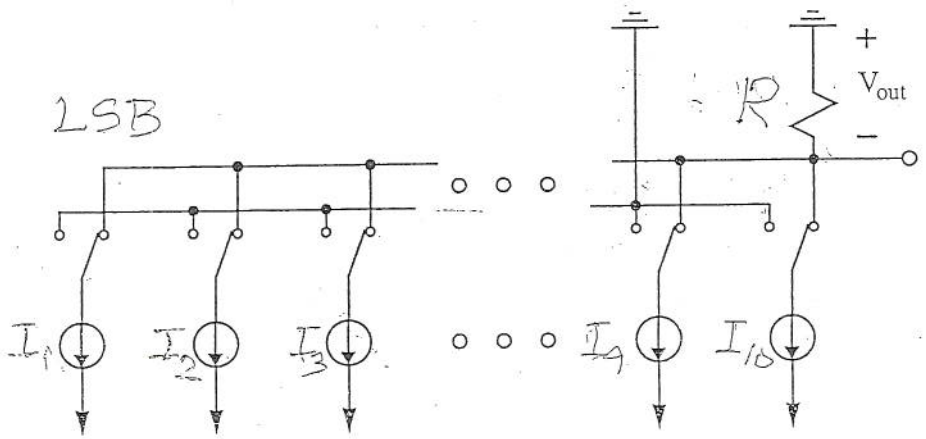
b. there must not be any missing code in the output?

2. (15 %) A 10-bit DAC is shown below. R = 50 Ω. The currents are ideally $I_k = 2^k$ μA, but each current may have a relative error e_k.

a. Find the magnitude of the largest permissible relative error $|e_{max}|$ for all currents, if |DNL| < ½ LSB.

b. What is the maximum INL for this error?

c. (5 % *extra credit)* What is the effect of the finite output impedances of the current sources? Assume $R_k = 10^6.2^{-k}.R$.

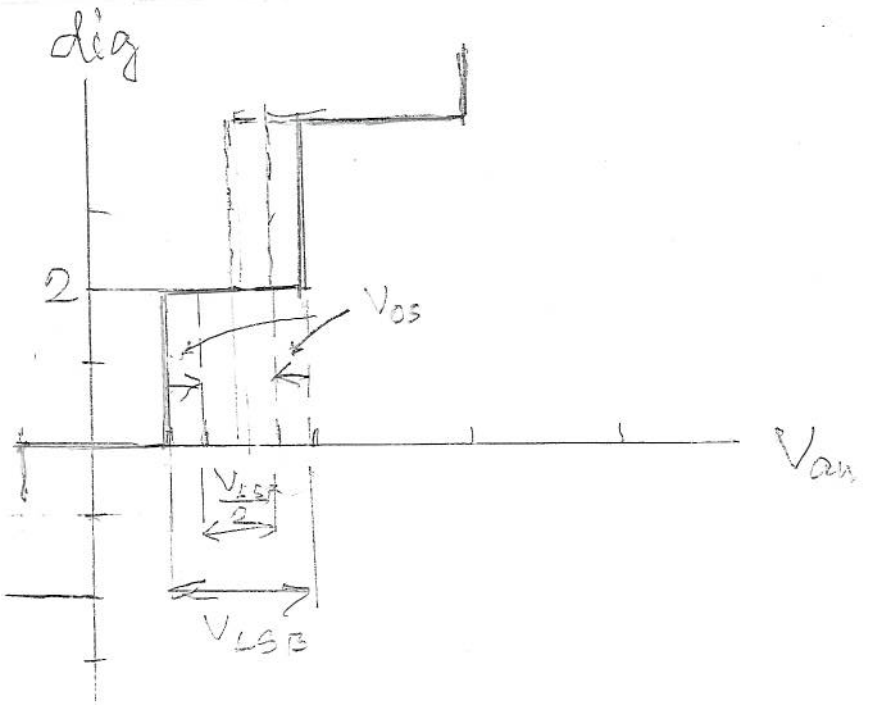


1. a. The input to the k^{th} comparator is $V_k = V_{ref,k} + V_{os,k} - V_{in}$. Hence, the $DNL_k = V_{os,k} - V_{os,k-1}$. For $|DNL_k| < (1/2) V_{LSB} = V_{ref}/2^{N+1}$, must have

$$|V_{os,k}| + |V_{os,k-1}| = 2|V_{os,max}| < 2^{-N-1} V_{ref}$$

$$\therefore |V_{os,max}| < V_{ref}/2^{N+2} = \frac{5}{2^{10}} \cong 4.9\ mV$$

b. Missing code occurs if $V_k < V_{k-1}$, which may occur if $2|V_{os,max}| > V_{LSB}$. Hence, to avoid it, $|V_{os,max}| < 9.8\ mV$



2.a Ideally, $V_{out} = R\sum_{k=1}^{10} b_k I_k$. With errors,

$$V_{out} = R\sum_{k=1}^{10} b_k 2^k \cdot 10^{-6}(1+e_k) \cdot DNL_{max}.$$

DNL_{max} occur for the major carry transitions $011\ldots1 \leftrightarrow 100\ldots0$. Then, the

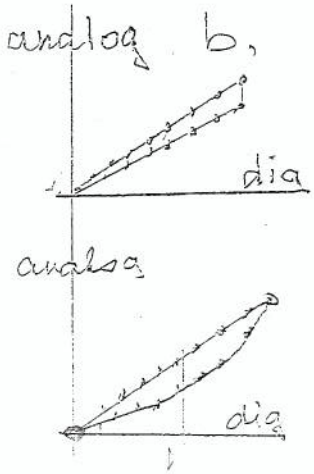
$$DNL = R\cdot 10^{-6}\sum_{k=1}^{10} 2^k e_k, \text{ and}$$

$$DNL_{max} = R\cdot 10^{-6}|e_{max}|\sum_{k=1}^{10} 2^k = \text{Hence,}$$

$DNL_{max} = V_{FS}|e_{max}|$, where V_{FS} is the full-scale output voltage:

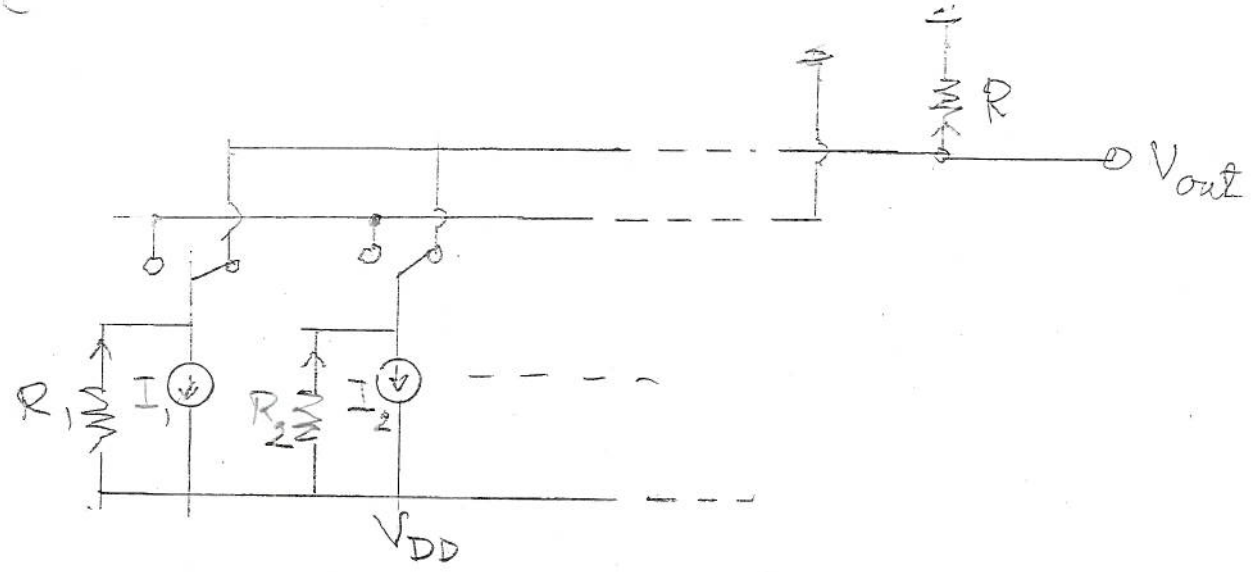
$V_{FS} = R(2^{11}-1)10^{-6} \cong 0.102$ V. Also, $V_{LSB} \cong 0.1$ mV. Hence, we have $|e_{max}| < V_{LSB}/(2V_{FS}) \cong 5\times10^{-4}$. Not realizable!

b. Absolute INL_{max} occurs for $e_k = e_{max}$, $\forall k$: $INL_{max_a} = DNL_{max} = 0.5\,V_{LSB}$.



End-point INL occurs for 100...00. Half of currents too large, half too small, so $INL_{max_{ep}} = 0.25\,V_{LSB}$.

2. c



KCL at V_{out} :

$$GV_{out} + \sum_k b_k I_k = \sum_k b_k G_k (V_{DD} - V_{out})$$

$$\left[G + \sum_k b_k G_k \right] V_{out} = \sum_k b_k (G_k V_{DD} - I_k)$$

$$V_{out} = \frac{\sum_k b_k \left(G \cdot 2^k 10^{-6} \cdot V_{DD} - 2^k \times 10^{-6} \right)}{G + \sum_k b_k G \cdot 2^k \times 10^{-6}}$$

$$= \frac{\sum_k b_k (G V_{DD} - 1)}{2^{-k} \cdot 10^6 \cdot G + G \sum_k b_k}$$

$V_{out} \not\propto \sum_k b_k 2^k$, nonlinear operation!