EE 230
Lecture 35
Data Converters
Determine the ratio of the small-signal transconductance of a BJT to that of a MOSFET if both are biased at a quiescent current of 1mA. Assume $uC_{OX}=1E-4A/V^2$, $V_T=1V$, $W=10\mu$, $L=8\mu$, $\lambda=0$, $J_A=1E-15$, $\beta=100$, $A_E=100\mu^2$ and $V_{AF}=\infty$. 
And the number is ?

1 3 8
5 2
9

? 4 6
7
Quiz 35

Determine the ratio of the small-signal transconductance of a BJT to that of a MOSFET is both are biased at a quiescent current of 1mA. Assume $u_{COX}=1E^{-4}A/V^2$, $V_T=1V$, $W=10u$, $L=8$, $\lambda=0$, $J_A=1E^{-15}$, $\beta=100$, $A_E=100u^2$ and $V_{AF}=\infty$.

\[
g_m = \frac{2I_{DQ}}{V_{GSQ} - V_T}
\]

\[
g_m = \frac{I_{CQ}}{V_t}
\]

\[
g_{mB} = \frac{V_t}{2I_{DQ}} = \frac{V_{GSQ} - V_T}{2V_t}
\]

\[
g_{mM} = \frac{I_{CQ}}{V_{GSQ} - V_T}
\]
Quiz 35

Determine the ratio of the small-signal transconductance of a BJT to that of a MOSFET is both are biased at a quiescent current of 1mA. Assume \( uC_{ox} = 1E-4A/V^2 \), \( V_T = 1V \), \( W = 10u \), \( L = 8u \), \( \lambda = 0 \), \( J_A = 1E-15 \), \( \beta = 100 \), \( A_E = 100u^2 \) and \( V_{AF} = \infty \).

\[
\frac{g_{mB}}{g_{mM}} = \frac{V_{GSQ} - V_T}{2V_T}
\]

\[
I_{DQ} = \frac{\mu C_{ox} W}{2L} (V_{GSQ} - V_T)^2
\]

\[
1mA = \frac{1E-4 \cdot 10}{2 \cdot 8} (V_{GSQ} - V_T)^2
\]

\[
V_{GSQ} - V_T = 4
\]

\[
\frac{g_{mB}}{g_{mM}} = \frac{V_{GSQ} - V_T}{2V_T} = \frac{4V}{2 \cdot 25mV} = 80
\]
Review from Last Time:

Small Signal-Large Signal Model of MOSFET in Saturation Region

Summary

Large Signal Model for Q-Point Calculations

\[ DQI \]

\[ \lambda \approx \frac{W}{2L} \left( V_{gsq} - V_T \right)^2 \]

Small Signal Model

Basic Model

\[ g_m = \mu C_{ox} \frac{W}{L} \left( V_{gsq} - V_T \right) \]

\[ g_o \approx \lambda I_{DQ} \]

Simplified

\[ g_m = \mu C_{ox} \frac{W}{L} \left( V_{gsq} - V_T \right) \]
Consider again:

Small signal analysis example

\[ A_v = \frac{2I_{DQ} R}{V_{SS} + V_T} \]

The gain expressions appear to be different!

\[ A_v = \frac{V_{OUT}}{V_{IN}} = -g_m R \]

but

\[ g_m = \frac{2I_{DQ}}{V_{GSQ} - V_T} \]

V_{GSQ} = -V_{SS}

thus

\[ A_v = \frac{2I_{DQ} R}{V_{SS} + V_T} \]
Small Signal Model of BJT

3-terminal device

Forward Active Model:

\[ I_C = J_S A_E e^{\frac{V_{BE}}{V_t}} \left( 1 + \frac{V_{CE}}{V_{AF}} \right) \]

\[ I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}} \]

Review from Last Time:

Usually operated in Forward Active Region when small-signal model is needed
Review from Last Time:
Small Signal-Large Signal Model of BJT in Forward Active Region

Summary

Large Signal Model for Q-Point Calculations

Small Signal Model

Basic Model

\[ g_\pi = \frac{I_{CQ}}{\beta V_t} \quad g_m = \frac{I_{CQ}}{V_t} \quad g_o = \frac{I_{CQ}}{V_{AF}} \]

Simplified

\[ g_\pi = \frac{1}{\beta V_t} \quad g_m = \frac{1}{V_t} \]
Data Converters

Standard Symbols:

Analog to Digital Converter

Digital to Analog Converter
Data Converters

Other Symbols:

Analog to Digital Converter

Number of Boolean Bits \( (n) \) is termed the resolution of the ADC
Data Converters

Analog variables: Voltage, Current, time, charge, occasionally other physical variables

Digital variables: Usually represented in binary form but other forms occasionally used (e.g. gray, Thermometer code)
Data Converters

Applications: Dominantly the interface between the continuous-time Continuous-amplitude physical environment and a digital system such as a computer, microprocessor, microcontroller, or finite state machine
Data Converters

Ideal n-bit DAC has $2^n$ output levels

$X_{\text{REF}}$ defines the output range of the DAC
Data Converters

Ideal n-bit ADC has $2^n - 1$ transition values

$X_{\text{IN}}$: $\left[ b_1 \ b_2 \ldots b_n \right]$

$X_{\text{REF}}$ defines the input range of the ADC
Data Converters

An ideal DAC

\[ X_{\text{OUT}} = X_{\text{REF}} \cdot D(X_{\text{IN}}) = X_{\text{REF}} \sum_{k=1}^{n} \frac{b_k}{2^k} \]

\( D(x) \) is the decimal equivalent of the boolean signal \( x \)
The LSB is the nominal value of the smallest change that occurs in the output of an ideal DAC or the nominal value of the smallest increment in the input that causes a change of a single binary digit in an ADC.

Continuous Domain

\[ X_{\text{LSB}} = \frac{X_{\text{REF}}}{2^n} \]

Boolean Domain

\[ X_{\text{LSB}}: [0,0,...,0,1] \]
Data Converters

\[ x_{\text{IN}} \rightarrow \text{ADC} \rightarrow x_{\text{OUT}} \]

\[ x_{\text{OUT}}: [b_1 b_2 \ldots b_n] \]

An ideal ADC

\[ X_{\text{REF}} D(B) < x_{\text{IN}} < X_{\text{REF}} D(B) + X_{\text{LSB}} \]
Example

Determine $V_{\text{LSB}}$ for a 16-bit ADC if $X_{\text{REF}}$ is a voltage of 1V.

$$X_{\text{LSB}} = \frac{1V}{2^{16}} = 15.25\mu V$$

Observe $X_{\text{LSB}}$ is very small and for a 16-bit ADC, must resolve an input signal to $\pm X_{\text{LSB}}/2 = \pm 7.5\mu V$
Resolution

The term “resolution” is an indicator of the number of levels an ADC can distinguish or the number of levels a DAC can provide.

*The exact meaning of the word “resolution” as related to data converters depends upon the context*

e.g. Consider a 10-bit data converter with a given $V_{\text{REF}}=1\text{V}$ ($V_{\text{LSB}}=.977\text{mV}$).

“the resolution of this data converter is 10-bits”
“this resolution of this data converter is 0.977 mV”
“this data converter resolves 1024 levels”
Resolution of audio DACs

**AUDIO D/A CONVERTERS**

Analog Devices offers a broad range of audio DACs for a number of applications. With a wide range of performance available, these audio DACs are perfectly suited for applications such as automotive audio, DVD players and recorders, Audio Video Receivers, Professional Mixing Consoles, and Digital Effects boxes.

### Audio D/A Converters

<table>
<thead>
<tr>
<th>Part# Results: 16</th>
<th>DAC DNR (dB)</th>
<th>SNR (dB)</th>
<th>DAC THD+N @ 1 kHz (-3dB)</th>
<th>Product Description</th>
<th>Price* (1000 pcs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD1953</td>
<td>112</td>
<td>112</td>
<td>100</td>
<td>SigmaDSP 3 Ch, 26-/48-Bit Processing D/A</td>
<td>$7.14</td>
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<tr>
<td>AD1954</td>
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<td>112</td>
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<td>SigmaDSP 3 Ch, 26-/48-Bit Processing D/A</td>
<td>$7.14</td>
</tr>
<tr>
<td>AD1933</td>
<td>110</td>
<td>110</td>
<td>96</td>
<td>192 kHz, 24-Bit CODEC w/ PLL</td>
<td>$3.66</td>
</tr>
<tr>
<td>AD1833A</td>
<td>110</td>
<td>110</td>
<td>95</td>
<td>Multi-Ch, 24-bit 192 kHz, Sigma-Delta D/A</td>
<td>$3.98</td>
</tr>
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<td>AD1958</td>
<td>109</td>
<td>108</td>
<td>96</td>
<td>Stereo, 24-bit 192 kHz Multibit Sigma-Delta D/A w/ PLL</td>
<td>**</td>
</tr>
<tr>
<td>AD1934</td>
<td>108</td>
<td>108</td>
<td>96</td>
<td>192 kHz, 24-Bit CODEC w/ PLL, I2C and SPI.</td>
<td>$3.15</td>
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<td>AD1851</td>
<td>96</td>
<td>110</td>
<td>90</td>
<td>16-Bit, 16.3 FS PCM Audio DACs Dual 5V Supplies</td>
<td>$4.71</td>
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<tr>
<td>AD1857</td>
<td>94</td>
<td>-</td>
<td>90</td>
<td>Stereo, Single Supply 16/18/20-bit Sigma-Delta D/A</td>
<td>**</td>
</tr>
<tr>
<td>AD1859</td>
<td>94</td>
<td>-</td>
<td>88</td>
<td>Stereo, Single Supply 18-bit Integrated Sigma-Delta D/A</td>
<td>$4.45</td>
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<tr>
<td>AD1858</td>
<td>94</td>
<td>-</td>
<td>90</td>
<td>Stereo, Single Supply 16-bit Sigma-Delta D/A</td>
<td>**</td>
</tr>
<tr>
<td>AD1868</td>
<td>92</td>
<td>96</td>
<td>88</td>
<td>Single Supply Dual 18-Bit Audio DAC</td>
<td>**</td>
</tr>
<tr>
<td>AD1866</td>
<td>90</td>
<td>95</td>
<td>86</td>
<td>Single Supply Dual 16-Bit Audio DAC</td>
<td>$10.57</td>
</tr>
</tbody>
</table>
Resolution of audio DACs

ESS Technology 32 bit Sabre DAC Chip

by Roy Harris

At the 2008 CES, I visited the ESS Technology room and I heard a demonstration of the Sabre 24 bit DAC chip. I was eager to review this chip after a brief listening session which included several of my reference CDs. I contacted the company to obtain a review sample, i.e., a DAC containing the Sabre chip but I did not receive the product from the company, during 2008. I received a call from a PR company in December of 2008, and was invited to visit the ESS Technology room at the 2009 CES for the introduction of a 32 bit Sabre DAC chip and was also offered an opportunity to review the Sabre DAC chip after January of 2009. I indicated that I would not attend the 2009 CES but expressed my interest to review the DAC chip.

Since it is not possible to review a DAC chip by itself, the subject of the review is an evaluation DAC, which includes the 32 bit Sabre DAC chip. The evaluation DAC is offered to engineers and other prospective purchasers of DAC chips to assess the performance of the chip. There is one company, Twisted Fear Audio, which offers a DAC, named the Buffalo DAC, incorporating the 32 bit Sabre DAC chip. Their website is www.twistedfearaudio.com. Currently, Samsung, Krell, McIntosh and Peach Tree Audio use the 24 bit Sabre DAC chip in some of their digital products. Visit the ESS Technology website for more information about the company and the DAC chip.
Example

Determine the number of bits of resolution, $n$, required in an ADC if it is to be used in a DMM that has accuracy corresponding to $m$ decimal digits.

Resolution of an $m$-digit DMM is $V_{\text{REF}}/10^m$.

Thus equating the resolution of an ADC represented in binary form to that of the DMM, we obtain the expression

$$\frac{V_{\text{REF}}}{2^n} = \frac{V_{\text{REF}}}{10^m}$$

It thus follows that

$$m = n \log_{10} 2$$

Solving for $n$, we obtain

$$n = \frac{m}{\log_{10} 2}$$

If $m=6$, $n=20$.

If $V_{\text{REF}}=1\text{V}$, $V_{\text{LSB}}=0.95\mu\text{V}$

If $V_{\text{REF}}=1\text{V}$, $V_{\text{LSB}}=112\text{nV}$

Very high resolution is required in applications such as this!
Example

If an ADC has ±x% accuracy, determine the effective resolution. (Will be more specific about ENOB later)

\[
\frac{1}{2^n} = \frac{2x}{100}
\]

\[
0 = n\log_{10} 2 + \log_{10} x - \log_{10} 100
\]

\[
n = \frac{2 - \log_{10} x}{\log_{10} 2}
\]

If \( m = 6 \), \( n = 20 \)

If \( m = 7 \), \( n = 23+ \)

If \( V_{\text{REF}} = 1\)V, \( V_{\text{LSB}} = 0.95\mu\)V

If \( V_{\text{REF}} = 1\)V, \( V_{\text{LSB}} = 112n\)V

Very high resolution is required in applications such as this!
The DMM and the Oscilloscope we have in the laboratory are basically an ADC, amplifier, and a computer with a case and front panel that makes them resemble the multimeters and oscilloscopes of the 50’s and 60’s. Interface is either through buttons and knobs on front or through computer interface.
The DMM and the Oscilloscope we have in the laboratory are basically an ADC, amplifier, and a computer with a case and front panel that makes them resemble the multimeters and oscilloscopes of the 50’s and 60’s. Interface is either through buttons and knobs on front or through computer interface.

What is the resolution of the ADC in the Oscilloscope and the DMM used in the laboratory?
### Characteristics

<table>
<thead>
<tr>
<th>Vertical System</th>
<th>DPO3012</th>
<th>DPO3014</th>
<th>DPO3032</th>
<th>DPO3034</th>
<th>DPO3052</th>
<th>DPO3054</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Channels</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Analog Bandwidth (-3dB)</td>
<td>100 MHz</td>
<td>100 MHz</td>
<td>300 MHz</td>
<td>300 MHz</td>
<td>500 MHz</td>
<td>500 MHz</td>
</tr>
<tr>
<td>Calculated Rise Time</td>
<td>3.5 ns</td>
<td>3.5 ns</td>
<td>1.17 ns</td>
<td>1.17 ns</td>
<td>700 ps</td>
<td>700 ps</td>
</tr>
<tr>
<td>5 mV/div (typical)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardware Bandwidth Limits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20 MHz or 150 MHz</td>
<td></td>
</tr>
<tr>
<td>Input Coupling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AC, DC, GND</td>
<td></td>
</tr>
<tr>
<td>Input Impedance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 MΩ ±1%, 75 Ω ±1%, 50 Ω ±1%</td>
<td></td>
</tr>
<tr>
<td>Input Sensitivity Range, 1 MΩ</td>
<td>1 mV/div to 10 V/div</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Sensitivity Range, 75 Ω, 50 Ω</td>
<td>1 mV/div to 1 V/div</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Resolution</td>
<td></td>
<td></td>
<td>8 bits</td>
<td>11 bits with Hi-Res</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Input Voltage, 1 MΩ</td>
<td></td>
<td></td>
<td>300 Vpeak with peaks ≤±450 V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Input Voltage, 75 Ω, 50 Ω</td>
<td></td>
<td></td>
<td>5 Vpeak with peaks ≤±20 V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC Gain Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±1.5% with offset set to 0 V</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Offset Range</th>
<th>1 MΩ</th>
<th>50 Ω, 75 Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mV/div to 99.5 mV/div</td>
<td>±1 V</td>
<td>±1 V</td>
</tr>
<tr>
<td>100 mV/div to 905 mV/div</td>
<td>±10 V</td>
<td>±5 V</td>
</tr>
<tr>
<td>1 V/div</td>
<td>±100 V</td>
<td>±5 V</td>
</tr>
<tr>
<td>1.01 V/div to 10 V/div</td>
<td>±100 V</td>
<td>NA</td>
</tr>
</tbody>
</table>

Channel-to-Channel Isolation (Any Two Channels at Equal Vertical Scale)

≥ 100:1 at ≤100 MHz and ≥ 30:1 at > 100 MHz up to the rated BW

**Accuracy is 1.5%**
Agilent 34410A and 34411A Multimeters
Setting the Standard for Next Generation Benchtop and System Testing

Product Overview
Agilent 34410A/11A
6 ½ Digit Multimeter
(includes the L4411A 1U DMM)

User’s Guide
**Accuracy Specifications** ± (% of reading + % of range)¹

<table>
<thead>
<tr>
<th>Function</th>
<th>Range</th>
<th>Frequency, Test Current or Burden Voltage</th>
<th>24 Hour Tcal ±1°C</th>
<th>90 Day Tcal ±5°C</th>
<th>1 Year Tcal ±5°C</th>
<th>Temperature Coefficient/°C 0°C to Tcal (Tcal -5°C) to 55°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Voltage</td>
<td>100.0000 mV</td>
<td>0.0030 + 0.0030</td>
<td>0.0040 + 0.0035</td>
<td>0.0050 + 0.0035</td>
<td>0.0005 + 0.0005</td>
<td>0.0005 + 0.0005</td>
</tr>
<tr>
<td></td>
<td>1.000000 V</td>
<td>0.0020 + 0.0006</td>
<td>0.0030 + 0.0007</td>
<td>0.0035 + 0.0007</td>
<td>0.0005 + 0.0001</td>
<td>0.0005 + 0.0001</td>
</tr>
<tr>
<td></td>
<td><strong>10.00000 V</strong></td>
<td><strong>0.0015 + 0.0004</strong></td>
<td><strong>0.0020 + 0.0005</strong></td>
<td><strong>0.0030 + 0.0005</strong></td>
<td><strong>0.0005 + 0.0001</strong></td>
<td><strong>0.0005 + 0.0001</strong></td>
</tr>
<tr>
<td></td>
<td>100.0000 µV</td>
<td>0.0020 + 0.0006</td>
<td>0.0035 + 0.0006</td>
<td>0.0040 + 0.0006</td>
<td>0.0005 + 0.0001</td>
<td>0.0005 + 0.0001</td>
</tr>
<tr>
<td></td>
<td>1000.0000 V</td>
<td>0.0020 + 0.0006</td>
<td>0.0035 + 0.0006</td>
<td>0.0040 + 0.0006</td>
<td>0.0005 + 0.0001</td>
<td>0.0005 + 0.0001</td>
</tr>
<tr>
<td>True RMS AC Voltage⁶</td>
<td>100.0000 mV to 750.0000 V</td>
<td>3 Hz – 5 Hz 0.50 + 0.02</td>
<td>0.50 + 0.03</td>
<td>0.50 + 0.03</td>
<td>0.10 ± 0.03</td>
<td>0.10 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>5 Hz – 10 Hz</td>
<td>0.10 ± 0.02</td>
<td>0.10 ± 0.03</td>
<td>0.10 ± 0.03</td>
<td>0.008 ± 0.003</td>
<td>0.008 ± 0.003</td>
</tr>
<tr>
<td></td>
<td>10 Hz – 20 kHz</td>
<td>0.02 ± 0.02</td>
<td>0.05 ± 0.03</td>
<td>0.06 ± 0.03</td>
<td>0.10 ± 0.05</td>
<td>0.005 ± 0.003</td>
</tr>
<tr>
<td></td>
<td>20 kHz – 50 kHz</td>
<td>0.05 ± 0.04</td>
<td>0.09 ± 0.05</td>
<td>0.10 ± 0.05</td>
<td>0.010 ± 0.005</td>
<td>0.010 ± 0.005</td>
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<tr>
<td></td>
<td>50 kHz – 100 kHz</td>
<td>0.20 ± 0.08</td>
<td>0.30 ± 0.08</td>
<td>0.40 ± 0.08</td>
<td>0.020 ± 0.008</td>
<td>0.020 ± 0.008</td>
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<tr>
<td></td>
<td>100 kHz – 300 kHz</td>
<td>1.00 ± 0.50</td>
<td>1.20 ± 0.50</td>
<td>1.20 ± 0.50</td>
<td>0.120 ± 0.020</td>
<td>0.120 ± 0.020</td>
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<tr>
<td>Resistance⁶</td>
<td>100.0000 Ω</td>
<td>1 mA</td>
<td>0.0030 + 0.0030</td>
<td>0.008 + 0.004</td>
<td>0.010 + 0.004</td>
<td>0.0006 ± 0.0005</td>
</tr>
<tr>
<td></td>
<td>1.000000 kΩ</td>
<td>1 mA</td>
<td>0.0020 + 0.0005</td>
<td>0.007 + 0.001</td>
<td>0.010 + 0.001</td>
<td>0.0006 ± 0.0001</td>
</tr>
<tr>
<td></td>
<td><strong>10.00000 µΩ</strong></td>
<td><strong>0.0020 + 0.0005</strong></td>
<td><strong>0.007 + 0.001</strong></td>
<td><strong>0.010 + 0.001</strong></td>
<td><strong>0.0006 + 0.0001</strong></td>
<td><strong>0.0006 + 0.0001</strong></td>
</tr>
<tr>
<td></td>
<td>100.0000 kΩ</td>
<td>10 µA</td>
<td>0.0020 + 0.0005</td>
<td>0.007 + 0.001</td>
<td>0.010 + 0.001</td>
<td>0.0006 ± 0.0001</td>
</tr>
<tr>
<td></td>
<td>1.000000 MΩ</td>
<td>5 µA</td>
<td>0.0020 + 0.0010</td>
<td>0.010 + 0.001</td>
<td>0.012 + 0.001</td>
<td>0.0010 ± 0.0002</td>
</tr>
<tr>
<td></td>
<td>10.000000 MΩ</td>
<td>500 nA</td>
<td>0.0100 ± 0.0010</td>
<td>0.030 ± 0.001</td>
<td>0.040 ± 0.001</td>
<td>0.0030 ± 0.0004</td>
</tr>
<tr>
<td></td>
<td>100.0000 MΩ</td>
<td>500 nA</td>
<td></td>
<td>10 MΩ</td>
<td>0.200 + 0.001</td>
<td>0.500 + 0.001</td>
</tr>
<tr>
<td></td>
<td>1.000000 GΩ</td>
<td>500 nA</td>
<td></td>
<td>10 MΩ</td>
<td>2.000 + 0.001</td>
<td>6.000 + 0.001</td>
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<tr>
<td>DC Current</td>
<td>100.0000 µA</td>
<td>&lt; 0.03 V</td>
<td>0.010 + 0.020</td>
<td>0.040 + 0.025</td>
<td>0.050 + 0.025</td>
<td>0.0020 + 0.0030</td>
</tr>
<tr>
<td></td>
<td><strong>1.000000 mA</strong></td>
<td><strong>&lt; 0.3 V</strong></td>
<td><strong>0.007 + 0.006</strong></td>
<td><strong>0.030 + 0.006</strong></td>
<td><strong>0.050 + 0.006</strong></td>
<td><strong>0.0020 + 0.0005</strong></td>
</tr>
<tr>
<td></td>
<td>10.00000 mA</td>
<td>&lt; 0.03 V</td>
<td>0.007 + 0.020</td>
<td>0.030 + 0.020</td>
<td>0.050 + 0.020</td>
<td>0.0020 + 0.0020</td>
</tr>
<tr>
<td></td>
<td>100.0000 mA</td>
<td>&lt; 0.3 V</td>
<td>0.010 + 0.004</td>
<td>0.030 + 0.005</td>
<td>0.050 + 0.005</td>
<td>0.0020 + 0.0005</td>
</tr>
<tr>
<td></td>
<td>1.000000 A</td>
<td>&lt; 0.8 V</td>
<td>0.050 + 0.006</td>
<td>0.080 + 0.010</td>
<td>0.100 + 0.010</td>
<td>0.0050 + 0.010</td>
</tr>
<tr>
<td></td>
<td>3.000000 A</td>
<td>&lt; 2.0 V</td>
<td>0.100 + 0.020</td>
<td>0.120 + 0.020</td>
<td>0.150 + 0.020</td>
<td>0.0050 + 0.020</td>
</tr>
</tbody>
</table>
End of Lecture 35