EE 230
Lecture 35

Data Converters

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, λ=0, J_A=1E-15, β=100, A_E=100u^2 and $V_{AF} = \infty$.

And the number is ?

1

3

8

5

4

?

2

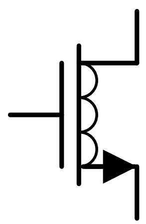
6

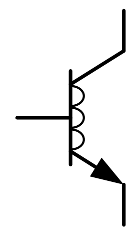
9

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 uC_{OX}=1E-4A/V^2 , V_T=1V, W=10u, L=8, λ=0, J_A=1E-15, β=100, A_E=100u^2 and V_{AF} = ∞.





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

$$g_m = \frac{I_{CQ}}{V_t}$$

$$\frac{g_{mB}}{g_{mM}} = \frac{\frac{I_{CQ}}{V_t}}{\frac{2I_{DQ}}{V_{GSQ} - V_T}} = \frac{V_{GSQ} - V_T}{2V_t}$$

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, λ=0, J_A=1E-15, β=100, A_E=100u^2 and V_{AF} = ∞.

$$\frac{g_{mB}}{g_{mM}} = \frac{V_{GSQ}-V_T}{2V_t}$$

$$I_{DQ}=\frac{\mu C_{OX}W}{2L}\left(V_{GSQ}-V_T\right)^2$$

$$1mA=\frac{1E\text{-}4 \bullet 10}{2 \bullet 8}\left(V_{GSQ}-V_T\right)^2$$

$$V_{GSQ}-V_T=4$$

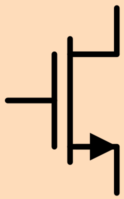
$$\frac{g_{mB}}{g_{mM}} = \frac{V_{GSQ}-V_T}{2V_t} = \frac{4V}{2 \bullet 25mV} = 80$$

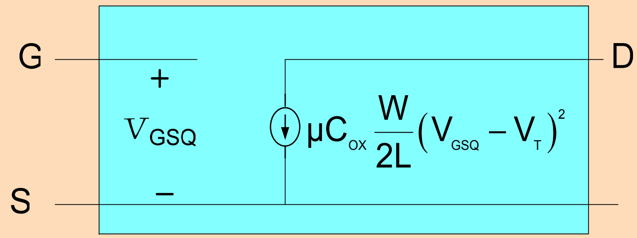
Review from Last Time:

Small Signal-Large Signal Model of MOSFET in Saturation Region

Summary

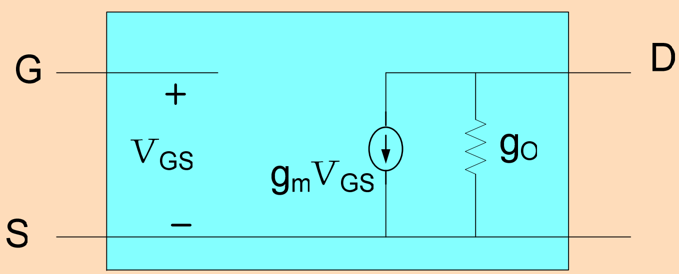
Large Signal Model for Q-Point Calculations





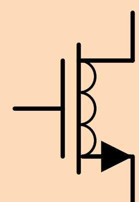
Small Signal Model

Basic Model

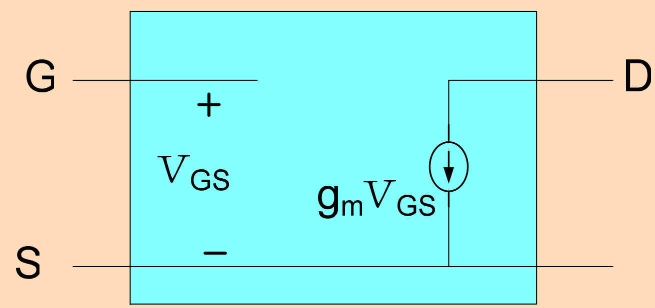


$$g_m = \mu C_{OX}\frac{W}{L}(V_{GSQ}-V_T)$$

$$g_o \cong \lambda I_{DQ}$$



Simplified

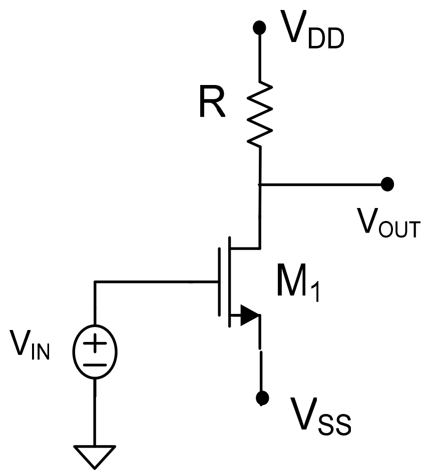


$$g_m = \mu C_{OX}\frac{W}{L}(V_{GSQ}-V_T)$$

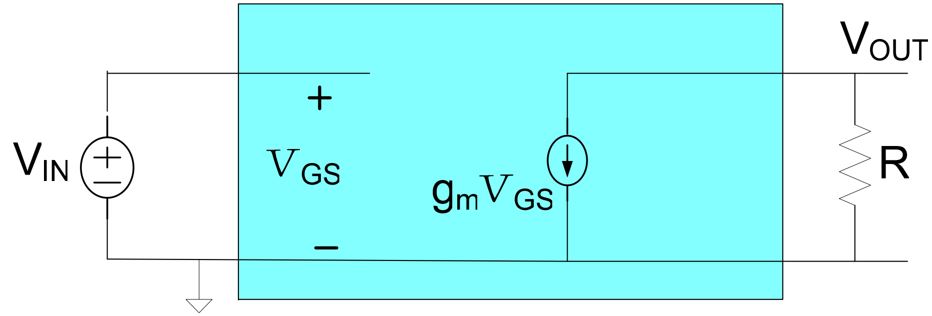
Review from Last Time:

Consider again:

Small signal analysis example

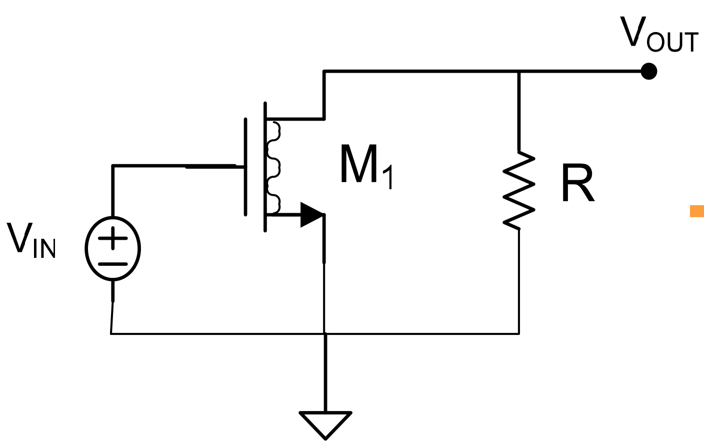


$$A_v = \frac{2I_{DQ}R}{[V_{SS}+V_T]}$$



$$A_V = \frac{V_{OUT}}{V_{IN}} = -g_m R$$

The gain expressions appear to be different !



but $g_m = \dfrac{2I_{DQ}}{V_{GSQ}-V_T}$ $\quad V_{GSQ} = -V_{SS}$

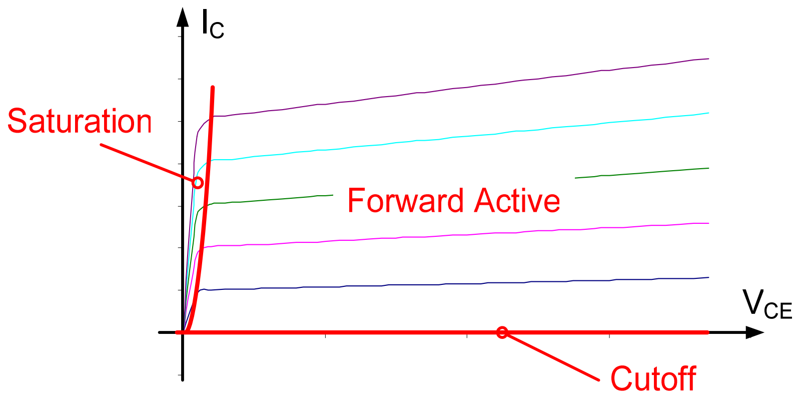
thus

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

Review from Last Time:

Small Signal Model of BJT

3-terminal device



Forward Active Model:

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

$$\mathbf{I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}}}$$

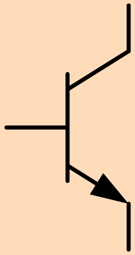
Usually operated in Forward Active Region when small-signal model is needed

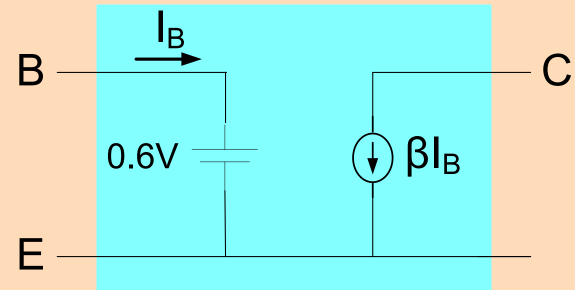
Review from Last Time:

Small Signal-Large Signal Model of BJT in Forward Active Region

Summary

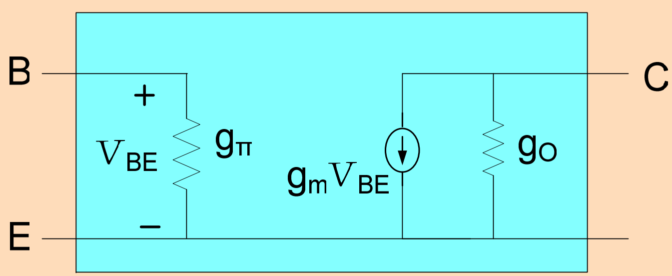
Large Signal Model for Q-Point Calculations



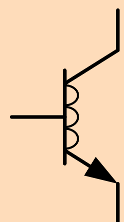


Small Signal Model

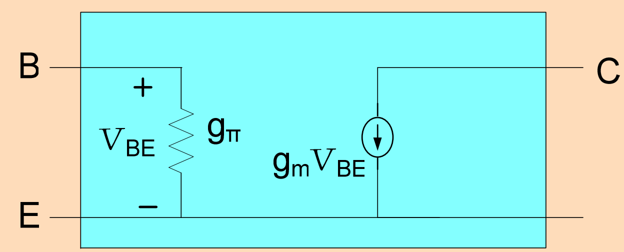
Basic Model



$$g_\pi = \frac{I_{CQ}}{\beta V_t} \qquad g_m = \frac{I_{CQ}}{V_t} \qquad g_o = \frac{I_{CQ}}{V_{AF}}$$



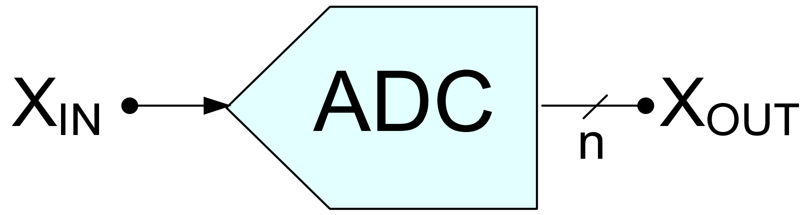
Simplified



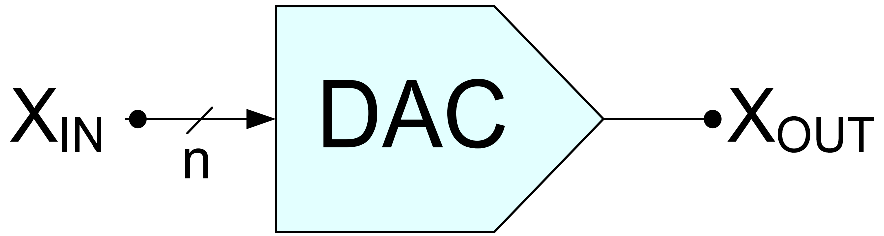
$$g_\pi = \frac{I_{CQ}}{\beta V_t} \qquad g_m = \frac{I_{CQ}}{V_t}$$

Data Converters

Standard Symbols:



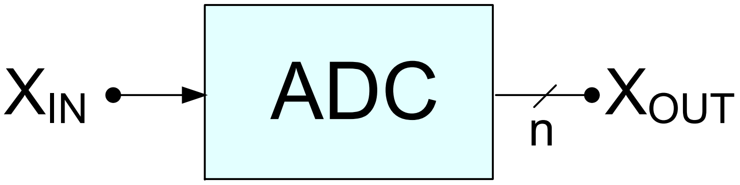
Analog to Digital Converter



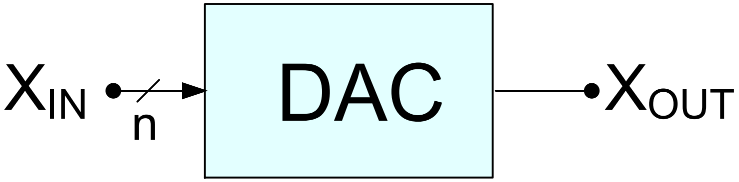
Digital to Analog Converter

Data Converters

Other Symbols:



Analog to Digital Converter



Digital to Analog Converter

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

Data Converters

	X_{IN}	X_{OUT}
ADC	Analog	Digital
DAC	Digital	Analog

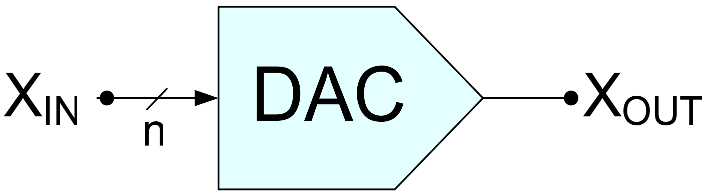
Analog variables: Voltage, Current, time, charge, occasionally other physical variables

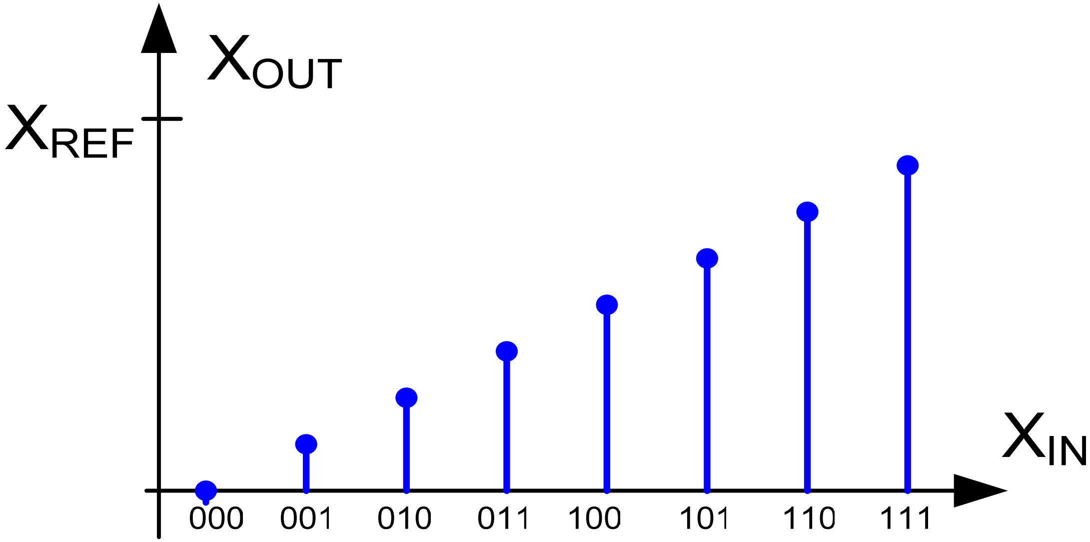
Digital variables: Usually represented in binary form but other forms occasionally used (e.g. gray, Thermometer code)

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



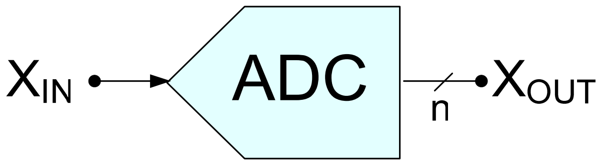


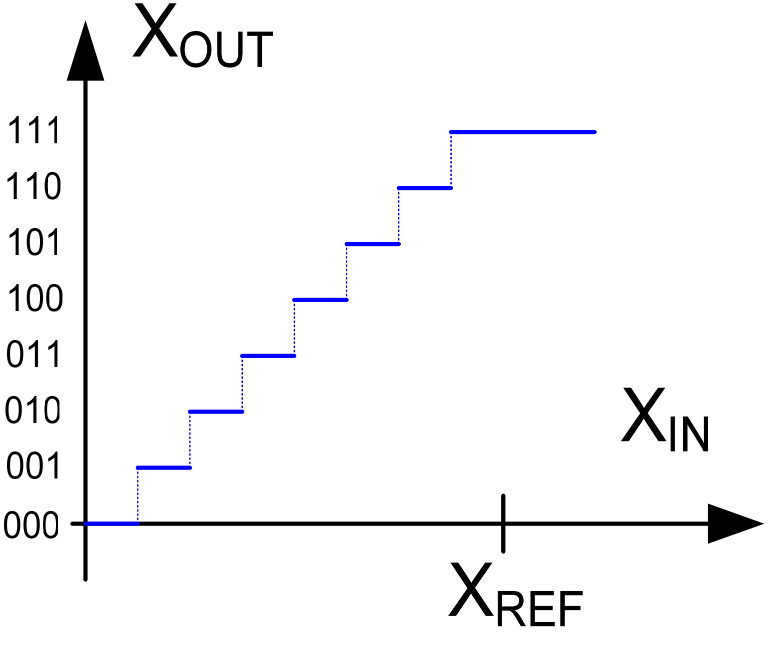
X_{IN}: $[b_1\, b_2 \ldots b_n]$

Ideal n-bit DAC has 2^n output levels

X_{REF} defines the output range of the DAC

Data Converters



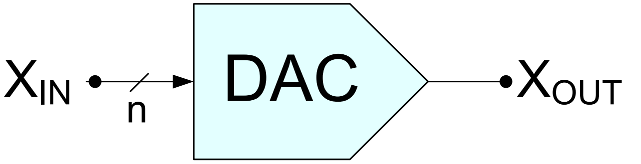


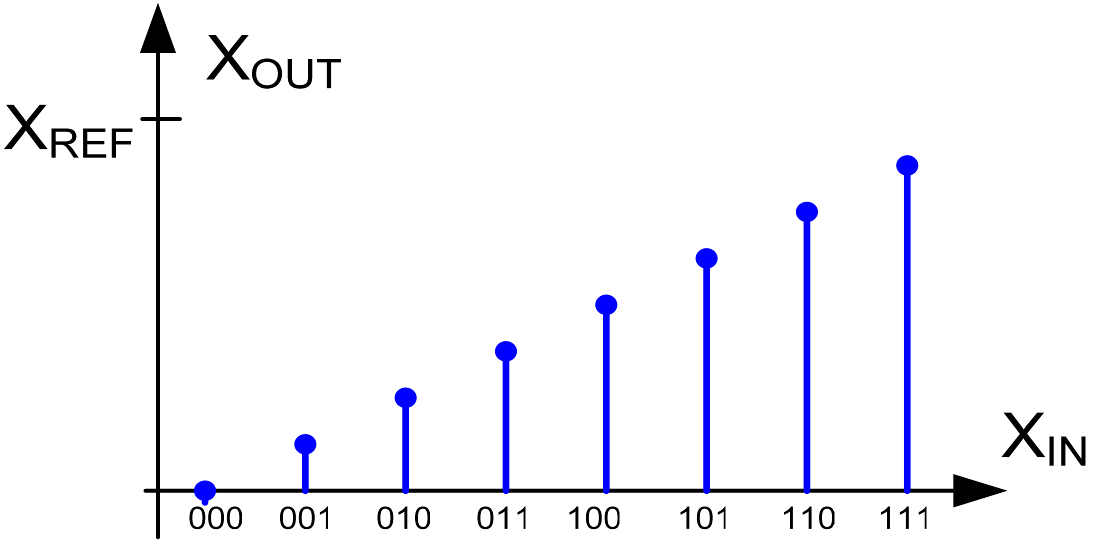
X_{OUT}: $[b_1\, b_2 \ldots b_n]$

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

X_{REF} defines the input range of the ADC

Data Converters





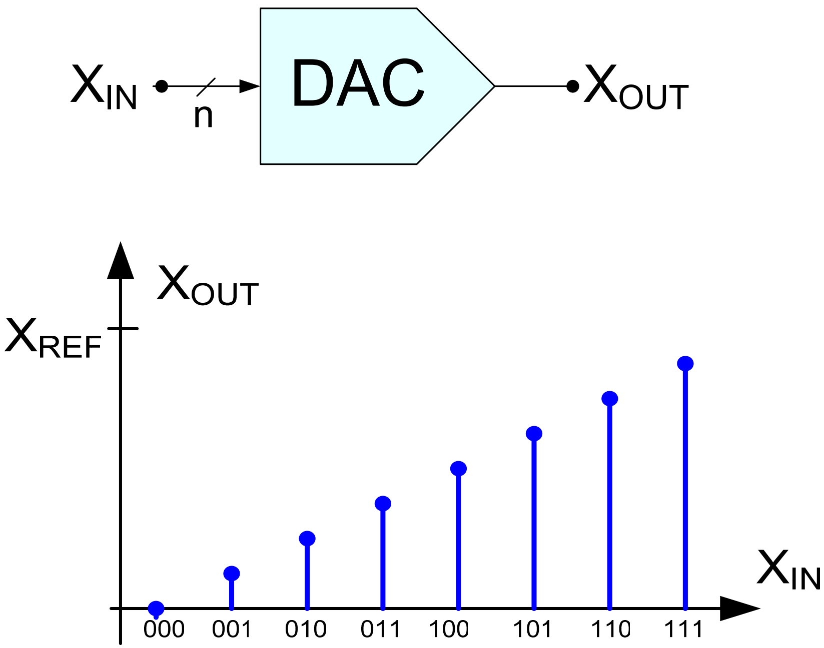
X_{IN}: [b_1 b_2....b_n]

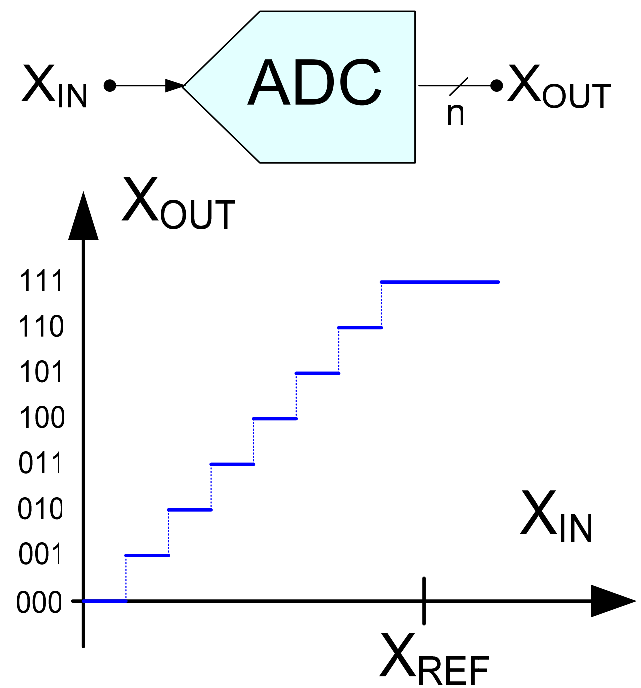
An ideal DAC

$$X_{OUT}=X_{REF}D\left(X_{IN}\right)=X_{REF}\sum_{k=1}^{n}\frac{b_k}{2^k}$$

D(x) is the decimal equivalent of the boolean signal x

Least Significant Bit





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

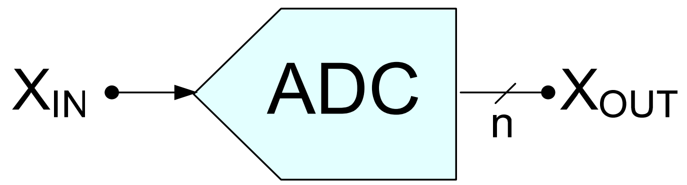
Continuous Domain

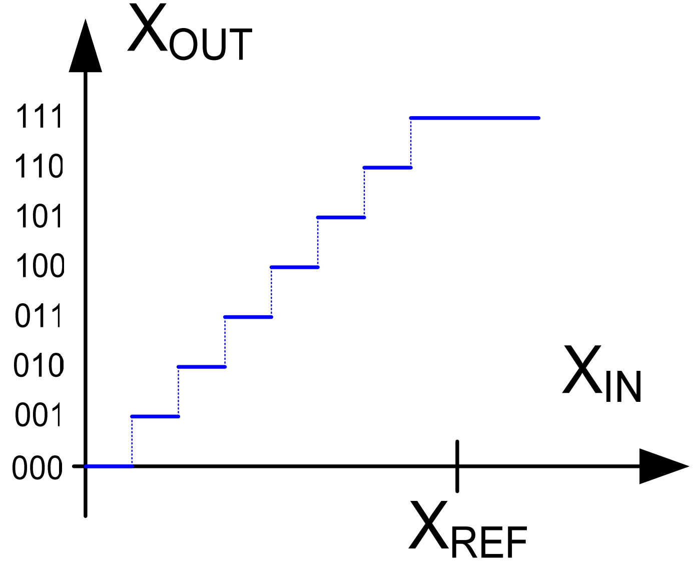
$$X_{LSB} = \frac{X_{REF}}{2^n}$$

Boolean Domain

$\mathbf{X_{LSB}}$**: [0,0,…0,1]**

Data Converters





$\mathbf{X_{OUT}}$: $[b_1\, b_2 \ldots . b_n]$

An ideal ADC

$$X_{REF} D(B) < X_{IN} < X_{REF} D(B) + X_{LSB}$$

Example

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

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

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

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_{REF}=1V (V_{LSB}=.977mV).

“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

APPLY FILTERS TO THIS TAE

Part# Results: 16	DAC DNR (dB)	SNR (dB)	DAC THD+N @ 1 kHz (-3dB)	Product Description	Price* (1000 pcs.)
AD1953	112	112	100	SigmaDSP 3 Ch, 26-/48-Bit Processing D/A	$7.14
AD1954	112	112	100	SigmaDSP 3 Ch, 26-/48-Bit Processing D/A	$7.14
AD1933	110	110	96	192 kHz, 24-Bit CODEC w/ PLL	$3.66
AD1833A	110	110	95	Multi-Ch, 24-bit 192 kHz, Sigma-Delta D/A	$3.98
AD1958	109	108	96	Stereo, 24-bit 192 kHz Multibit Sigma-Delta D/A w/ PLL	**
AD1934	108	108	96	192 kHz, 24-Bit CODEC w/ PLL, I2C and SPI.	$3.15
AD1851	96	110	90	16-Bit, 16 3 FS PCM Audio DACs Dual 5V Supplies	$4.71
AD1857	94	-	90	Stereo, Single Supply 16/18/20-bit Sigma-Delta D/A	**
AD1859	94	-	88	Stereo, Single Supply 18-bit Integrated Sigma-Delta D/A	$4.45
AD1858	94	-	90	Stereo, Single Supply 16-bit Sigma-Delta D/A	**
AD1868	92	98	88	Single Supply Dual 18-Bit Audio DAC	**
AD1866	90	95	86	Single Supply Dual 16-Bit Audio DAC	$10.57

Resolution of audio DACs

ESS Technology 32 bit Sabre DAC Chip

APRIL 17, 2009 • 7 COMMENTS
in DIGITAL

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 called 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 Pear Audio which offers a DAC, named the Buffalo Dac, incorporating the 32 bit Sabre DAC chip. Their website is www.twistedpearaudio.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 $V_{REF}/10^m$

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

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

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 m=7, n=23+

If V_{REF}=1V, V_{LSB}=0.95μV

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

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

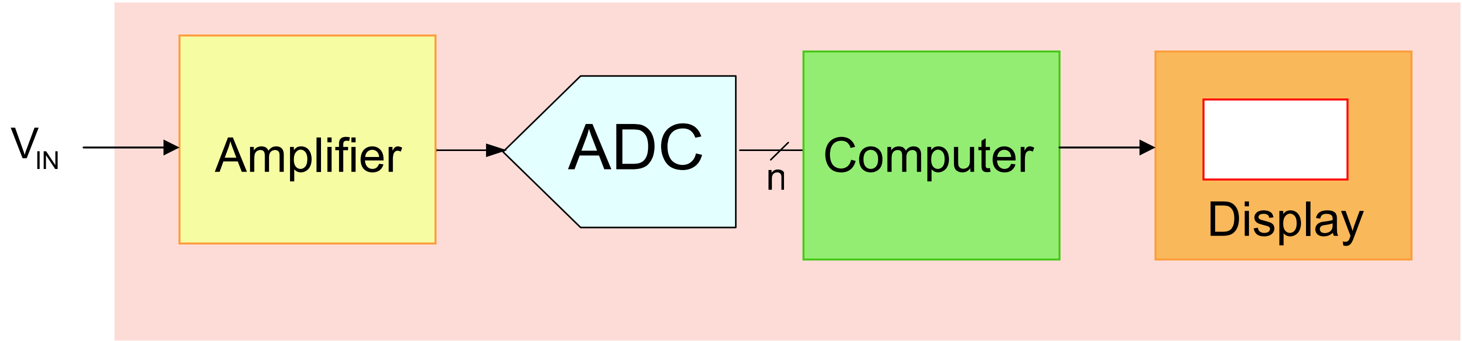
If m=7, n=23+

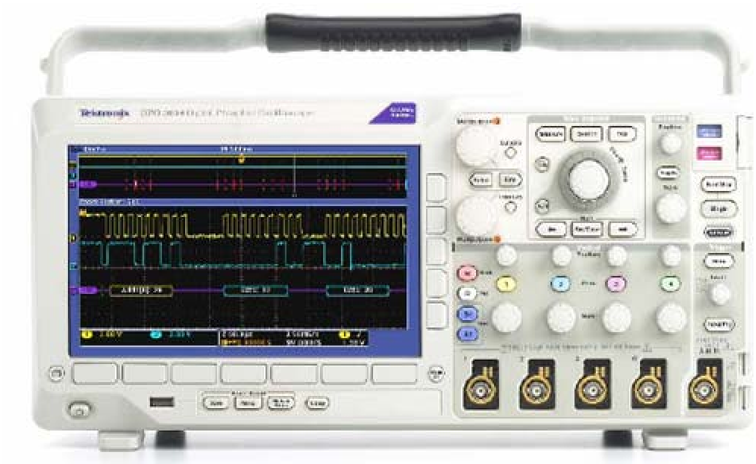
If V_{REF}=1V, V_{LSB}=0.95μV

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

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 mulitmeters and oscilloscopes of the 50's and 60's. Interface is either through buttons and knobs on front or through computer interface.





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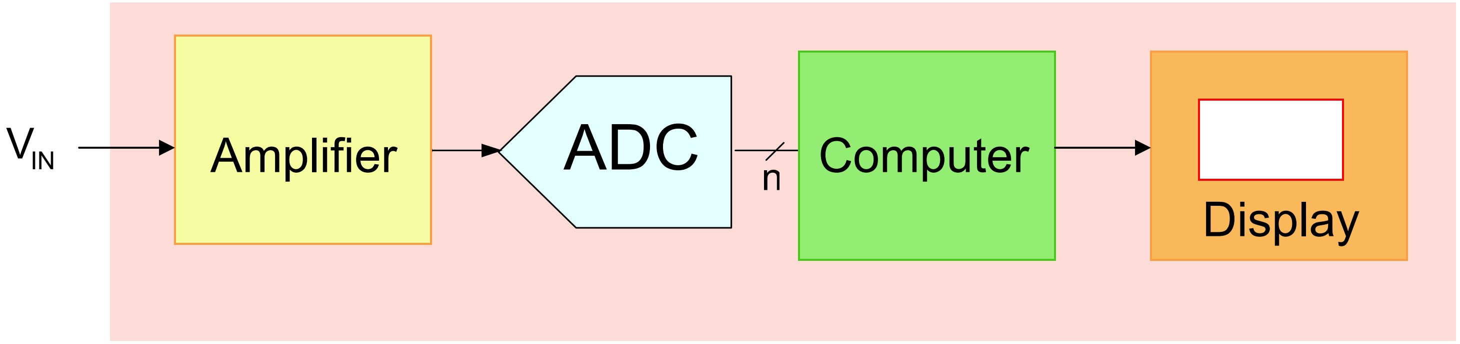
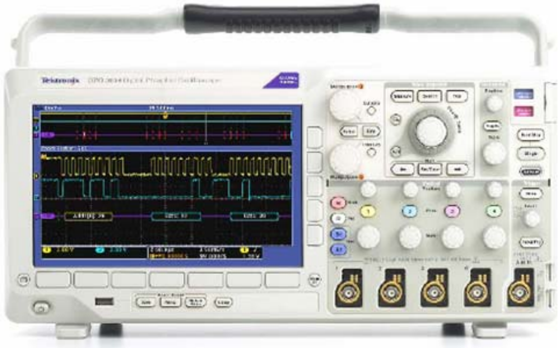


What is the resolution of the ADC in the Oscilloscope and the DMM used in the laboratory?



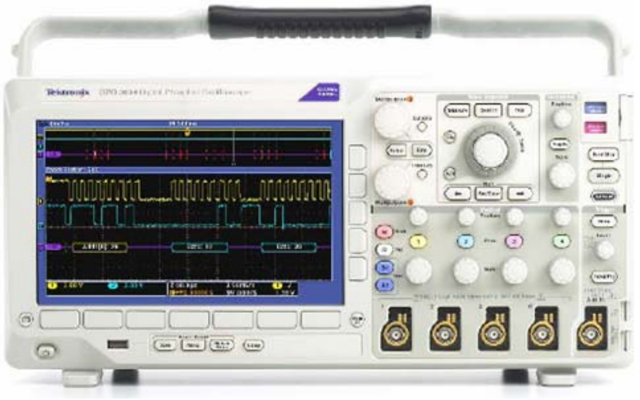
DPO3000 Series
Digital Phosphor Oscilloscopes

User Manual

www.tektronix.com

071-2410-01

Tektronix



▸ Characteristics

Vertical System	DPO3012	DPO3014	DPO3032	DPO3034	DPO3052	DPO3054
Input Channels	2	4	2	4	2	4
Analog Bandwidth (–3dB)	100 MHz	100 MHz	300 MHz	300 MHz	500 MHz	500 MHz
Calculated Rise Time 5 mV/div (typical)	3.5 ns	3.5 ns	1.17 ns	1.17 ns	700 ps	700 ps
Hardware Bandwidth Limits	20 MHz or 150 MHz					
Input Coupling	AC, DC, GND					
Input Impedance	1 MΩ ±1%, 75 Ω ±1%, 50 Ω ±1%					
Input Sensitivity Range, 1 MΩ	1 mV/div to 10 V/div					
Input Sensitivity Range, 75 Ω, 50 Ω	1 mV/div to 1 V/div					
Vertical Resolution	8 bits (11 bits with Hi-Res)					
Max Input Voltage, 1 MΩ	300 V_{RMS} with peaks ≤±450 V					
Max Input Voltage, 75 Ω, 50 Ω	5 V_{RMS} with peaks ≤± 20 V					
DC Gain Accuracy	±1.5% with offset set to 0 V					
Offset Range		**1 MΩ**			**50 Ω, 75 Ω**	
1 mV/div to 99.5 mV/div		±1 V			±1 V	
100 mV/div to 995 mV/div		±10 V			±5 V	
1 V/div		±100 V			±5 V	
1.01 V/div to 10 V/div		±100 V			NA	
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

D

D

U

Agilent 34410A/11A 6 ½ Digit Multimeter

(includes the L4411A 1U DMM)

User's Guide

Agilent Technologies

Accuracy Specifications ± (% of reading + % of range)[1]

Function	Range[3]	Frequency, Test Current or Burden Voltage	24 Hour[2] Tcal ±1°C	90 Day Tcal ±5°C	1 Year Tcal ±5°C	Temperature Coefficient/°C 0°C to (Tcal -5°C) (Tcal +5°C) to 55°C
DC Voltage	100.0000 mV		0.0030 + 0.0030	0.0040 + 0.0035	0.0050 + 0.0035	0.0005 + 0.0005
	1.000000 V		0.0020 + 0.0006	0.0030 + 0.0007	0.0035 + 0.0007	0.0005 + 0.0001
	10.00000 V		**0.0015 + 0.0004**	**0.0020 + 0.0005**	**0.0030 + 0.0005**	**0.0005 + 0.0001**
	100.0000 V		0.0020 + 0.0006	0.0035 + 0.0006	0.0040 + 0.0006	0.0005 + 0.0001
	1000.000 V[4]		0.0020 + 0.0006	0.0035 + 0.0006	0.0040 + 0.0006	0.0005 + 0.0001
True RMS AC Voltage[5]	100.0000 mV to 750.000 V	3 Hz – 5 Hz	0.50 + 0.02	0.50 + 0.03	0.50 + 0.03	0.010 + 0.003
		5 Hz – 10 Hz	0.10 + 0.02	0.10 + 0.03	0.10 + 0.03	0.008 + 0.003
		10 Hz – 20 kHz	**0.02 + 0.02**	**0.05 + 0.03**	**0.06 + 0.03**	**0.005 + 0.003**
		20 kHz – 50 kHz	0.05 + 0.04	0.09 + 0.05	0.10 + 0.05	0.010 + 0.005
		50 kHz – 100 kHz	0.20 + 0.08	0.30 + 0.08	0.40 + 0.08	0.020 + 0.008
		100 kHz – 300 kHz	1.00 + 0.50	1.20 + 0.50	1.20 + 0.50	0.120 + 0.020
Resistance[6]	100.0000 Ω	1 mA	0.0030 + 0.0030	0.008 + 0.004	0.010 + 0.004	0.0006 + 0.0005
	1.000000 kΩ	1 mA	0.0020 + 0.0005	0.007 + 0.001	0.010 + 0.001	0.0006 + 0.0001
	10.00000 kΩ	**100 µA**	**0.0020 + 0.0005**	**0.007 + 0.001**	**0.010 + 0.001**	**0.0006 + 0.0001**
	100.0000 kΩ	10 µA	0.0020 + 0.0005	0.007 + 0.001	0.010 + 0.001	0.0006 + 0.0001
	1.000000 MΩ	5 µA	0.0020 + 0.0010	0.010 + 0.001	0.012 + 0.001	0.0010 + 0.0002
	10.00000 MΩ	500 nA	0.0100 + 0.0010	0.030 + 0.001	0.040 + 0.001	0.0030 + 0.0004
	100.0000 MΩ	500 nA || 10 MΩ	0.200 + 0.001	0.600 + 0.001	0.800 + 0.001	0.1000 + 0.0001
	1.000000 GΩ	500 nA || 10 MΩ	2.000 + 0.001	6.000 + 0.001	8.000 + 0.001	1.0000 + 0.0001
DC Current	100.0000 µA	< 0.03 V	0.010 + 0.020	0.040 + 0.025	0.050 + 0.025	0.0020 + 0.0030
	1.000000 mA	**< 0.3 V**	**0.007 + 0.006**	**0.030 + 0.006**	**0.050 + 0.006**	**0.0020 + 0.0005**
	10.00000 mA	< 0.03 V	0.007 + 0.020	0.030 + 0.020	0.050 + 0.020	0.0020 + 0.0020
	100.0000 mA	< 0.3 V	0.010 + 0.004	0.030 + 0.005	0.050 + 0.005	0.0020 + 0.0005
	1.000000 A	< 0.8 V	0.050 + 0.006	0.080 + 0.010	0.100 + 0.010	0.0050 + 0.0010
	3.000000 A	< 2.0 V	0.100 + 0.020	0.120 + 0.020	0.150 + 0.020	0.0050 + 0.0020

End of Lecture 35