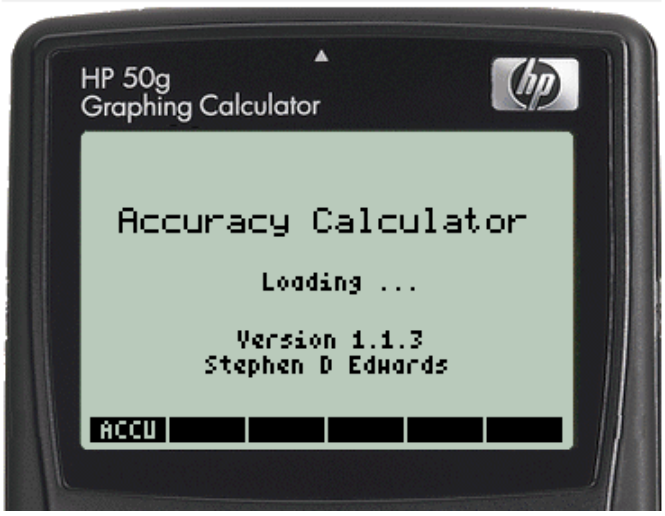
ACCURACY CALCULATOR USER'S GUIDE



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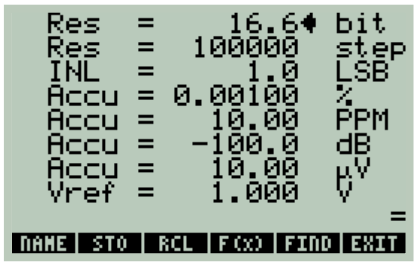
SECTION 1 - INTRODUCTION

Accuracy Calculator (ACCU) is a program written for the HP50g calculator that aids in the design and analysis of data converter application circuits. ACCU calculates the DC accuracy of an ideal data convertor. The DC accuracy of a data converter is the measure of the maximum deviation from the ideal linear transfer function. Each parameter can be entered or found. ACCU can also be run on a PC using the free program HPUserEdit 5.4, found at www.hpcalc.org, or the calculator page at www.maximintegrated.com.

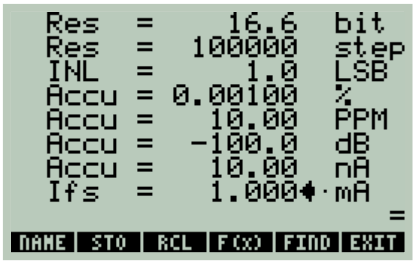
Three parameters can be entered or found,

- Resolution, **Res,** in bits or steps
- Integral Nonlinearity, **INL,** in LSB
- Accuracy, **Accu**, in %, PPM, dB, µV, or nA

ACCU finds any parameter as a function of the others, making it useful for both design and analysis of both Analog-to-Digital Convertors (ADC) and Digital-to-Analog Convertors (DACs) applications circuits. These parameters appear in ACCU as shown below:



The alternative parameters **Accu** in nA and **Ifs** in mA can be displayed instead of **Accu** in uV and **Vref** in V.



A small dot to the right of the selection arrow serves as a reminder that an alternative parameter is available. Press the right arrow key to select the alternative parameter.

Refer to Section 7 for an explanation of these parameters and how they are calculated.

SECTION 2 - INSTALLATION

ACCU can be installed on the HP50g calculator or a Windows PC.

Installing ACCU on the HP50g Calculator

ACCU may be installed in any one of three ways:

A. Best when installing one calculator:

Copy the executable file ACCU.hp to the home directory or subdirectory of the HP50g calculator. Launch ACCU.hp.

B. Best when installing between two and six calculators:

Copy the executable file ACCU.hp to the root directory of an SD card, and the much smaller file ACCU to the home directory or subdirectory of the HP50g calculator. Launch ACCU.

C. Best when installing six or more calculators:

Install ACCU using the Calculator Launcher (CALC) utility found at www.maximintegrated.com/design/tools/calculators/hp50g/. Refer to the CALC User's Guide for an explanation of this utility.

Refer to the HP50g Graphing Calculator User's Guide for instructions on how to copy files to the calculator.

Installing ACCU on a Windows PC

ACCU can be run on a Windows PC using the free program HPUserEdit 5.4. HPUserEdit is an IDE for the HP50g and contains a suitable emulator.

To install HPUserEdit:

Download and install HPUserEdit 5.4, found at www.hpcalc.org. Search for "HPUserEdit5". The default language is Spanish. However, other languages can be selected as follows,

1. Select 'Opciones' (Options)
2. Select 'Idiomas' (Language)
3. Select the preferred language (English is assumed in this document)

To run ACCU:

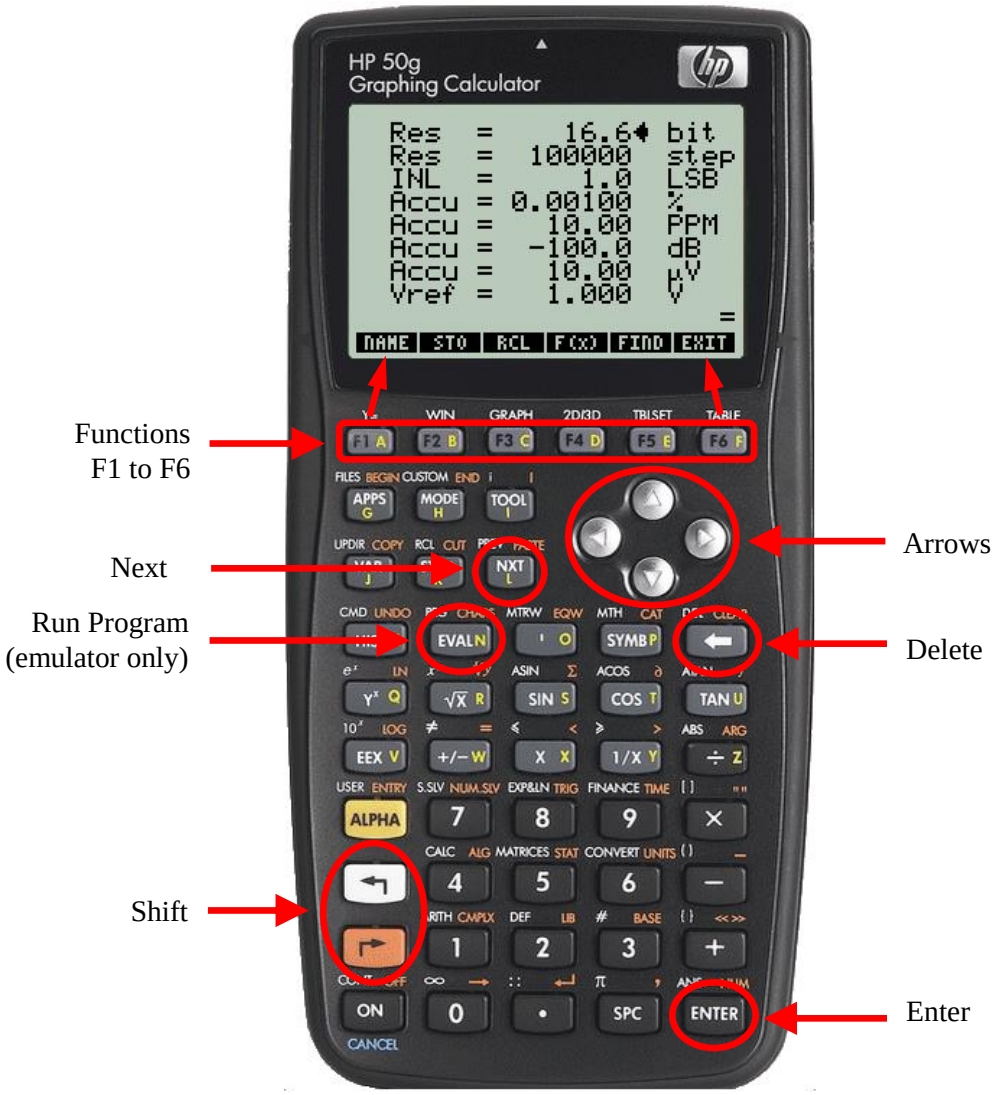
1. Launch HPUserEdit
2. Launch the HP50g emulator by selecting Emulator/Run_the_Emulator from the menu bar. A virtual HP50g appears.
3. Drag and drop ACCU.hp to the calculator screen and click the EVAL key.

The splash screen shown on page 1 of this guide is displayed when the calculator is loading. It appears momentarily, and may not be visible when run on a PC.

ACCU creates a file named 'CalcDB' in the calculator's home directory the first time it is run. 'CalcDB' holds the parametric values used by ACCU when launched, and is used by the STO and RCL commands to store and recall the parameters.

SECTION 3 - KEYBOARD

The following diagram shows the location of all keys used by ACCU:



For convenience, when using the emulator, the calculator keys map to the PC keyboard as follows:

Calculator Keys	↔	PC Keyboard
Numbers	↔	Numbers
Enter and Delete	↔	Enter and Delete
Yellow Letters	↔	Letters
Arrows	↔	Arrows
Left Shift	↔	Shift
Right Shift	↔	Control

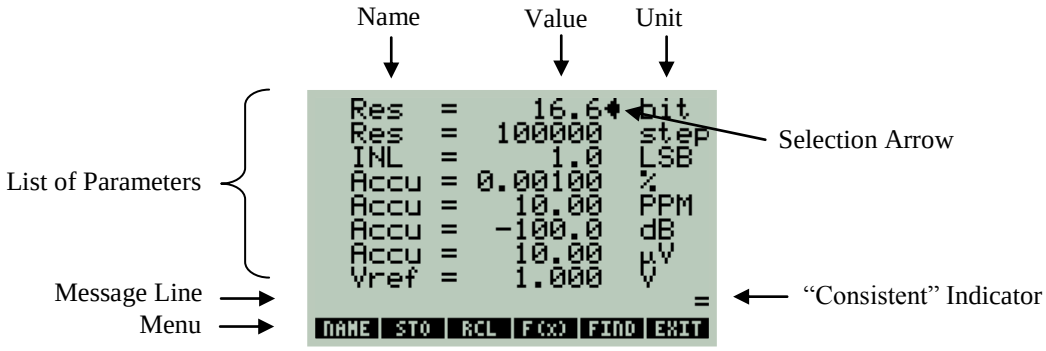
SECTION 4 - COMMANDS

ACCU has three sets of commands:

- Main Menu Commands
- Extended Menu Commands
- Help Comman
- Plot Commands

Main Menu Commands

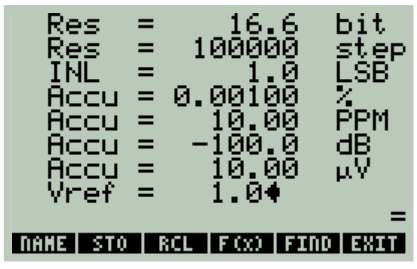
After launching ACCU for the first time, the following screen appears, listing eight related parameters.



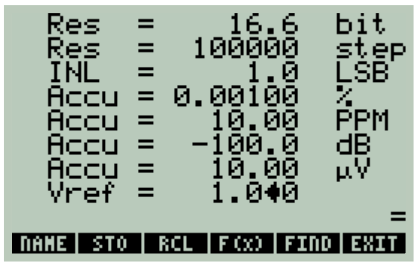
▼ or ▲ select a parameter, as indicated by the selection arrow.
▶ display an alternative parameter (**uV** and **V**, or **nA** and **mA** only)
◀ (insert) or [DEL] (delete) enter or edit a parameter. Press [ENTER] when finished.
[F1] ( ) display a description of the selected parameter in the message line
[↰] [F1] ( ) display the full precision of the selected parameter in the message line
[F2] ( ) store all parameters
[F3] ( ) recall all stored parameters
[F4] ( ) plot any parameter with respect to any other parameter
[F5] ( ) find the selected parameter
[F6] ( ) or [ON] (Cancel) exit the program
[↰] [F6] ( ) launch previous run calculator (for physical calculators only - requires CALC)
[↱] [ON] turn off the calculator

Enter or edit a parameter value by using one of the following keys:

the delete key ([DEL]),



and the left arrow (insert) key (◀)



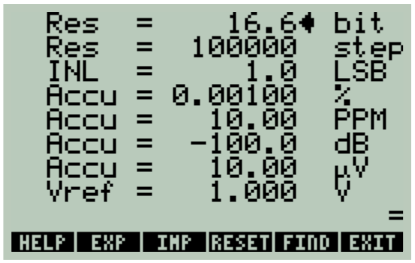
Press [ENTER] when finished.

The equal sign (=), in the lower right hand corner of the display, indicates that all the parameters are consistent with each other. That is to say, the accuracy shown **Accu** (in %, PPM, dB, and μV) is consistent with the **INL** (in LSB) and resolution **Res** (in bits and steps). The parameters are always consistent immediately following a F5 (CALC) command, and the "=" will appear. Any entry of a parameter value will show the "≠" sign, indicating that the parameters may no longer be consistent. The one exception is entering **Vref**. Entering **Vref** automatically changes **Accu** (in μV) such that the accuracy is unchanged and therefore leaves the indicator unchanged.

Parameters having the same name but different units (i.e., **Accu** and **Res**) are always consistent within themselves. Therefore, the equivalent units of a selected parameter are automatically found when a new value is entered, even if the all the parameters are not consistent (≠ is displayed).

Extended Menu Commands

Press the NXT key to display the Extended Menu showing four additional commands. Press NXT again to return to the Main Menu.



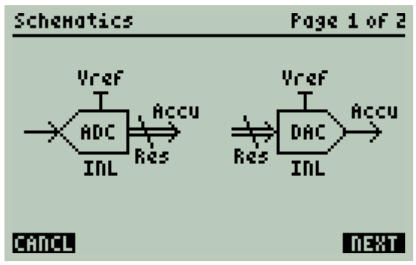
← The Extended Menu

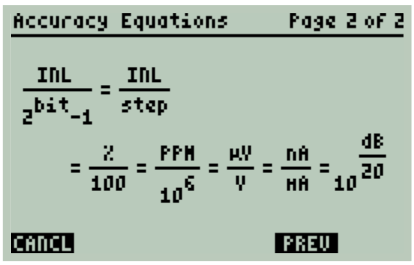
F1 (EQUA) display the equations used by ACCU
F2 (EXP) export the selected parameter to the stack upon exiting
F3 (IMP) import a number present in level 1 of the stack when ACCU was launched, to the selected parameter.
F4 (RESET) enter all default parameter values. Parameters are not stored until STO is executed.

The Main Menu reappears after executing an extended menu command.

Help Command

Press F1 (HELP) to display the help screen, and F5 (PAGE) and F6 (NEXT) to view pages 1 and 2 shown below. Press F1 (CANCL) to return to the parameter display.

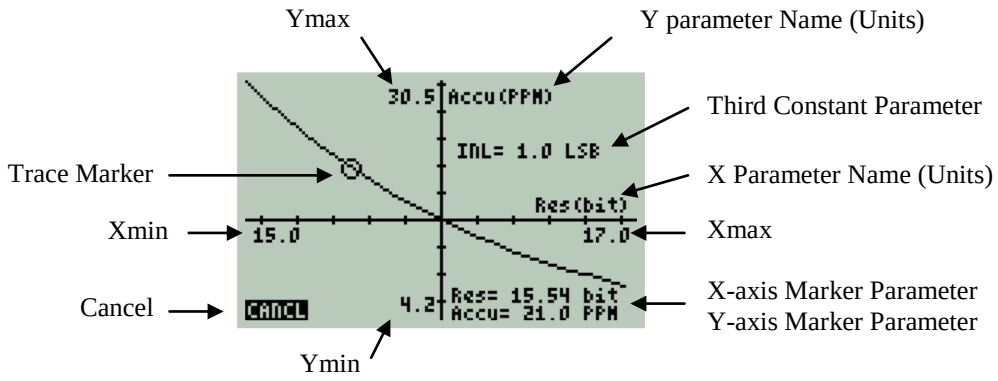




Plot Commands

PLOT (F4 in the Main Menu) plots any parameter with respect to any other parameter.

The key elements of the plot display are show below:



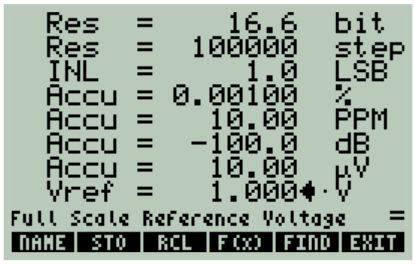
The following keys are active when a plot is displayed:

▲	Zoom out
▼	Zoom in
→ ◀	Move trace marker left by 1 pixel
◀	Move trace marker left by ½ division
← ◀	Move trace marker left by 2 divisions
→ ▶	Move trace marker right by 1 pixel
▶	Move trace marker right by ½ division
← ▶	Move trace marker right by 2 divisions
F1 (PARAM)	Return to the parameter display

SECTION 5 - MESSAGES

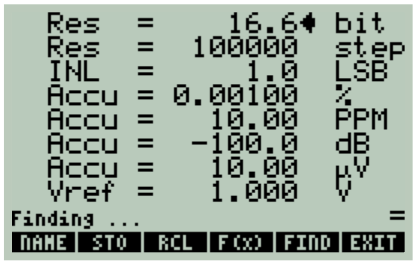
ACCU displays five types of messages on the message line:

1. Name Messages



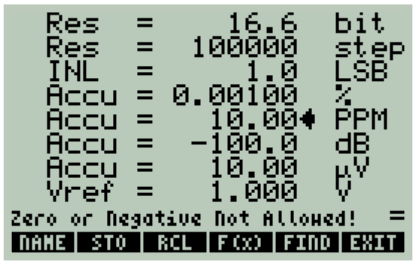
Name messages describe the selected parameter when [NAME] is active.

2. Busy Messages



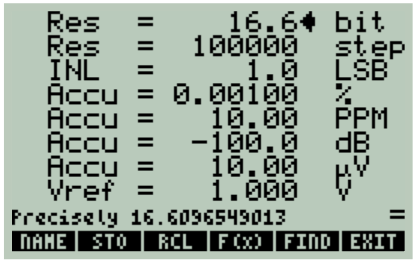
Busy messages explain what the program its doing.

3. Error Messages



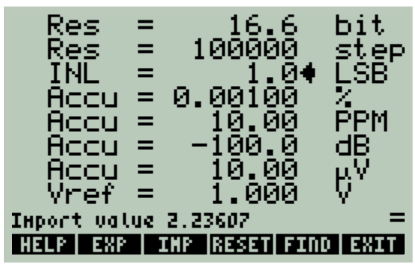
Error messages warn of an illegal entry, command, or result.

4. Full Precision Messages



Full Precision messages show the full precision of the selected parameter, when [↰] [NAME] is active.

5. Import Messages



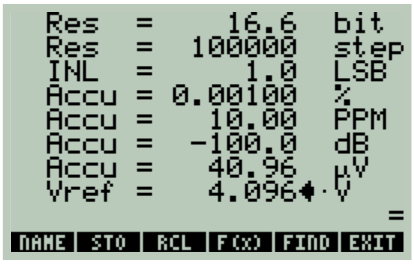
Import messages show the value to be imported.

SECTION 6 - EXAMPLES

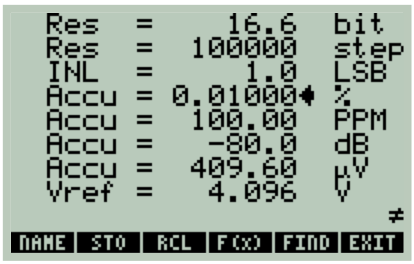
ACCU enable all parameters to entered, find, or plotted.

Entering (◀ , ◀) and Finding (F5)

This example illustrates how to use ACCU to solve a common design problem. The problem is to find the minimum specifications of a DAC that meets the accuracy requirements of an application. Specifically, find the minimum required resolution (in bits) and INL (in LSB) needed achieve a DC accuracy of 0.01% or better? This application uses a 4.096V voltage reference.

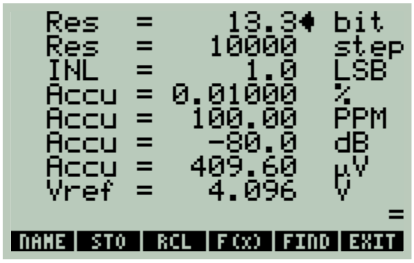


Step 1:
Starting with the default parameter values, enter the reference voltage used in the application. Use the up or down arrow keys to move the selection arrow (◆) from **Res** to **Vref.** Then use the ◀ or ◀ key to enter 4.096.



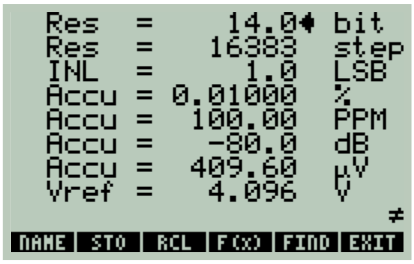
Step 2:

Enter the accuracy required by moving the arrow down or up to **Accu** and enter 0.01%. Note that the equivalent PPM, dB, and µV expressions update automatically.



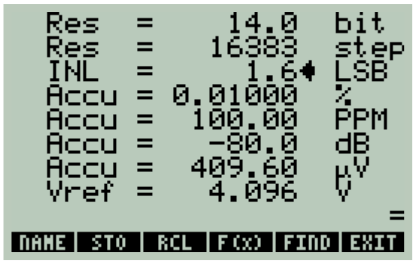
Step 3:

Find the minimum resolution required to meet this accuracy. Move the arrow back up to **Res** (in bits) and press the F5 (FIND) menu key. The result is 13.3 bit. Note that the equivalent resolution in steps updates automatically



Step 4:

Because data converters are only available in whole number of bits, enter the next higher whole number of bits, 14.

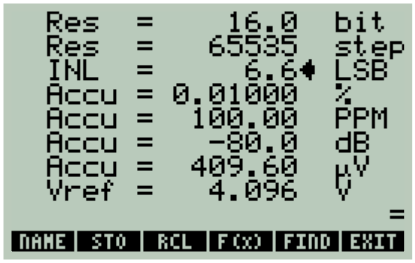


Step 5:

Find the **INL** that correspond to this accuracy and resolution. Move the arrow down to **INL** and press F5 (FIND). Finally, it is found that a 0.01% accuracy can be achieved using a 14-bit data converter having an **INL** ≤ 1.6 LSB.

The field of candidate DACs has been narrowed to those having 14-bit resolution, less then 1.6 LSB INL max, and operate with a supply voltage greater then 4.096V. A quick search of the Maxim DAC Parametric Table, at www.maximintegrated.com/products/data_converters/ yields about a dozen candidates, such as the MAX5141 with 14-bit, ±1 LSB INL max, and 5V supply.

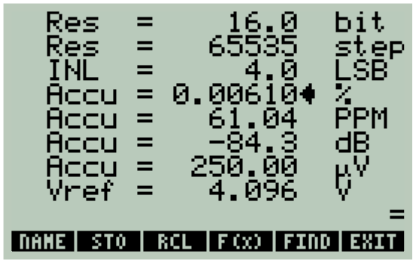
Alternatively, a higher resolution converter with a greater **INL** can be used. But how much greater?



Step 6:

Enter a 16-bit resolution and find the resulting **INL**. A 16-bit converter with in an **INL** ≤ 6.6 LSB can also be used to achieve the same 0.01% accuracy.

Searching the Maxim DAC Parametric Table for 16-bit DACs with ±4 LSB INL max, yields about a dozen more candidates, such as the MAX5441 having 16-bits, 4 LSB INL max, and a 5V supply.

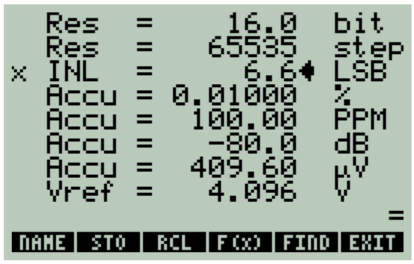


Step 7:

Find the resulting accuracy of this 16-bit, 4 LSB INL, DAC. Enter 4 **INL** and find **ACCU**. It is found that this DAC has an accuracy of 0.0061%, providing a 39% margin over the required 0.010% accuracy.

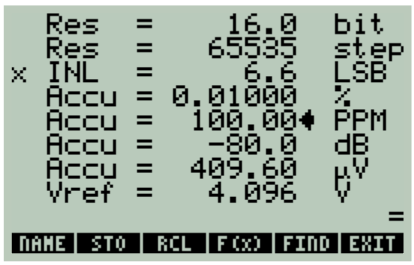
Plotting (F4 in the Main Menu)

Any parameter can be plotted with respect to any other parameter using the F4 (plot) key. The procedure is demonstrated as follows,



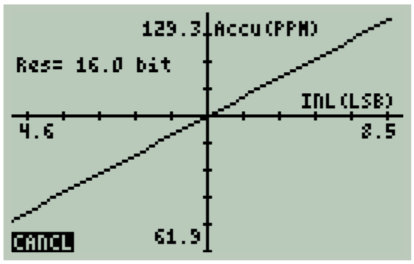
Step 1:

Select the independent (x-axis) parameter by moving the selection arrow to **INL** and pressing the F4 key. An 'x' appears to the left of the parameter.



Step 2:

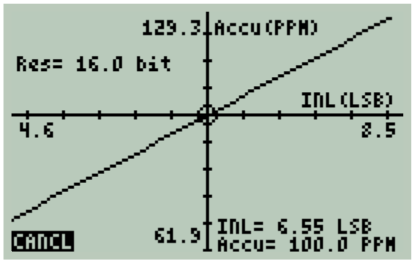
Move the selection arrow to the dependent parameter (y-axis) **Accu** in PPM, and press the F4 key again.



Step 3:

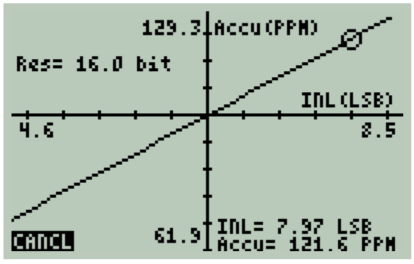
The following plot appears. This plot shows how the accuracy of a data converter, **Accu** (in PPM), changes as the **INL** changes from 4.6 to 8.5 LSB, when the resolution is 16 bits.

Note that the constant third parameter, **Res**, is also shown.



Step 4:

Press the left or right arrow key (◀ ▶) to display a circular marker at the origin with the x-axis and y-axis values in the lower right corner of the display.

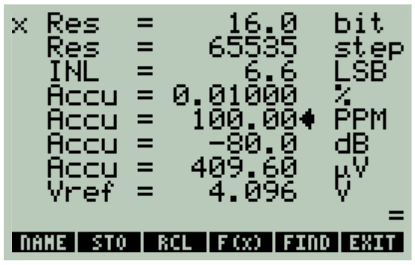


Step 5:

Use the left and right arrow keys to move the marker left and right along the curve. The x-axis and y-axis parameter values of the marker's position appear on the lower right corner of the display.

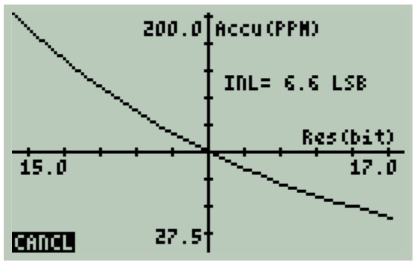
Zooming (▲ , ▼)

Zooming is demonstrate in following example by plotting **Accu** (in PPM) vs. **Res** (in bits).



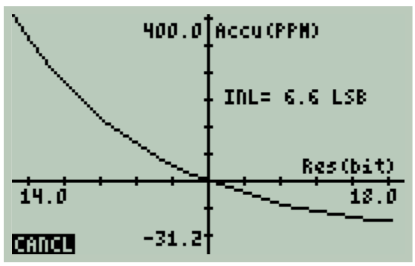
Step 1:

Select **Res** (in bits) as the independent variable, and **Accu** (in PPM) as the dependent variable.



Step 2:

Press F4 to show this plot.



Step 3:

Zoom out by pressing the up arrow key (▲) twice. The span of the x-axis increases by 2X.

Each press of the up or down arrow key increases or decreases the span of the x-axis by a factor of the square root of 2.

SECTION 7 - BACKGROUND

Data Convertor Accuracy and How it is Calculated

The DC accuracy of a data converter is the measure of the maximum deviation from the ideal linear transfer function. It is commonly specified in one of five ways:

1. Integral Nonlinearity (INL) measured in Least Significant Bits (LSBs) with respect to the number of steps in full scale.
2. Percentage (%) of full scale
3. Parts Per Million (PPM) of full scale
4. Decibels (dB) with respect to full scale (0dB)
5. Microvolts (uV) with respect to full scale reference voltage (Vref) or nanoamps (nA) with respect to full scale current (Ifs)

"Accuracy" means "accurate to". For example, an accuracy of 0.001% means a data converter is accurate to 0.001%, or to 10 PPM, or to -100dB of full scale, or to 10uV of 1V, or to 10nA of 1mA, etc. Smaller numbers indicate greater accuracy. Accuracy can also be thought of as the tolerance, or maximum error, of a conversion.

Accu is related to **Res** and **INL**, by, $$Accu = \frac{INL_{LSB}}{2^{\mathrm{Res}_{bit}} - 1} \quad (1)$$

where **Res** is the resolution of the data convertor and is expressed equivalently in units of bits or steps where, $\mathrm{Res}_{step} = 2^{\mathrm{Res}_{bit}} - 1$ and **INL** (Integral Nonlinearity) is the data convertor's largest deviation from it's ideal linear response (in LSB).

Accu can be expressed equivalently in four units; %, PPM, dB, and μV as,

$$Accu = \frac{Accu_{\%}}{100} = \frac{Accu_{PPM}}{10^6} = \frac{Accu_{uV}}{Vref} = \frac{Accu_{nA}}{Iref} = 10^{\left(\frac{Accu_{dB}}{20}\right)} \quad (2)$$

Substituting equation (1) into equation (2) yields the final equation relating all eight parameters,

$$\frac{INL_{LSB}}{2^{\mathrm{Res}_{bit}} - 1} = \frac{INL_{LSB}}{\mathrm{Res}_{step}} = \frac{Accu_{\%}}{100} = \frac{Accu_{PPM}}{10^6} = \frac{Accu_{uV}}{Vref} = \frac{Accu_{nA}}{Iref} = 10^{\left(\frac{Accu_{dB}}{20}\right)}$$

ACCU uses this relationship to find any parameter as a function of the others, or to plot any two parameters with respect to each other.

These relationships apply equally to Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs). See Figures 1 to 4.

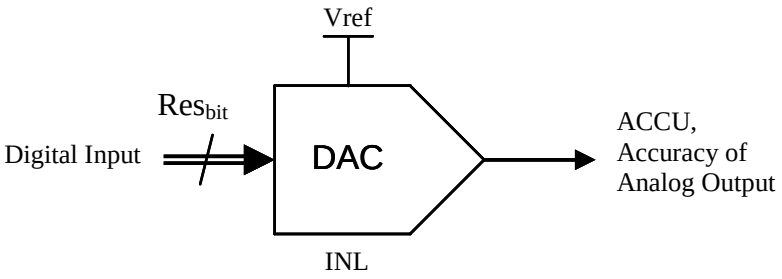


Figure 1: DAC Parameters

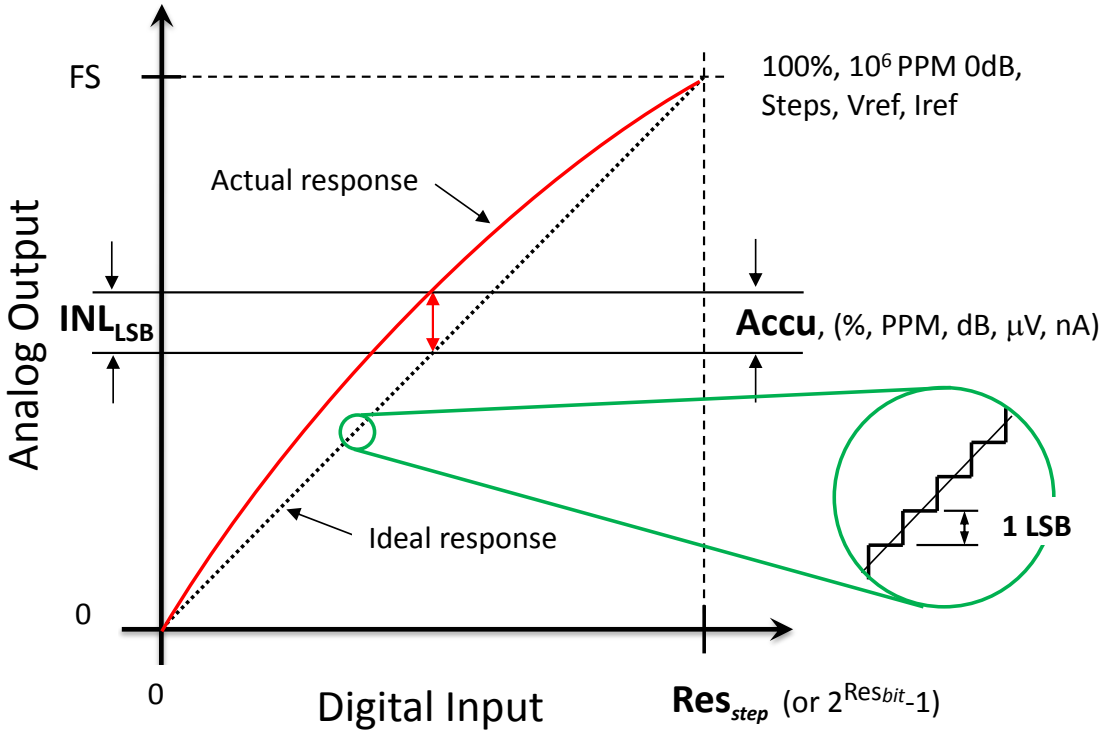


Figure 2: Accuracy parameters applied to DACs

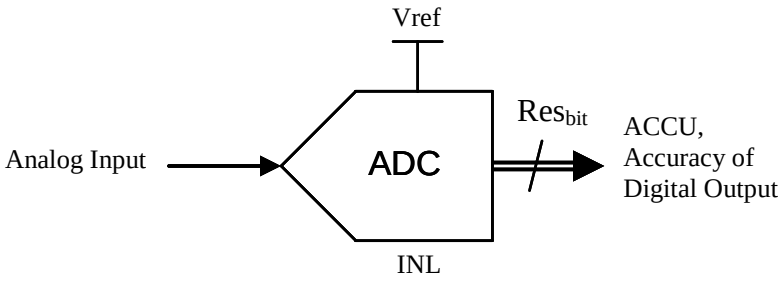


Figure 3: ADC and DAC Parameters

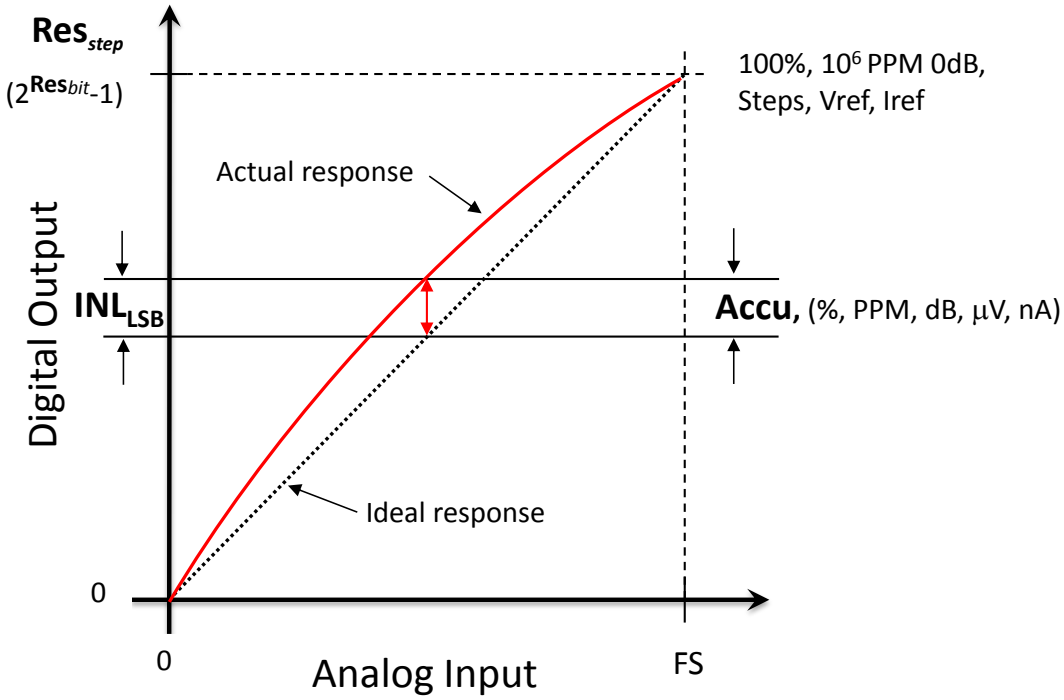


Figure 4: Accuracy parameters applied to ADCs

Real devices usually have irregular deviations from the ideal response. See Figure 5.

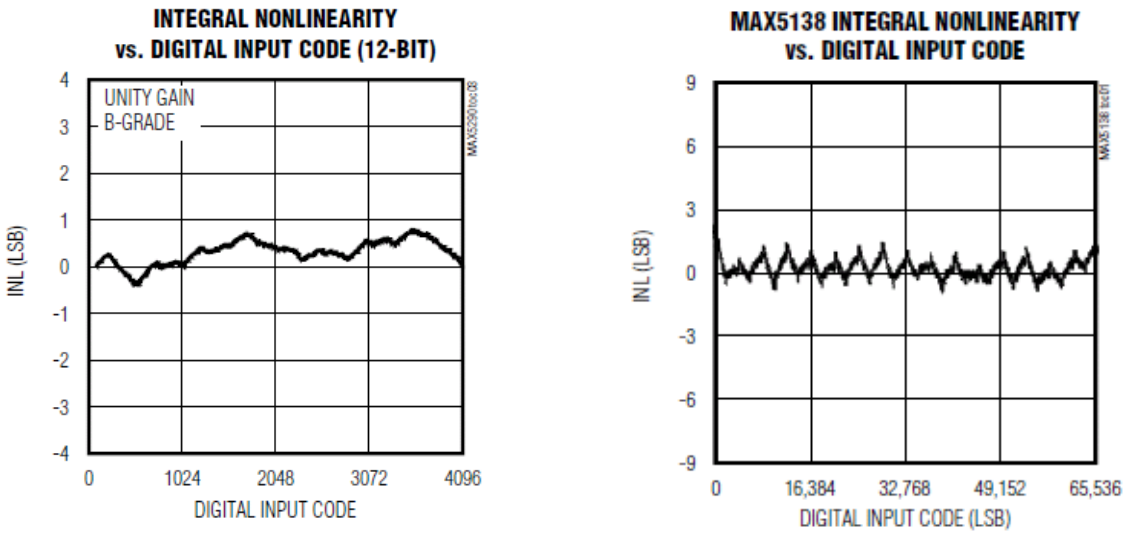


Figure 5: Two examples of real INL responses

The INL used in ACCU is the maximum deviation from the ideal response (the x-axis on the above graphs), and is usually taken directly from the Electrical Characteristics Table of the device data sheet.

SECTION 8 - TOOLS, MODELS, AND SOFTWARE NOTICE

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