Comparison of Operational Transconductance Amplifiers

By: Paul Brown and Wallace Tennille

Introduction

The described experiments compared various properties of several different operational transconductance amplifiers (OTAs). The OTAs tested were the CA3080, LM13700, JRC13700, JRC13600, and also two OTAs that were built with matched pair transistors. The matched pairs used were the LS358/LS318 BJT's and the 2SC1483/2SA793. Some preliminary tests were run by creating a simple VCA with the OTA's and manually adjusting the control current (I_{con}) and taking each measurement. This method was inefficient, so an Agilent VEE program was created to automate the process.

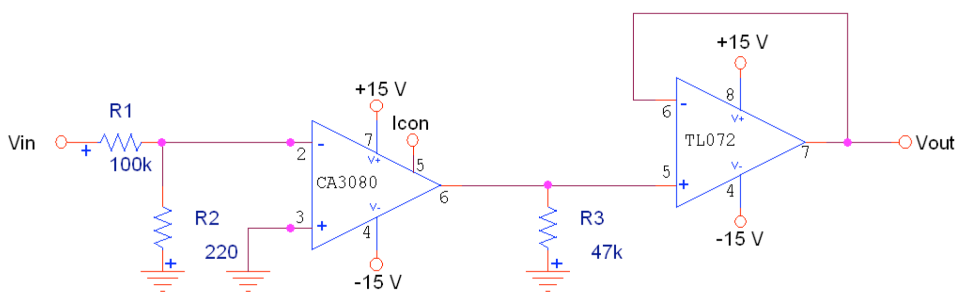
For each OTA, the VEE program was used to measure the gain versus I_{con}, the output DC level versus I_{con}, and for some OTA's the voltage at the control current pin was measured. This was repeated for sinusoidal input signals at 100Hz, 1kHz, 10kHz, and 100kHz to test performance at different frequencies.

Setup

A generic VCA circuit was built to accommodate easy swapping of different OTA's. The design was based on the Bergfotron CA3080 VCA1 schematic. The schematic for the full design can be found at the following URL.

http://hem.bredband.net/bersyn/VCA/ca3080 vca 1.htm

Our design consisted of the bottom portion of that circuit, and is shown below.



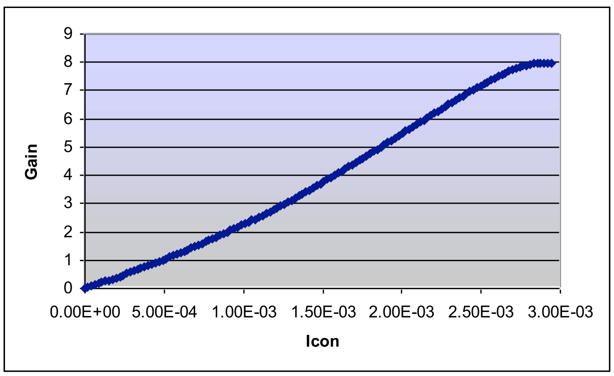
The input signal was produced by a function generator set to output a sine wave at the tested frequencies. Our control current was created by producing a voltage drop across a resister. One end of the resister was connected to a DC power supply and the other to the control current pin on the OTA. To accurately measure I_{con}, a multimeter was used to measure the voltage difference across the known resistance of the resistor. An additional multimeter was used to measure both the AC and the DC voltage at the output of the TL072 opamp. The VEE program controlled both of the multimeters and the DC power supply. A screenshot of the VEE program used for these experiments is provided in Appendix A.

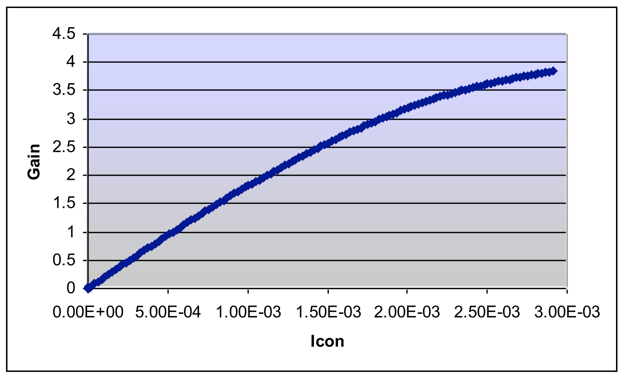
Results:

- *Gain vs. Control Current*

The first parameter tested for each OTA was gain versus I_{con}. The absolute maximum value of I_{con} for each OTA was listed in their respective datasheets as 2 mA. Our testing pushed beyond this limit up to just below 3 mA. This was done in order to see the OTA's behavior beyond it's specified limit. The data not shown explicitly in this section is included in Appendix B.

It is desirable for an OTA to have a linear relationship between control current and gain. Below is a typical response from a CA3080 OTA and a LM13700 OTA.





CA3080 #1, 10kHz Input Signal

LM13700 #1, 10 kHz Input Signal

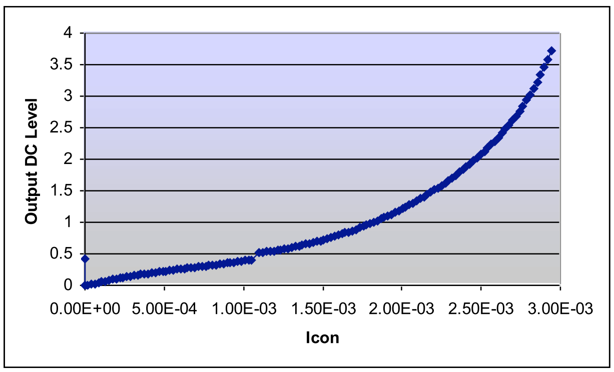
The majority of the plot for the CA3080 is linear, and at approximately 2.8 mA the gain first exhibits nonlinearities. At this point, increasing control current has no additional effect on the gain. For the LM13700, the linearity ends at approximately 2.0 mA but has a much slower drop-off rate than the CA3080 and it drops off smoothly. This is also typical of the JRC13700, JRC13600, and the home-made OTA's.

It was also observed that at higher frequency input signals, the gain begins to attenuate. For signals at 100 Hz, 1 kHz, and 10 kHz, the gain was almost identical, but at 100 kHz the gain drops noticeably. This trend appears for all OTA's tested, which can be seen in Appendix B.

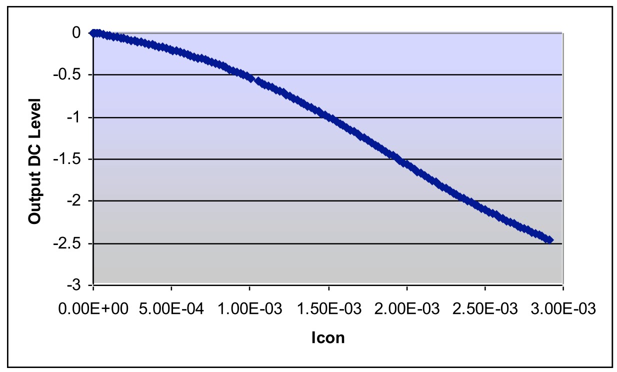
The amplitude of each OTA's gain also differed between models. The CA 3080 had the highest gain-to-current ratio of the store-bought OTA's. The next highest was the JRC13600, followed by the JRC1700. The OTA with the lowest gain-to-current ratio was the LM13700. This can also be seen in the graphs in Appendix B.

- *Output DC Level vs. Control Current*

Though it may not be of interest in synthesizer design, it was noticed that the DC level of the output signal is also related to the control current, and this relationship is different for different OTA's. Plots of this relationship for the CA3080 and the LM13700 are shown below.



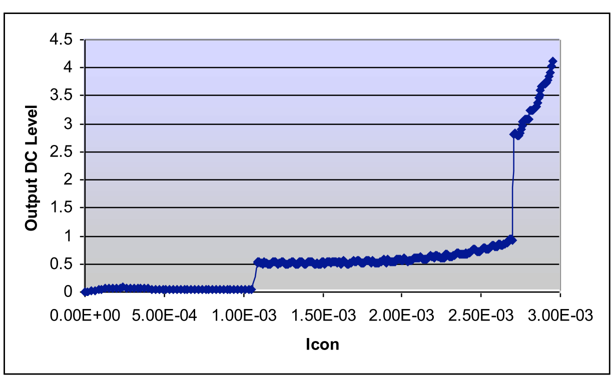
CA3080 #1, 10 kHz Input Signal



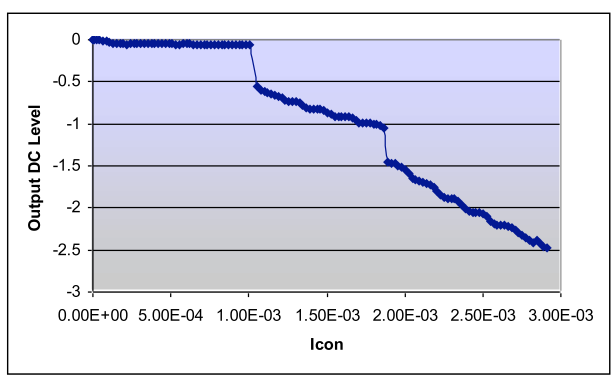
LM13700 #1, 10 kHz Input Signal

The CA3080 Output DC Level exhibited an exponential increase in response to increasing control current, while all other OTA's exhibited an almost linear decreasing response.

Also, it was surprising to find that the DC Level exhibits strange behavior at low frequencies, particularly with a 100 Hz and 1 kHz input signal. This is shown in the plots below.



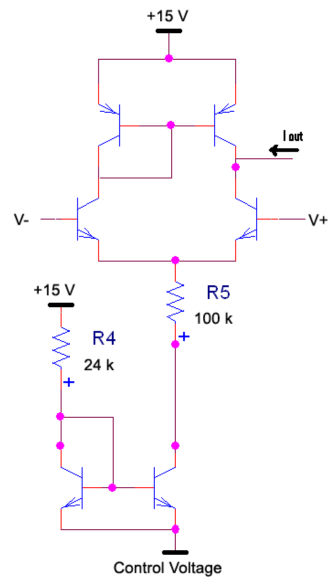
CA3080 #1, 100 Hz Input Signal



LM13700 #1, 100 Hz Input Signal

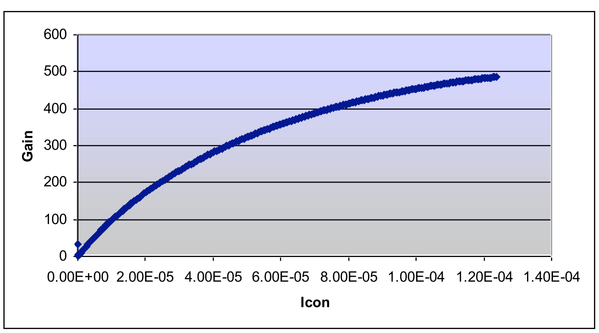
- *Home-made OTA's*

Instead of buying OTA's, they can also be made from matched-pair BJT's. The schematic below was used to build two different OTA's, one using a LS358/LS318 BJT combination and the other using a 2SC1483/2SA793 BJT combination.

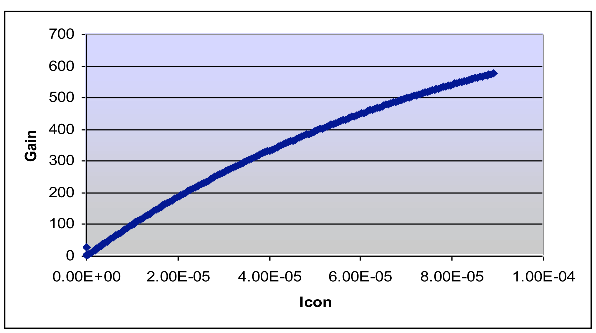


Generic Schematic for home-made OTA.

The same tests used on the store-bought OTA's were run on both of these home-made OTA's, but only for a 10 kHz input signal. Some interesting data was observed for these OTA's. The gain curves of these OTA's were similar in shape to the store-bought OTA's, but the magnitude of the gain was insanely high compared to that of the other OTA's. The plots are shown below. The gain from the 2SC1483/2SA793 matched pair OTA produced a higher and slightly more linear gain than the OTA made from the LS358/LS318 matched pair BJT's



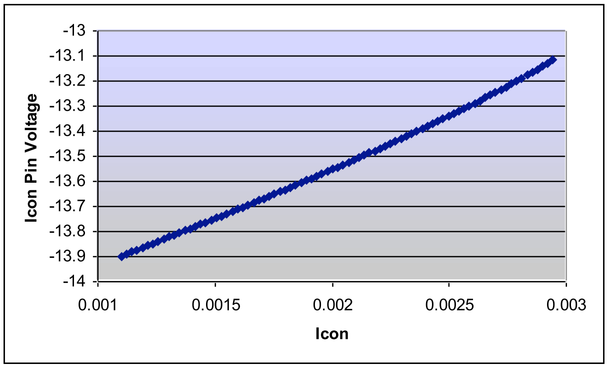
LS358/LS318 Matched Pair OTA Gain



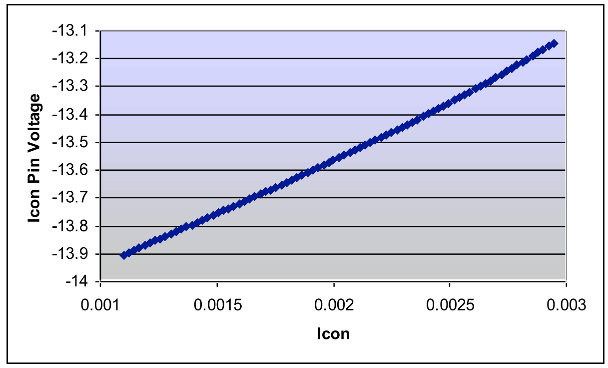
2SC1483/2SA793 Matched Pair OTA Gain

- *Voltage at the Control Current Pin*

While testing the CA3080 OTA's, the voltage at the control current pin was measured. Although this information might not be useful, it is included in this report. The plots are shown below.



I_{con} Pin Voltage for CA30380 #1

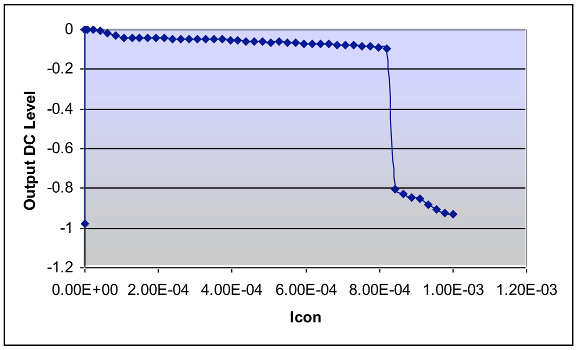


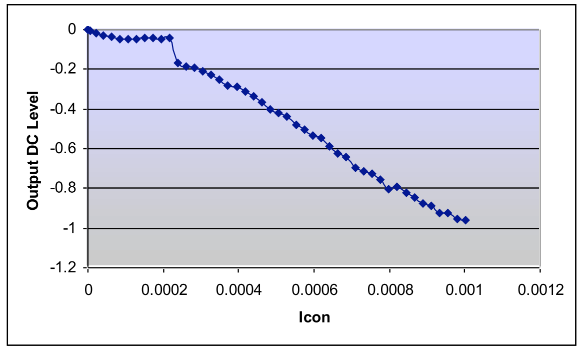
I_{con} Pin Voltage for CA30380 #2

The voltage at the pin increased linearly with control current.

- *Hysteresis*

As previously mentioned, while testing the DC voltage level at the output of the VCA circuit, there were sharp jumps in the voltage levels for lower frequencies. Initially it was thought that there might be errors in the experimental setup, or that the OTA's were just faulty. This test was run with a much smaller step size confined to the area containing the jump, and instead of a jump, the response showed a smooth transition. From this observation, it was determined that the effect only occurred when the control current sweeping range began much lower than where the jump occurred. This seems to be an example of a hysteresis effect in the OTA, and to test this hypothesis, the control current was stepped in the opposite direction, from high to low. As can be seen in the plots below, the break then occurred at a lower control current as hypothesized by hysteresis. Though not tested, this effect probably occurs in the other OTA's.





I_{con} swept from low to high

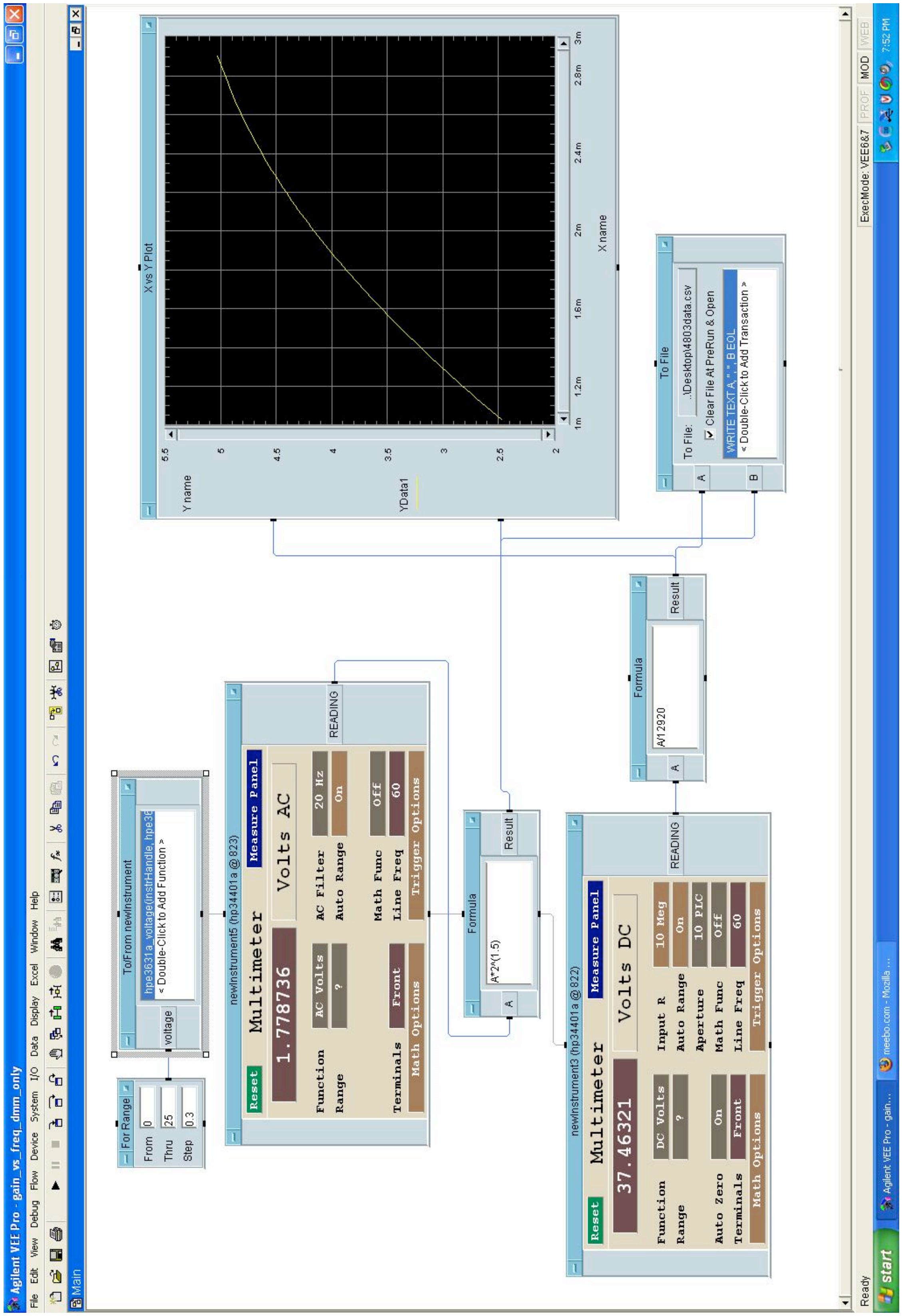
I_{con} swept from high to low

Conclusion:

From the data collected during this experiment, several conclusions can be made about the performance of OTA's. Each OTA tested has a unique relationship between control current and gain. Even the 13600 and 13700 class OTA's, based on similar circuit architectures, each have almost identically shaped curves but a slightly different response amplitude. Also, higher frequencies tend to attenuate the OTA's gain. Lower frequencies produce a hysteresis effect on the DC level of the output signal. The home-made OTA's tested produced such a peculiarly high gain that it is very possible the implementation used for the OTA was incorrect. Regardless, the shape of the response curve of the home-made OTA's was nearly identical to that of the store-bought OTA's. Finally, the voltage at the control pin has a linear relationship to the control current and does not stay at a constant voltage as expected.

More testing would be beneficial to further confirm these observations. In particular, a frequency response of each OTA would be helpful in determining the frequency at which the gain begins to diminish. Also, further testing would be necessary to confirm the hypothesized hysteresis effect. A more knowledgeable construction of a home-made OTA would provide a more accurate comparison to the store-bought OTA's.

Appendix A



Agilent VEE Pro - gain_vs_freq_dmm_only
File Edit View Debug Flow Device System I/O Data Display Excel Window Help
Main
For Range
From 0
Thru 25
Step 0.3
To/From newInstrument
voltage
hpe3631a_voltage(instrHandle, hpe3
« Double-Click to Add Function »
newInstrument5 (hp34401a @ 823)
Reset
Multimeter
Measure Panel
1.778736
Volts AC
Function AC Volts
Range ?
AC Filter 20 Hz
Auto Range On
Terminals Front
Math Func Off
Line Freq 60
Math Options
Trigger Options
READING
Formula
A*2^(1.5)
A
Result
newInstrument3 (hp34401a @ 822)
37.46321
Volts DC
Function DC Volts
Input R 10 Meg
Auto Range On
Aperture 10 PLC
Auto Zero On
Math Func Off
Terminals Front
Line Freq 60
Formula
A/12920
X vs Y Plot
Y name
YData1
X name
To File
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Clear File At PreRun & Open
WRITE TEXT A,",",B EOL
« Double-Click to Add Transaction »
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ExecMode: VEE6&7
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WEB
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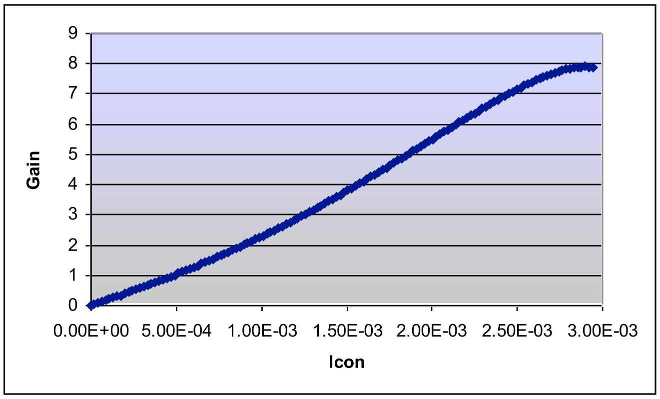
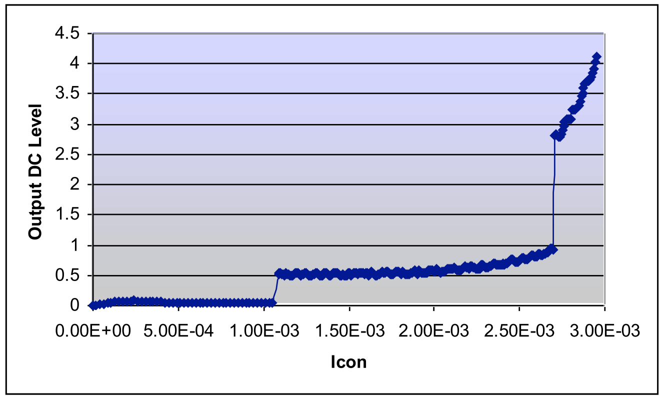
Agilent VEE Pro - gain...
meebo.com - Mozilla ...
7:52 PM

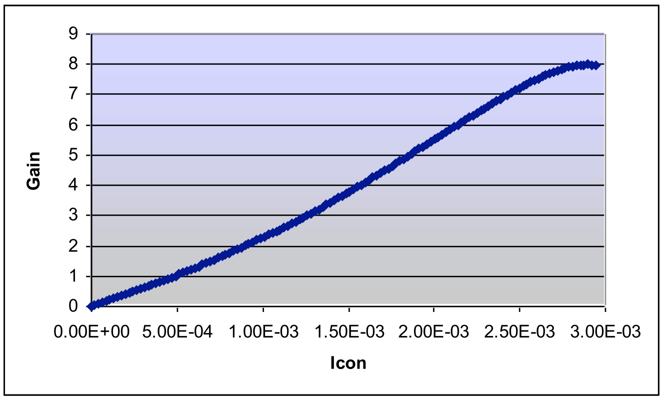
Appendix B

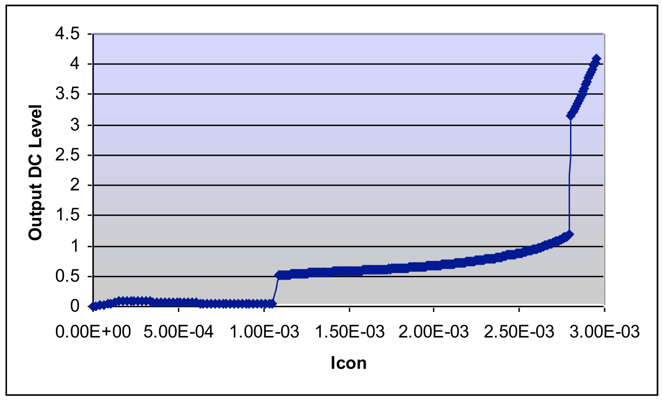
CA3080 #1, 100Hz Input Signal



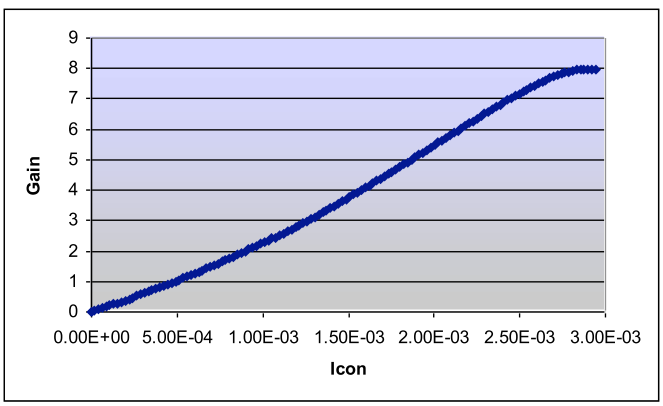


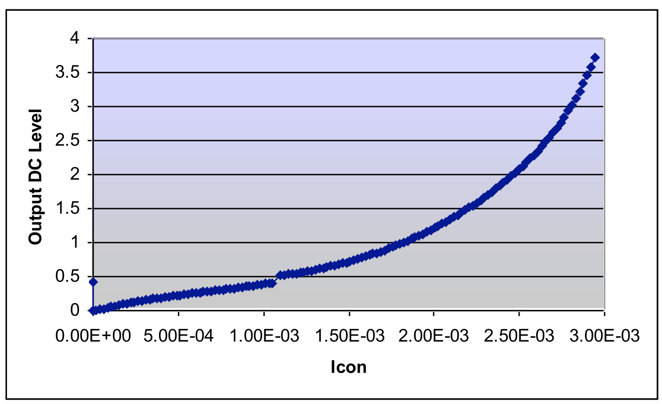
CA3080 #1, 1kHz Input Signal



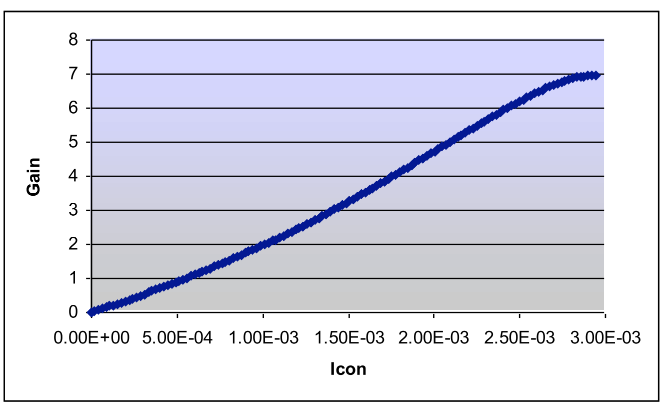


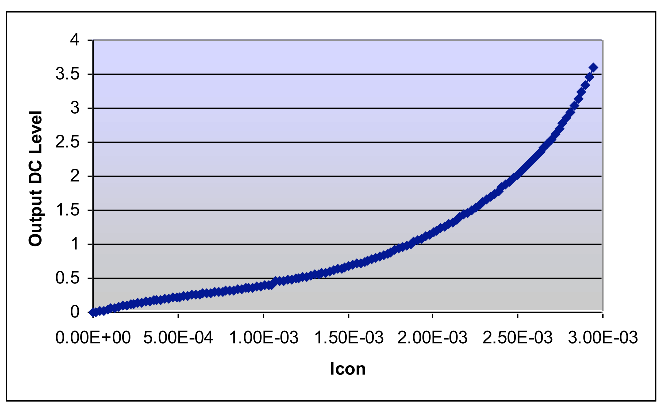
CA3080 #1, 10kHz Input Signal



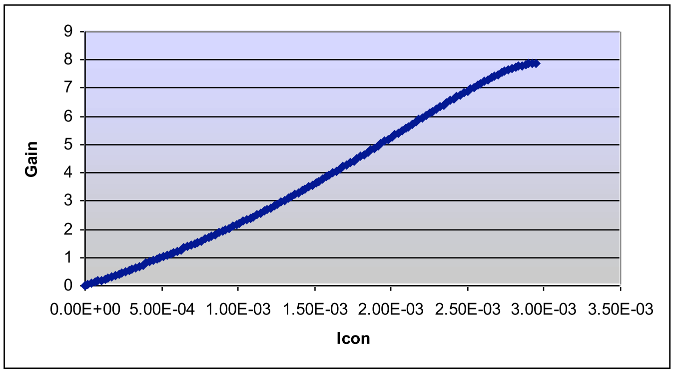


CA3080 #1, 100kHz Input Signal

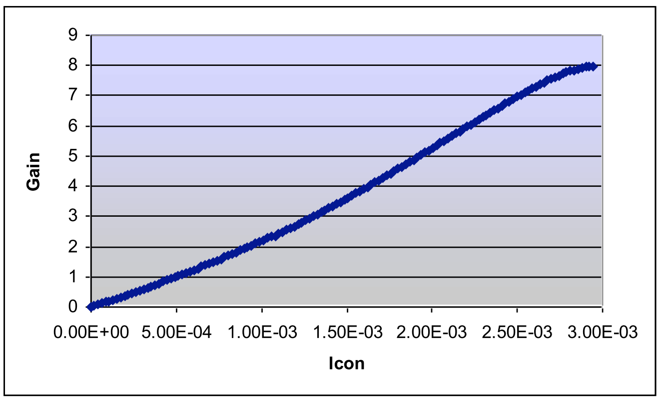




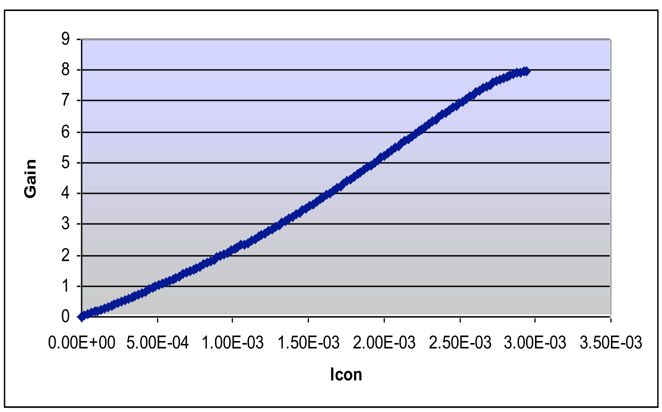
CA3080 #2, 100Hz Input Signal

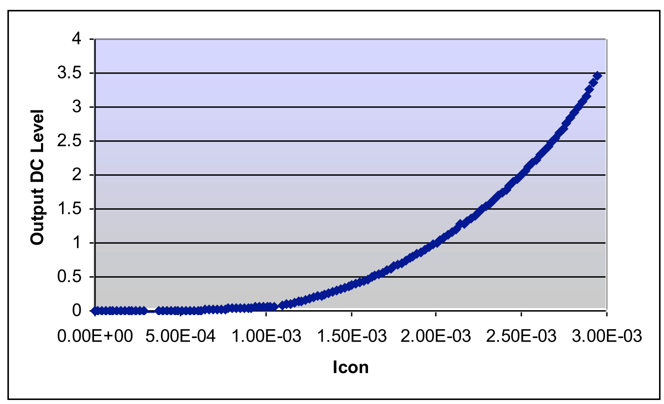


CA3080 #2, 1kHz Input Signal

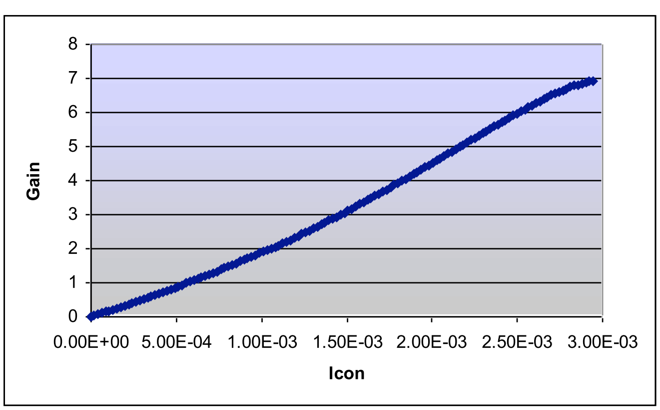


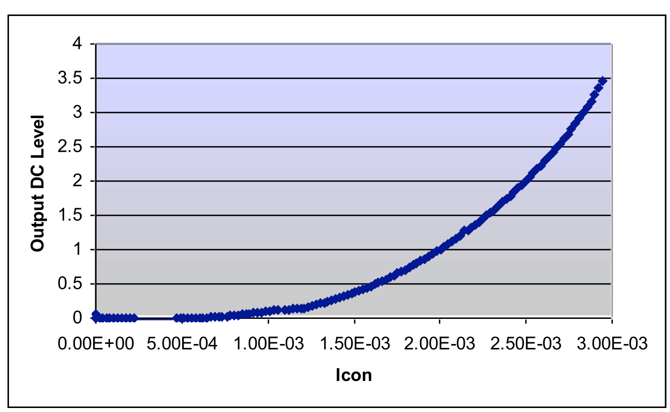
CA3080 #2, 10kHz Input Signal



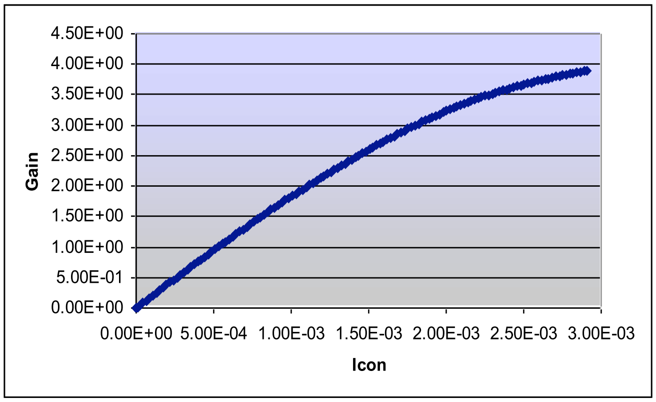


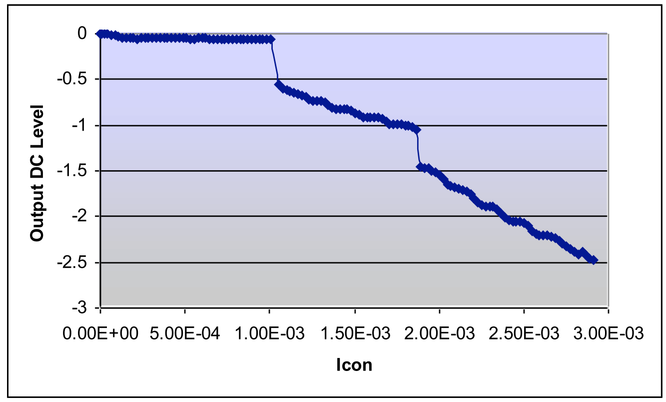
CA3080 #2, 100kHz Input Signal



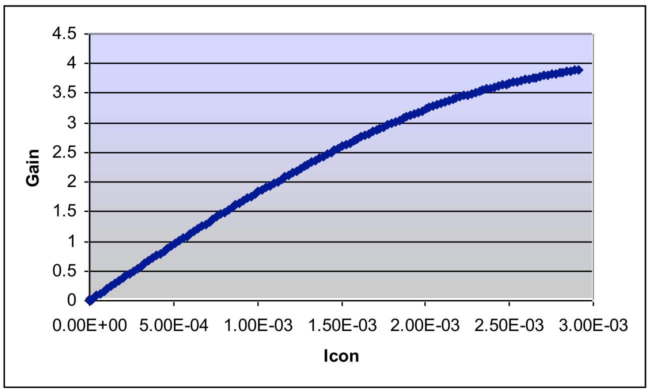


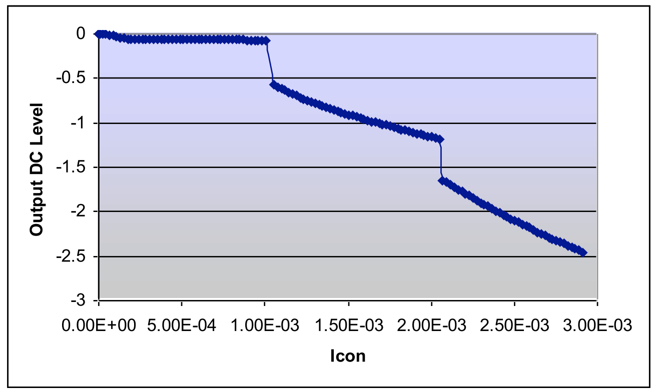
LM13700 #1, 100Hz Input Signal



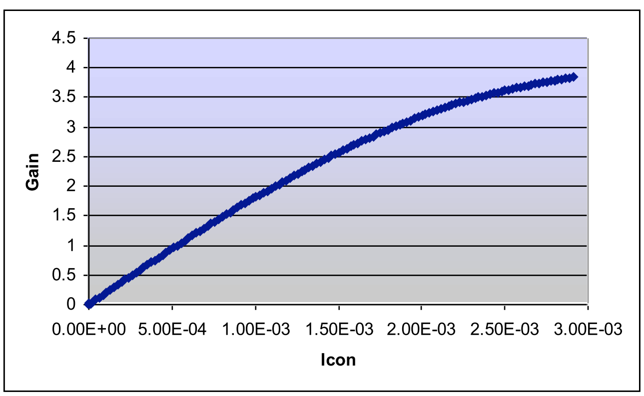


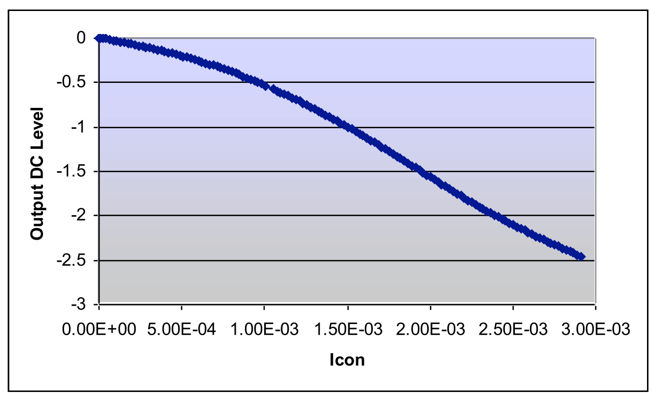
LM13700 #1, 1kHz Input Signal



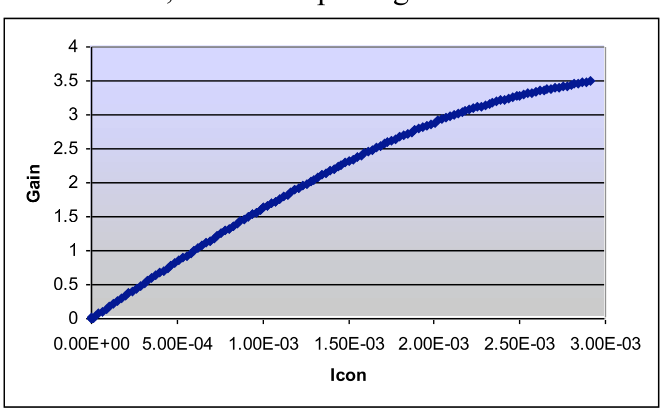


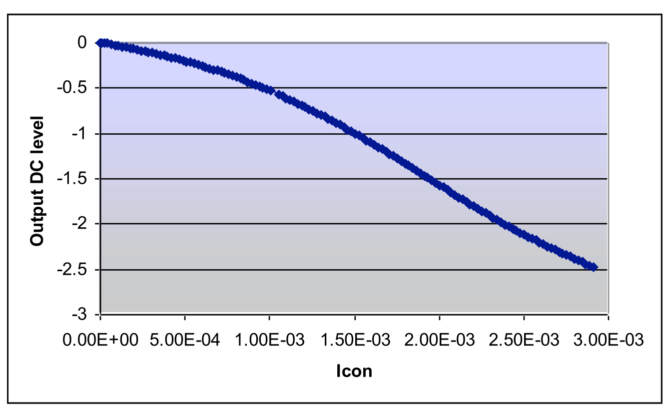
LM13700 #1, 10kHz Input Signal



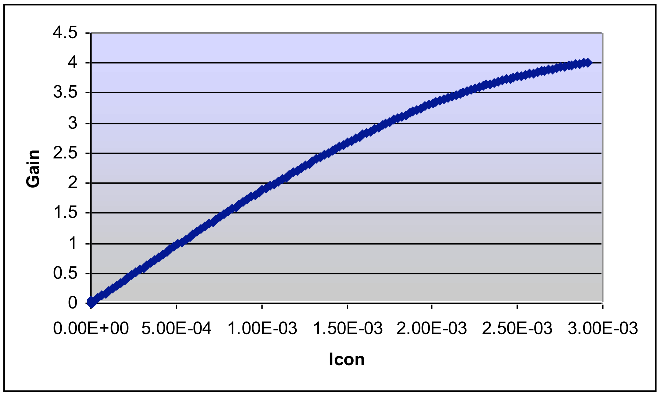


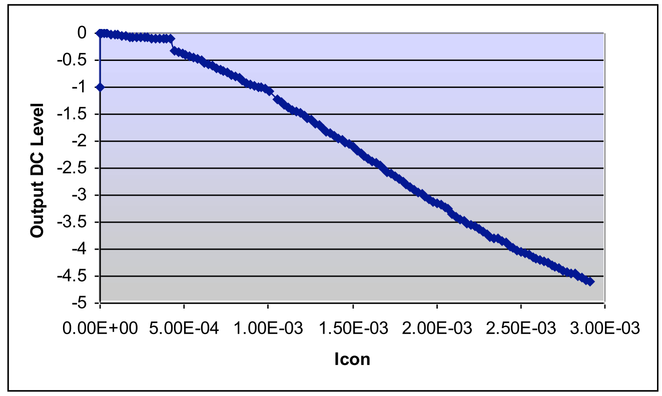
LM13700 #1, 100kHz Input Signal



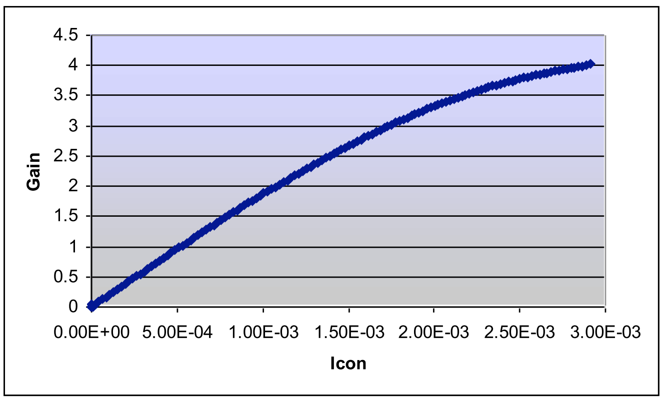


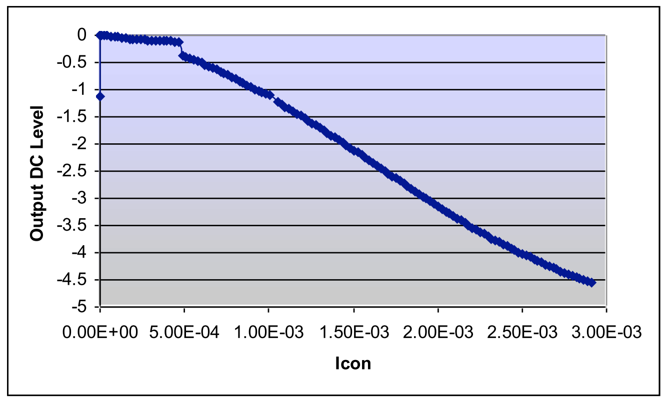
LM13700 #2, 100Hz Input Signal



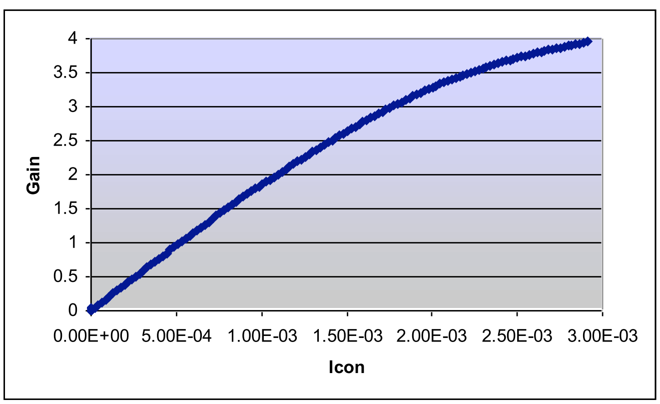


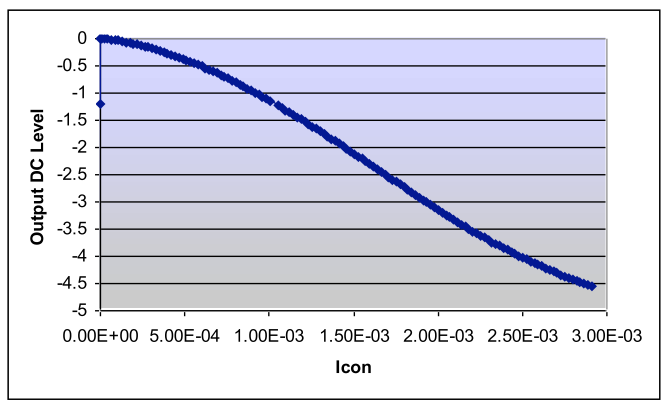
LM13700 #2, 1kHz Input Signal



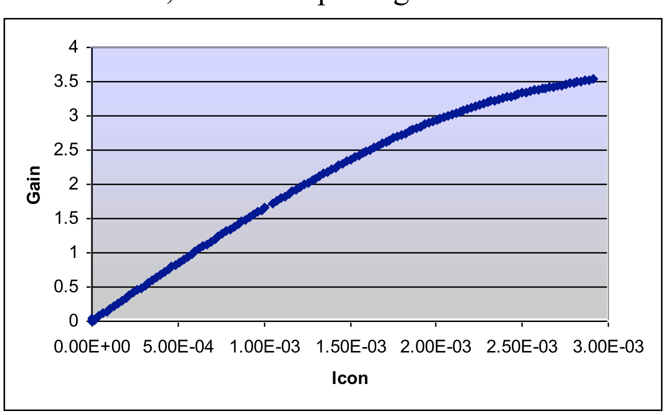


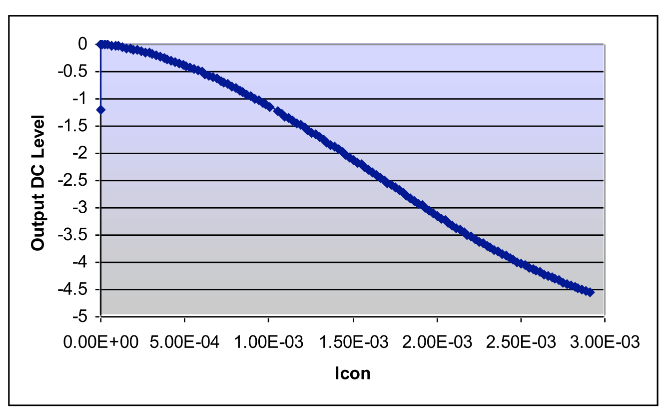
LM13700 #2, 10kHz Input Signal



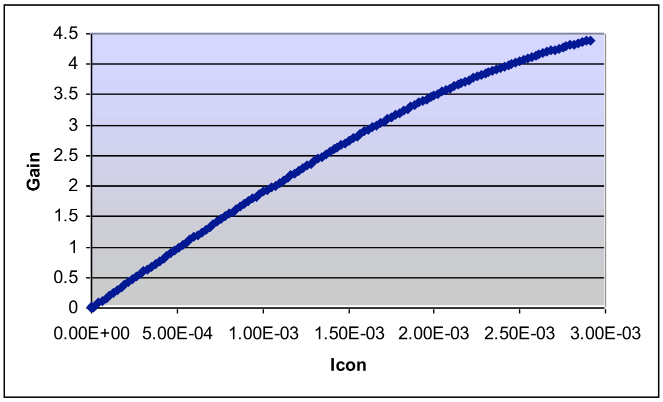


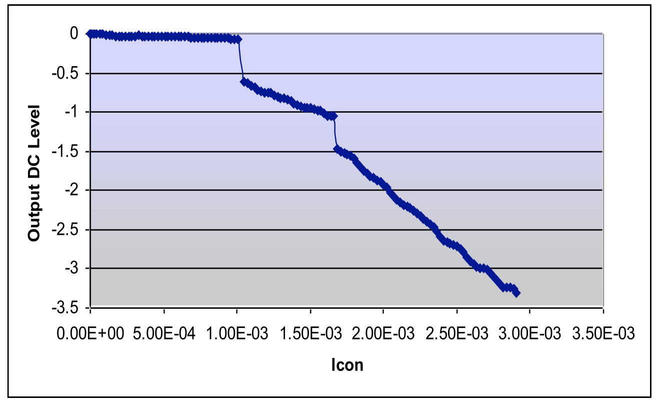
LM13700 #2, 100kHz Input Signal





JRC13700 #1, 100Hz Input Signal





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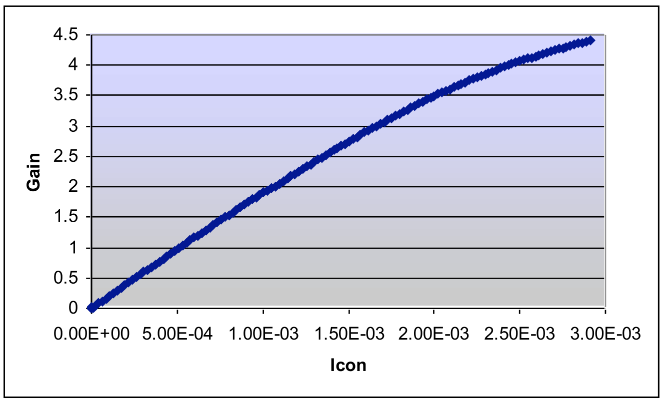
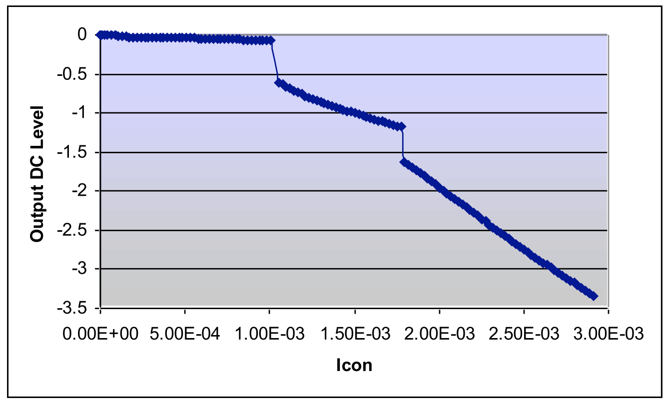
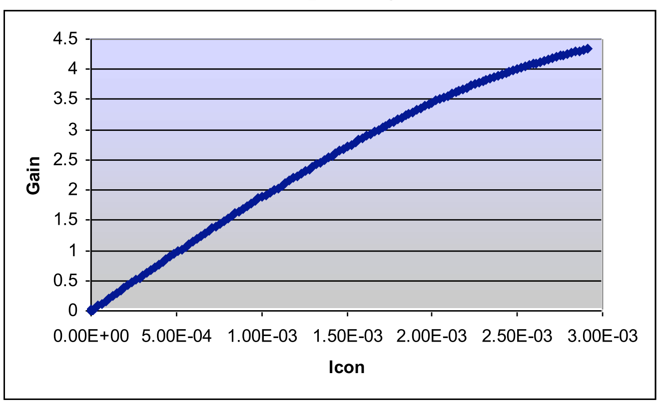
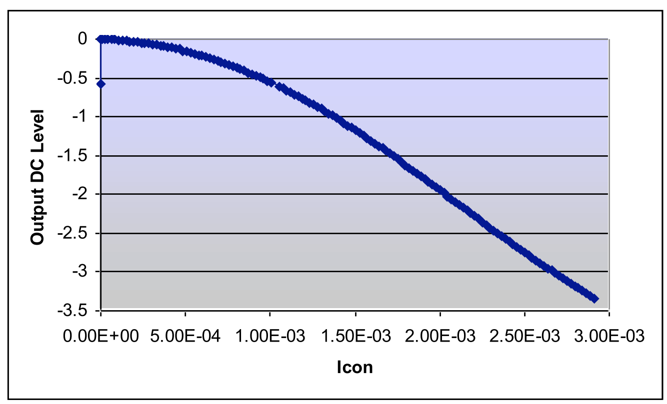


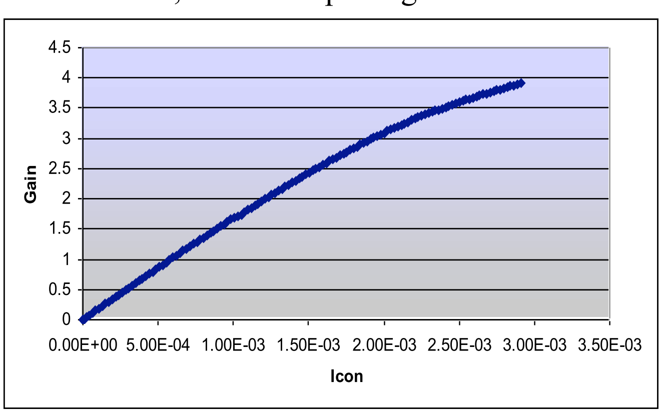


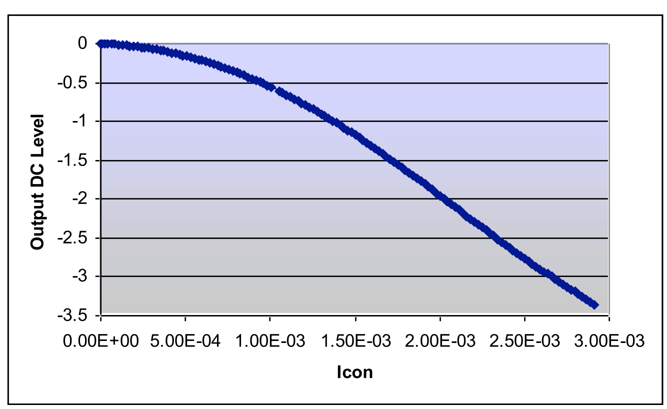
JRC13700 #1, 10kHz Input Signal



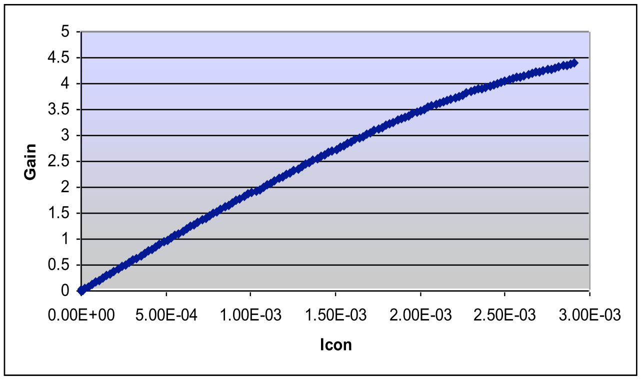


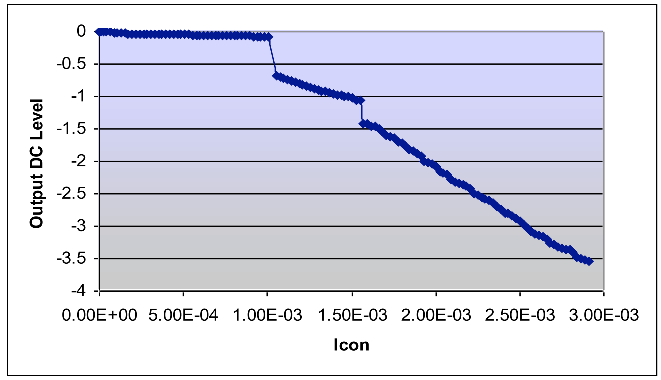
JRC13700 #1, 100kHz Input Signal



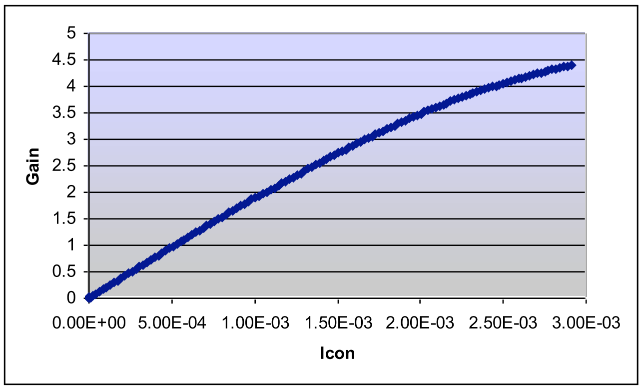


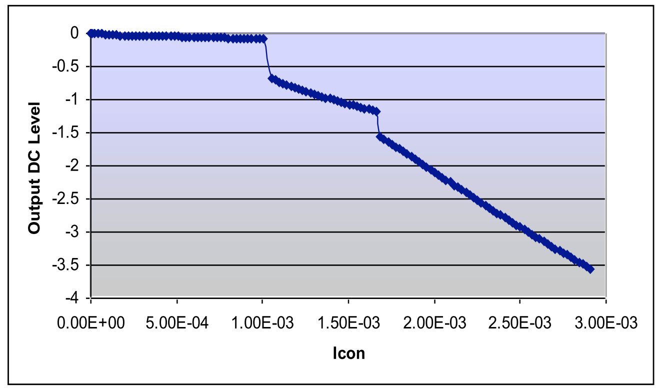
JRC13700 #2, 100Hz Input Signal



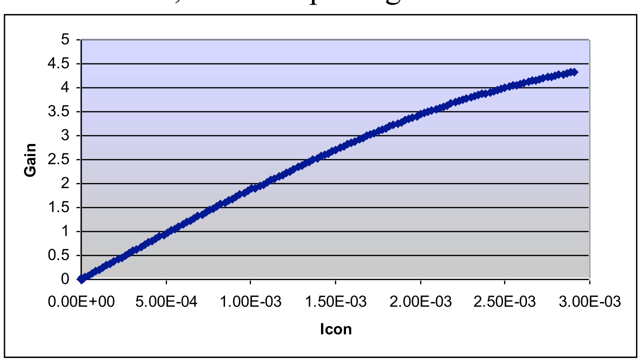


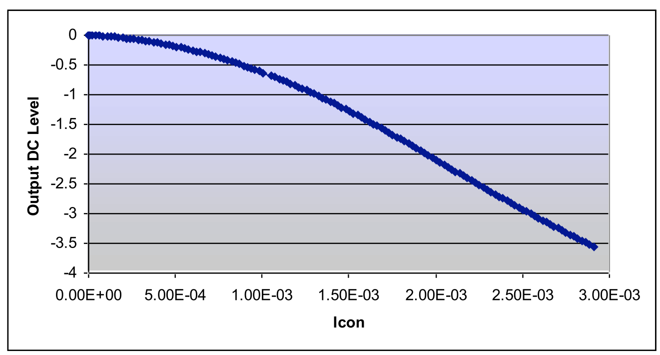
JRC13700 #2, 1kHz Input Signal



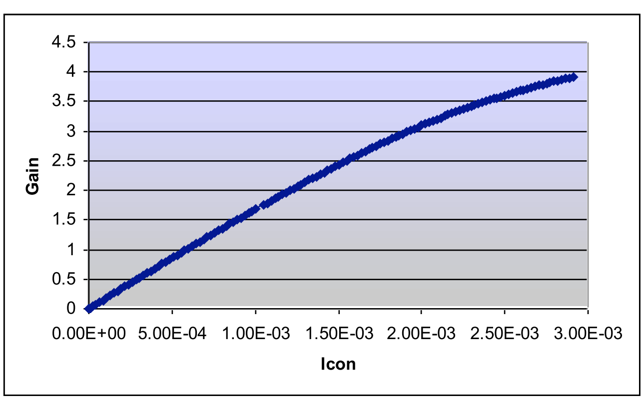


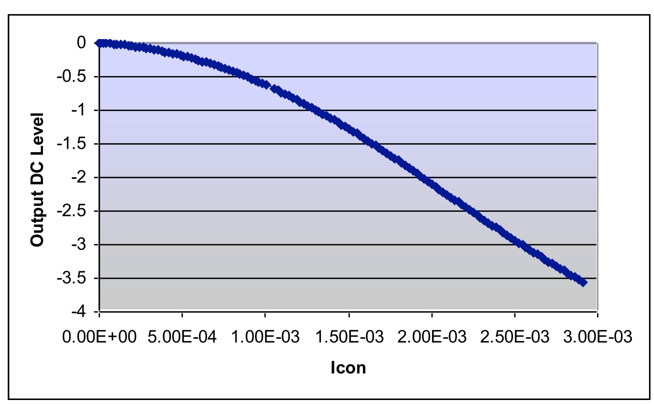
JRC13700 #2, 10kHz Input Signal



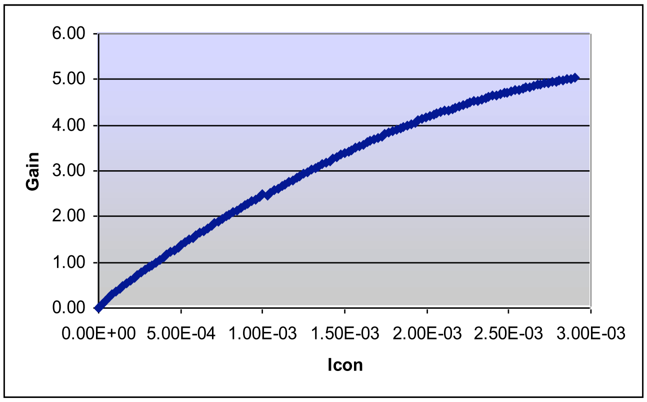


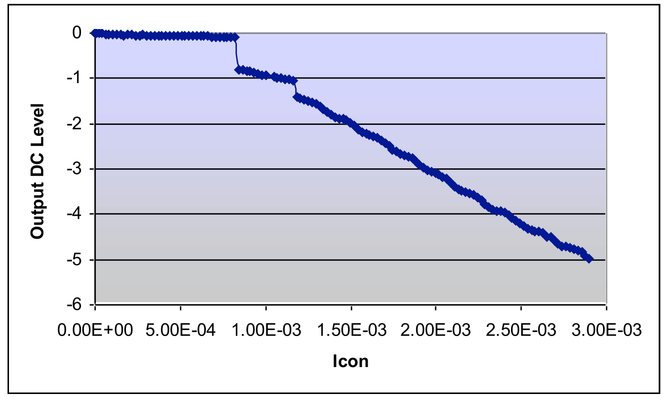
JRC13700 #2, 100kHz Input Signal



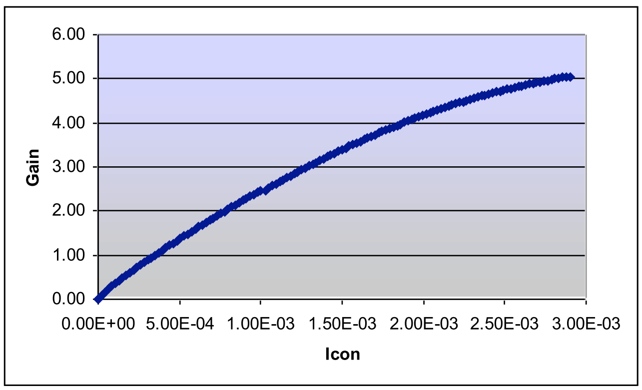


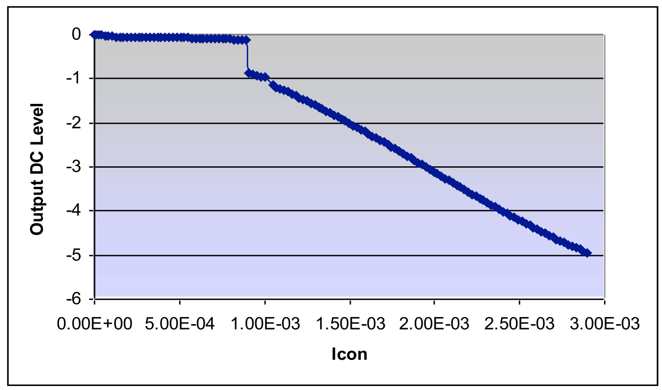
JRC13600, 100Hz Input Signal



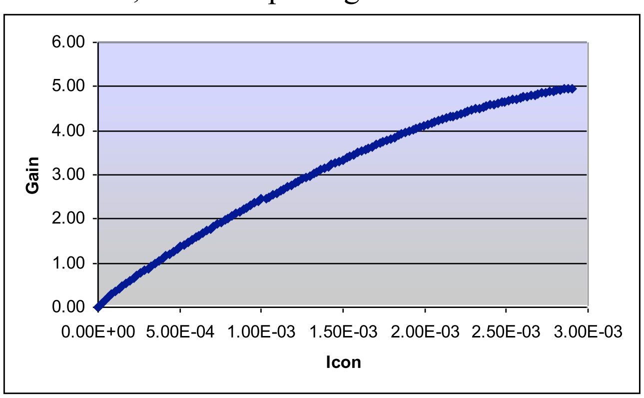


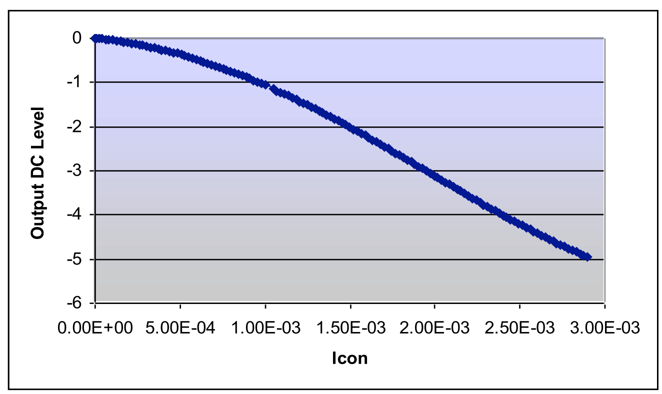
JRC13600, 1kHz Input Signal



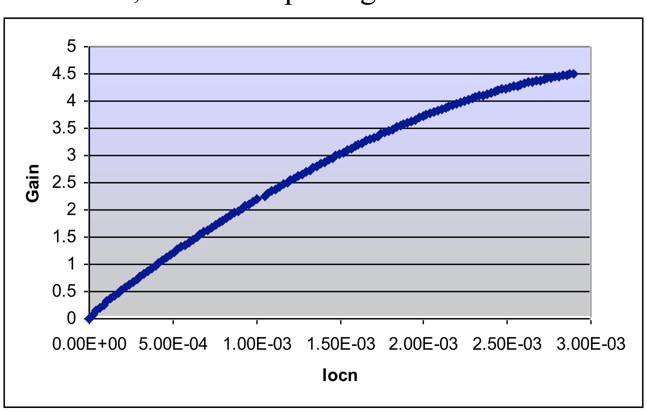


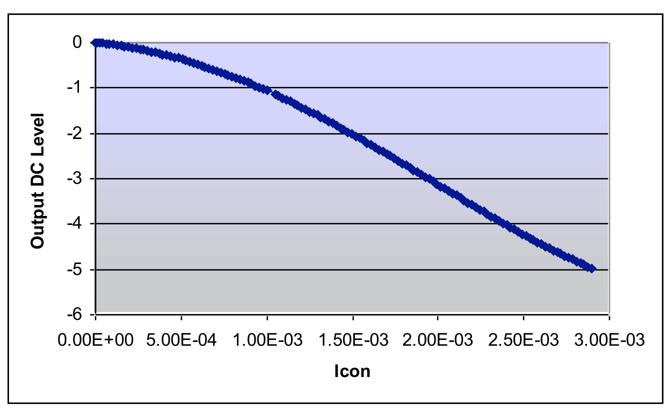
JRC13600, 10kHz Input Signal



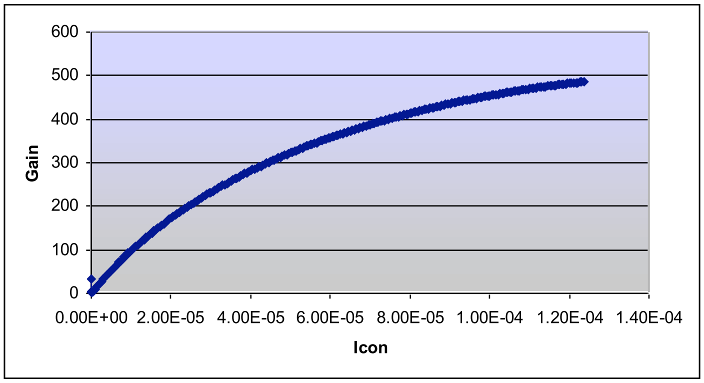


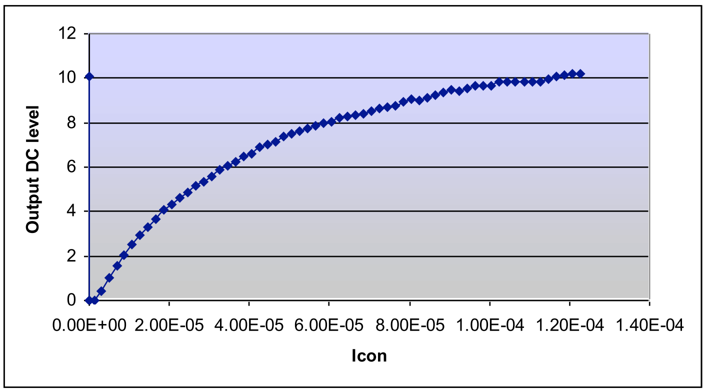
JRC13600, 100kHz Input Signal





OTA made from LS358/LS318 Matched Pair OTA, 10kHz Input Signal





OTA made from 2SC1483/2SA793 Matched Pair OTA, 10kHz Input Signal