Welcome!

Device Characterization with the Keithley Model 4200-SCS Characterization System

4200-CVU Applications Training Module 2 Agenda

- Theory of Operation and Measurement Overview
- **Measurement Techniques and Optimization**
- Troubleshooting

ITM Settings That Affect Measurement Time

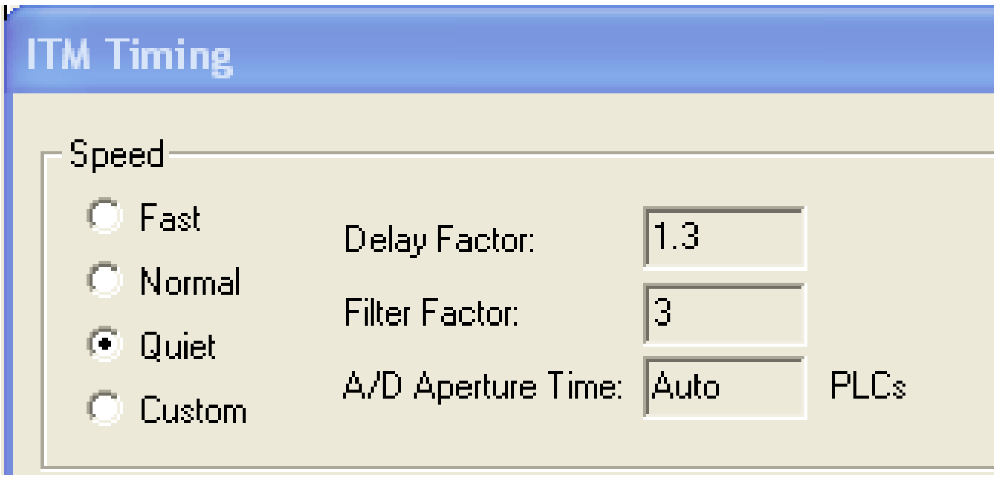
•Timing Menu:
  Speed Mode: Fast, Normal, Quiet
  Sweep Delay (sweep mode)
  Interval Time (sampling mode)
  Hold Time (PreSoak Time)

•Autorange: time is added to settle at each range – only added to first reading taken once the range has changed:
  1 μA: 400 ms; 30 μA: 200 ms; 1 mA: 100 ms

•Measurement Range: the lower the current measurement range, the more delay time is added to each reading to settle (implies higher impedance)

•Test Frequency: the higher the frequency, the more time is added to settle the reading (implies higher impedance)

ITM Timing Menu Speeds: Fast, Normal, Quiet, Custom Modes



Choosing the appropriate Speed Mode involves a speed vs. noise trade-off.

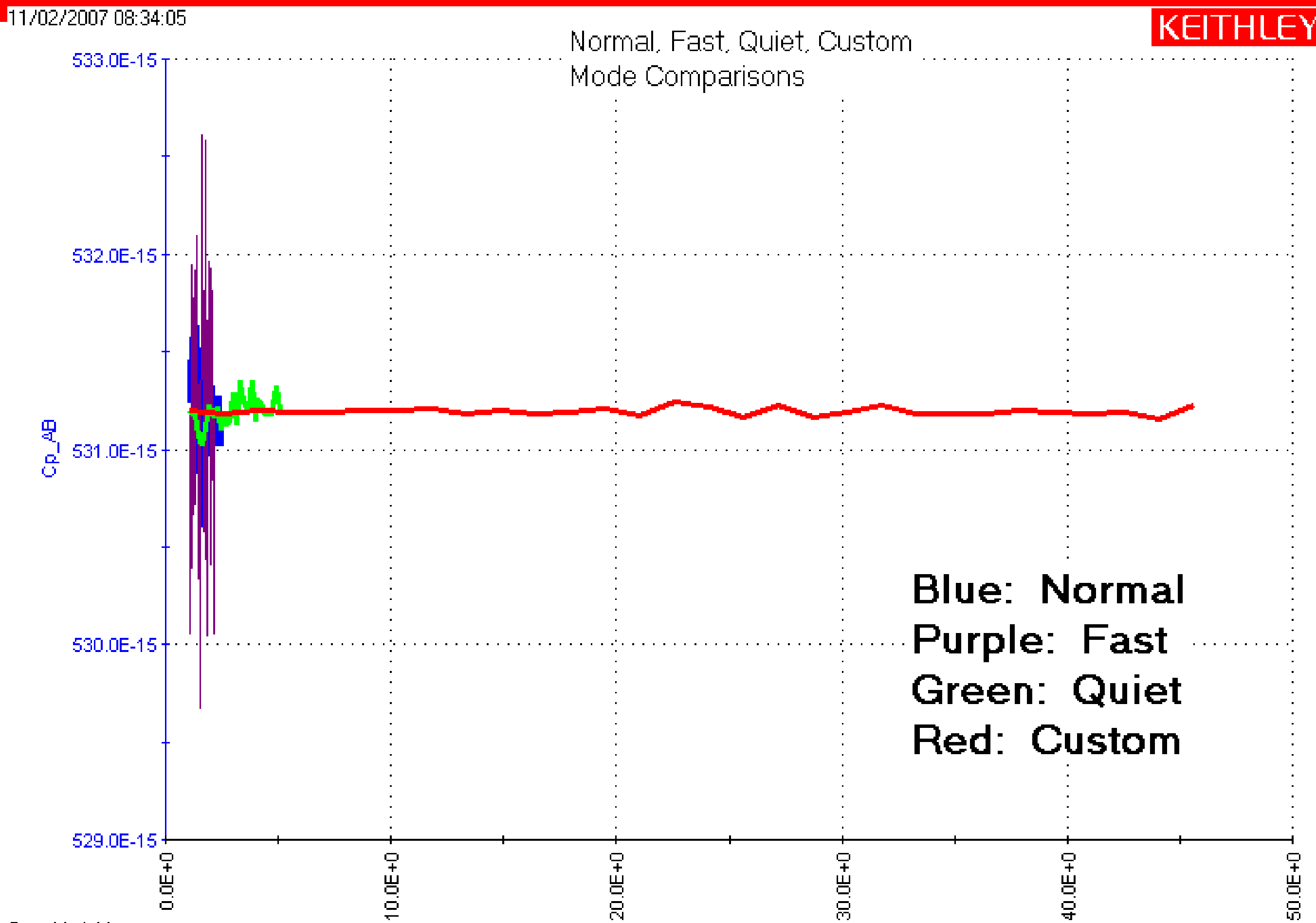
Fast: Fastest time, highest noise.

Normal: Most common setting. Allows sufficient settling times for most measurements.

Quiet: High accuracy, slower time setting. Allows more time for DC settling and provides longer integration time.

Custom: can be programmed for the highest accuracy (with the settling time).

Fast, Normal, Quiet Modes
High Impedance DUT



Data Variables
Data:STDDEV = 234.87800e-18
Append1:STDDEV = 766.65393e-18
Append2:STDDEV = 76.83155e-18
Append3:STDDEV = 20.44167e-18

Test Device: .53 pF cal cap; Test Frequency: 1MHz; 30 uArange

Normal, Fast, Quiet, and Custom Speed Modes High Impedance DUT

The capacitance measurements on the .53 pF cal cap were made at 1 MHz test frequency on the 30 uA range. The average reading time and standard deviation for 30 readings taken shown below:

Speed Mode	Avg. Time per Reading	Std. Deviation
Normal	48 ms	234E-18
Fast	39 ms	766E-18
Quiet	138 ms	76.8E-18
Custom (10 plc, 3 filter)	1.5 s	20.4E-18

Notice there is not a large difference between the Average Reading Times between the Normal and Fast modes.

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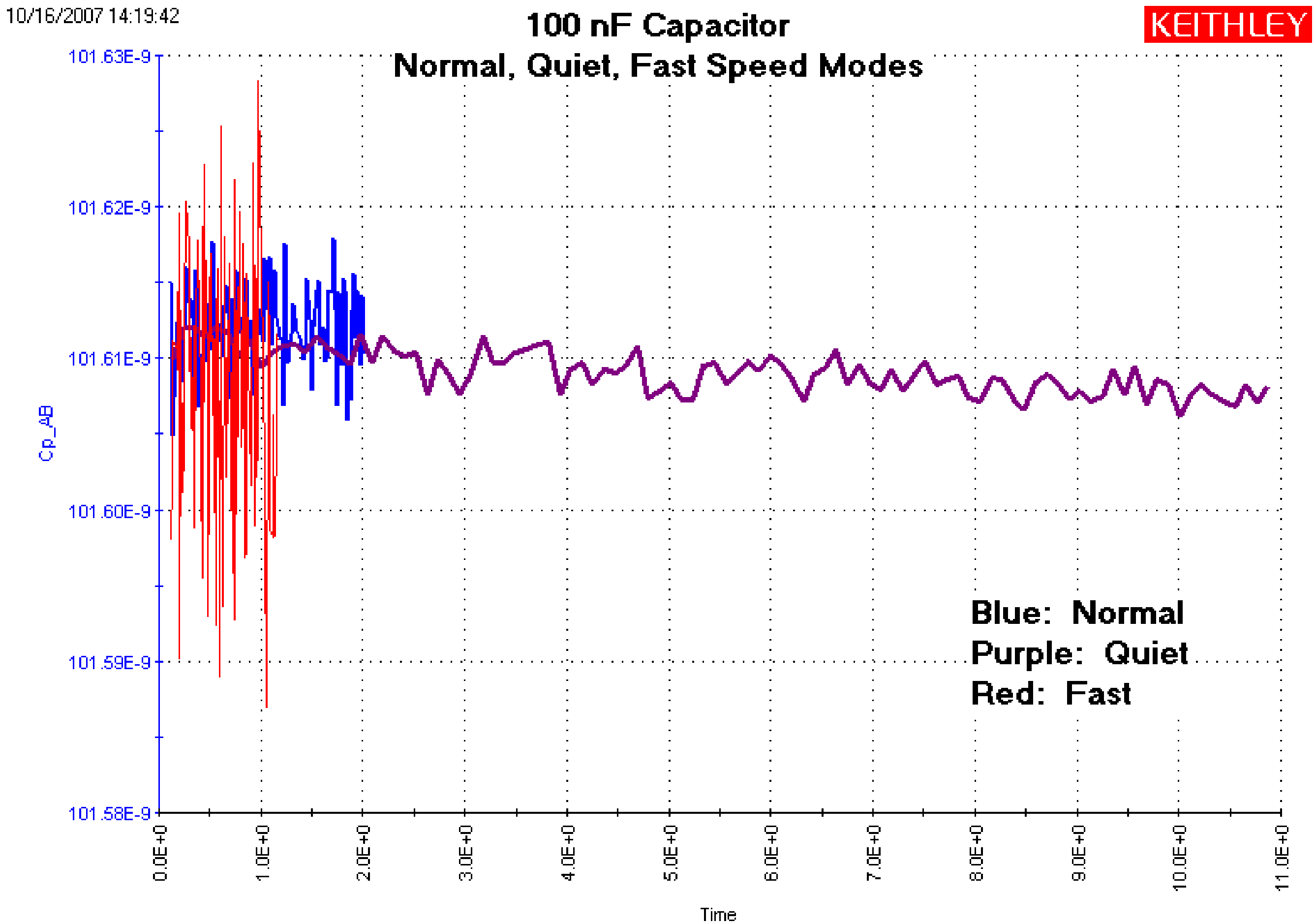
Fast, Normal, Quiet Modes
100 nF Cap, Lower Impedance



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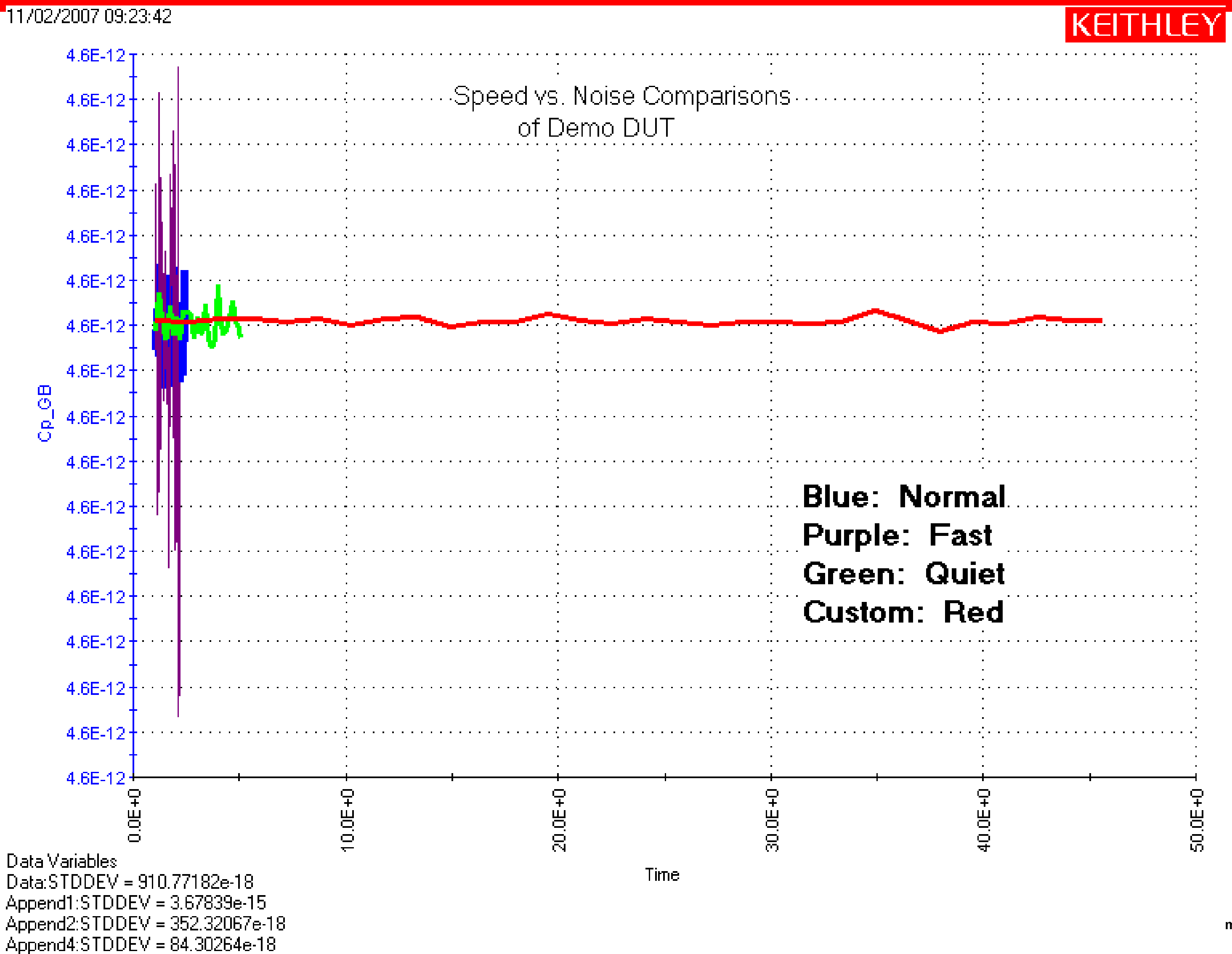
Fast, Normal, Quiet Modes
Low Impedance DUT

The capacitance measurements on the much lower impedance 100 nF cap were made at 100 kHz test frequency with auto-range ON. The total test time and standard deviation for each test are as follows:

Speed Mode	Total Test Time (100 readings)	Std. Deviation
Fast	1.1626 s	8.6008E-12
Normal	2.0056 s	2.8494E-12
Quiet	10.8735 s	1.4357E-12

Notice that with the lower impedance DUT (higher current), that the Fast mode is now about twice as fast as the Normal mode. Less settle time is added to each reading than on a lower current range.

Speed vs. Noise Comparisons of a MOSFET in accumulation



Choosing Appropriate Hold and Sweep Delay Times

Choosing appropriate hold and sweep delay times is important to many applications.

The condition of a device when all internal capacitances are fully charged after an applied step voltage is referred to as “equilibrium”.

If capacitance measurements are made before the device is in equilibrium, inaccurate results may occur.

To choose the delay times for a C-V sweep, step an applied voltage using the Sampling Mode, and plot the capacitance as a function of time. Observe the settling time from the graph. Use this time for the Hold Time for the initial applied voltage or for the Sweep Delay Time applied at each step in the sweep. The Sweep Delay Time may not need to be as long as the first step. The customer will need to experiment.

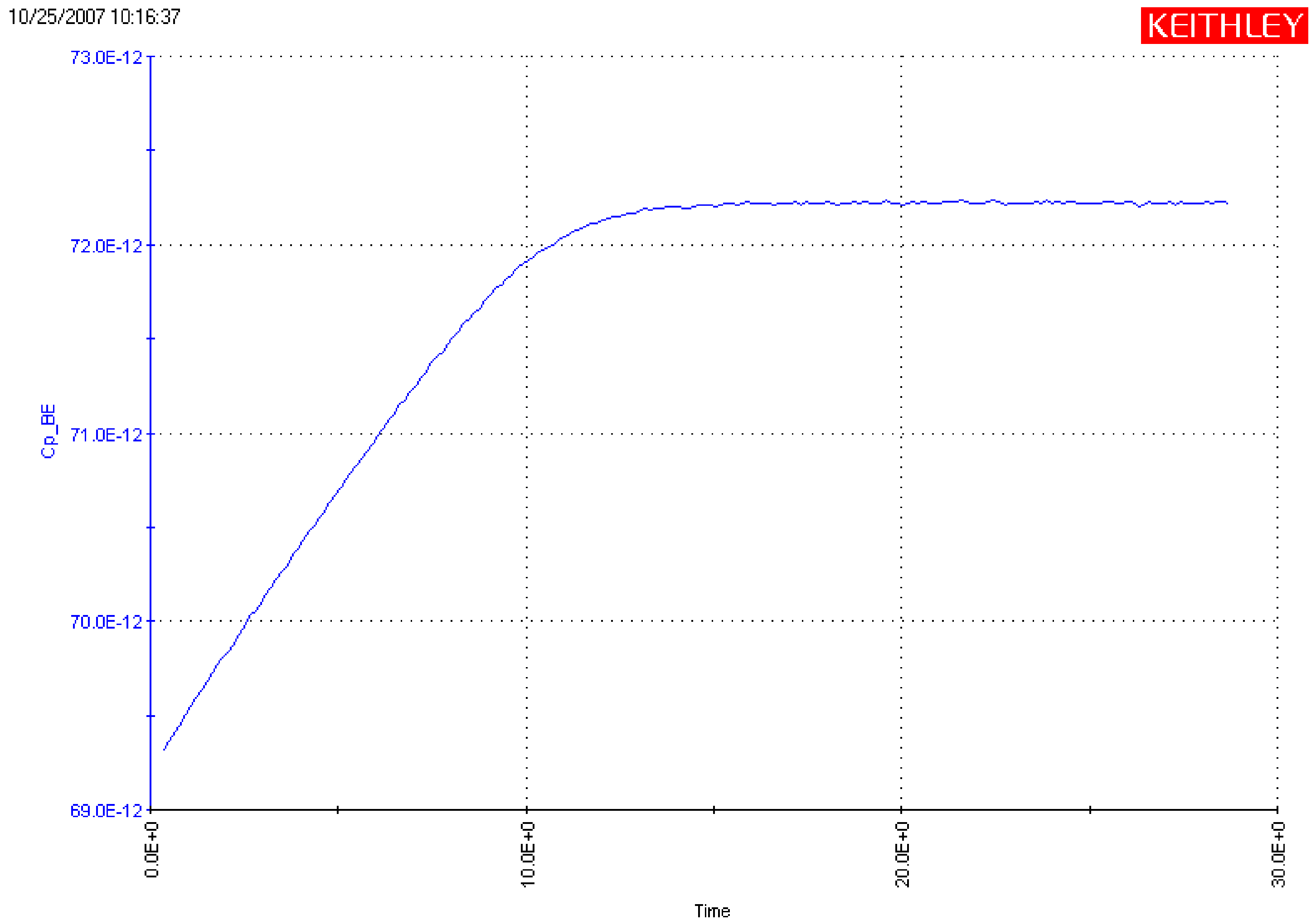
Choosing Appropriate Hold and Sweep Delay Times

To choose the delay times for a C-V sweep:

-step an applied voltage using the Sampling Mode
-use initial conditions of Hold Time=0, Interval Time=0, and PreSoak V =0
-plot the capacitance as a function of time.
-observe the settling time from the graph.
-use this time for the Hold Time for the initial applied voltage or for the Sweep Delay Time applied at each step in the sweep.

The Sweep Delay Time may not need to be as long as the first step. The user will need to experiment.

Example: Equilibrium Time Measurement



Analyzing MOS Cap C-V Curves for Equilibrium

C-V measurements on MOS caps should only be made under equilibrium conditions. A MOS cap takes time to charge up after a voltage step is applied.

To allow the MOS cap to reach equilibrium:

•Allow a sufficient Hold Time while applying the PreSoak Voltage. This is the voltage applied prior to the C-V Sweep.

•After each DC voltage step of the sweep, allow an adequate Delay time before taking the measurement.

There are two primary indicators that can be used to determine whether a device has remained in equilibrium. 1) Check the shape of the C-V curve when sweeping from either direction (hysteresis), and 2) The curves should exhibit a smooth, equilibrium shape.

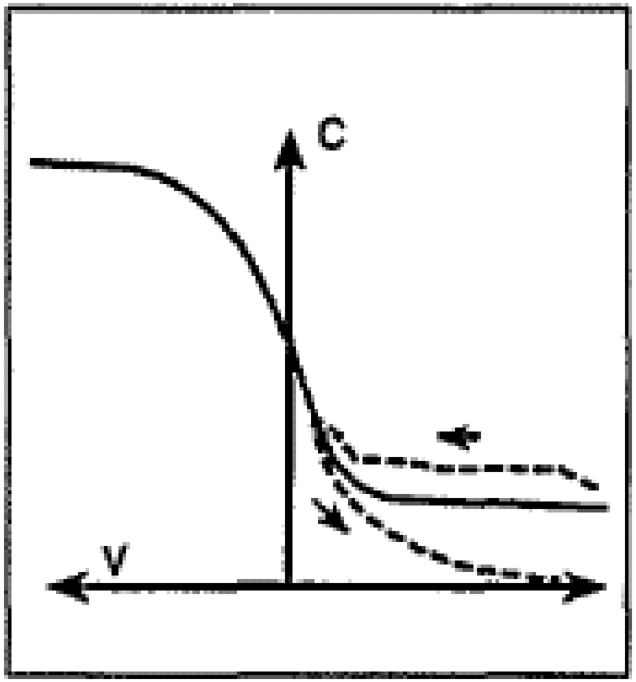
Analyzing MOS Cap C-V Curves for Equilibrium

One way to determine if the device is in equilibrium is to check the shape of the C-V curves in the inversion region when the sweep direction is changed.

If the device is settled at all points of the sweep, it should make no difference if the sweep goes from accumulation to inversion or from inversion to accumulation.

The dotted lines in the curves indicate unsettled readings in the inversion region.

The solid line indicates measurements taken in equilibrium.



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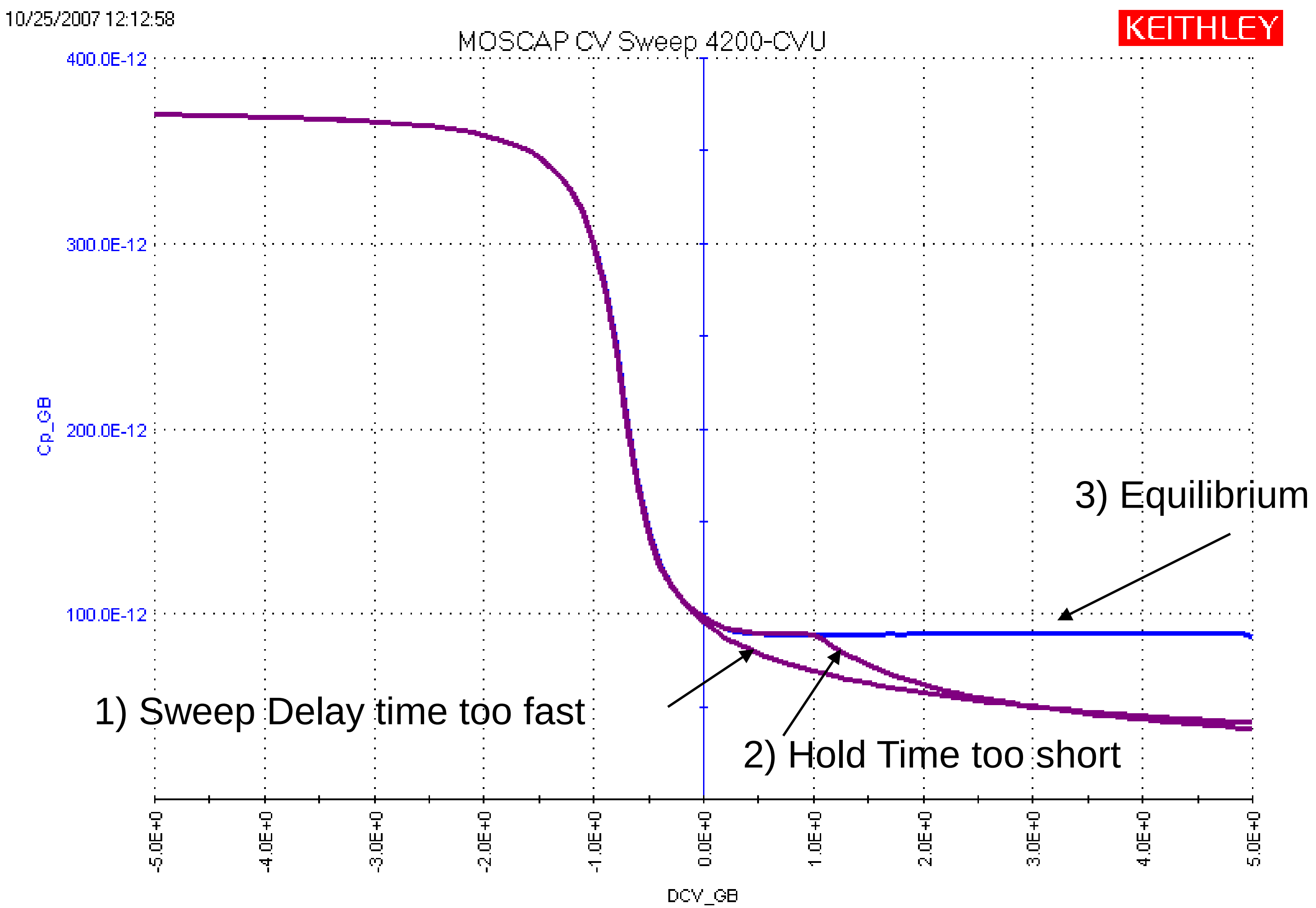
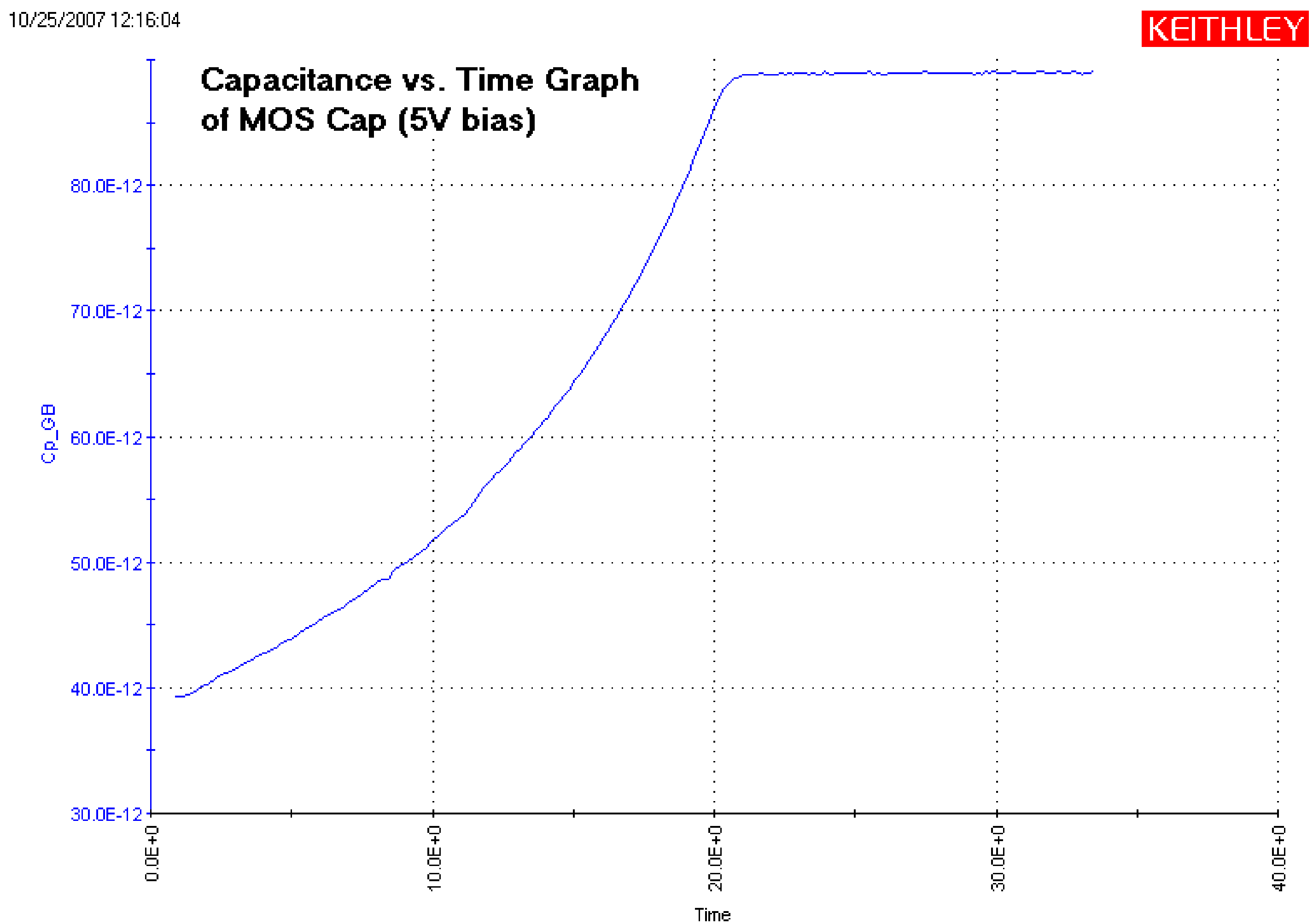
C-V Curves of MOS Cap Showing Non-Equilbrium



Determining the Equilibrium Time of a MOS Cap



Reducing the Effects of Stray Capacitance

- **Offset Connection Compensation:**

  Open: Corrects for large impedance, small capacitance offsets

  Short: Corrects for low impedance, high capacitance offsets

- **Guarding:**

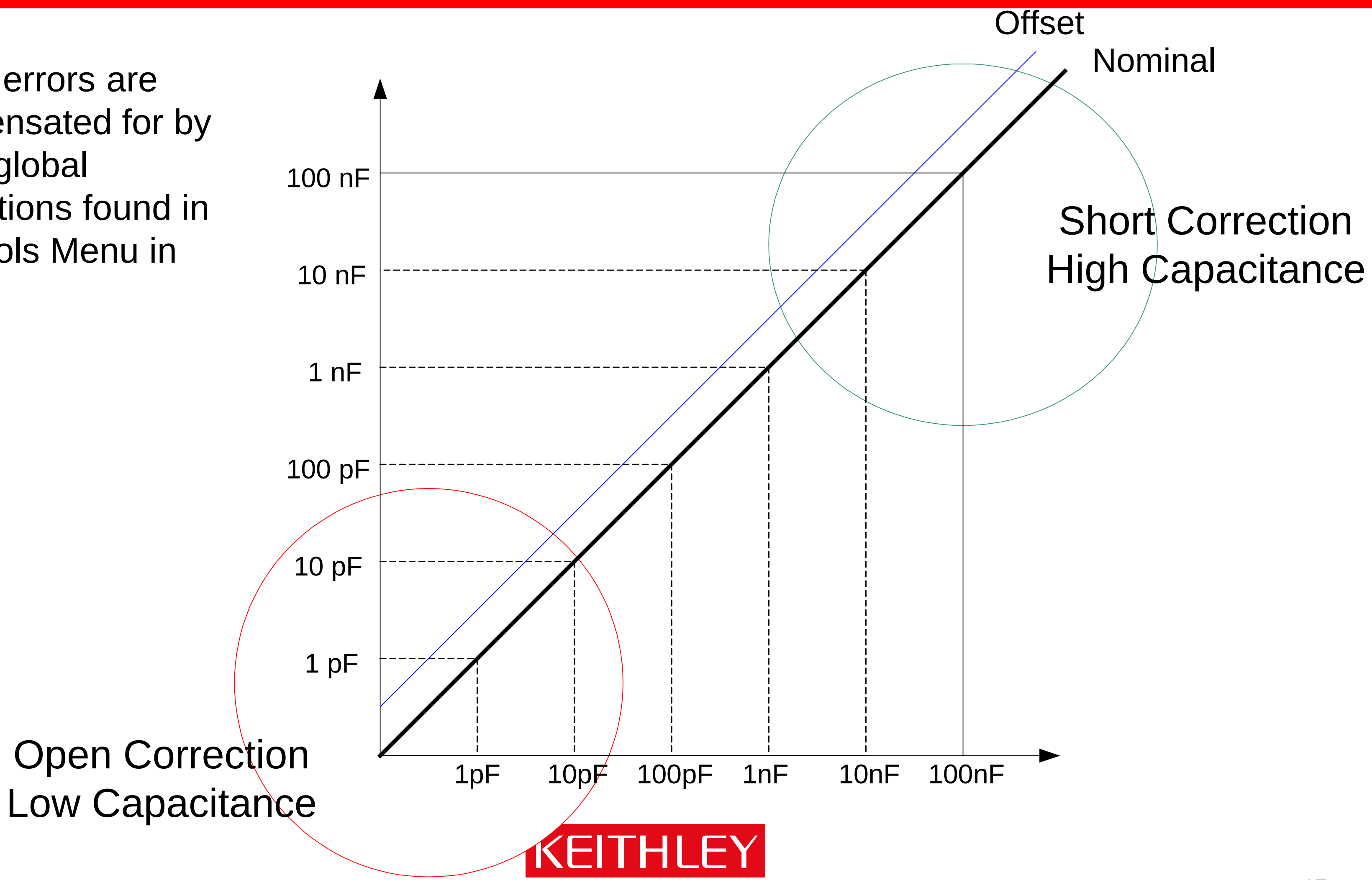
  Wafer Level Measurements, Packaged Devices

- **Proper Connections of the Ammeter Terminal of the CVU:**

  Effects of capacitive loading of the terminals on the ammeter

Open/Short Correction

Offset errors are compensated for by using global corrections found in the Tools Menu in KITE.



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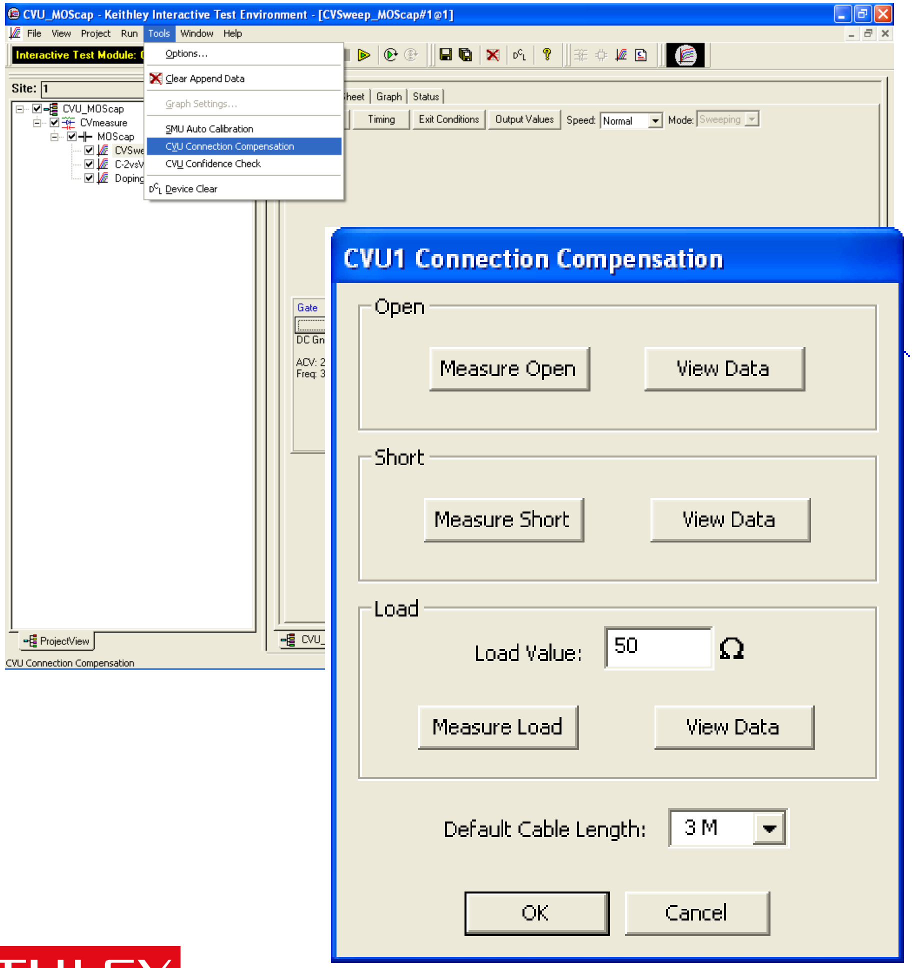
Open/Short Correction

Correction is a two part process. The corrections are performed, and then they are enabled within an ITM.

To perform the corrections, Open the Tools Menu and select CVU Connection Compensation.

For an Open correction: click on Measure Open. Probes must be up or DUT should be removed from the test fixture. (Use open for <10pF, switch matrix)

For a Short correction: Click on Measure Short. Connect short between all output terminals. BNC barrel can be used between BNC tees. Or, short probes together. (Use short for >10 nF)



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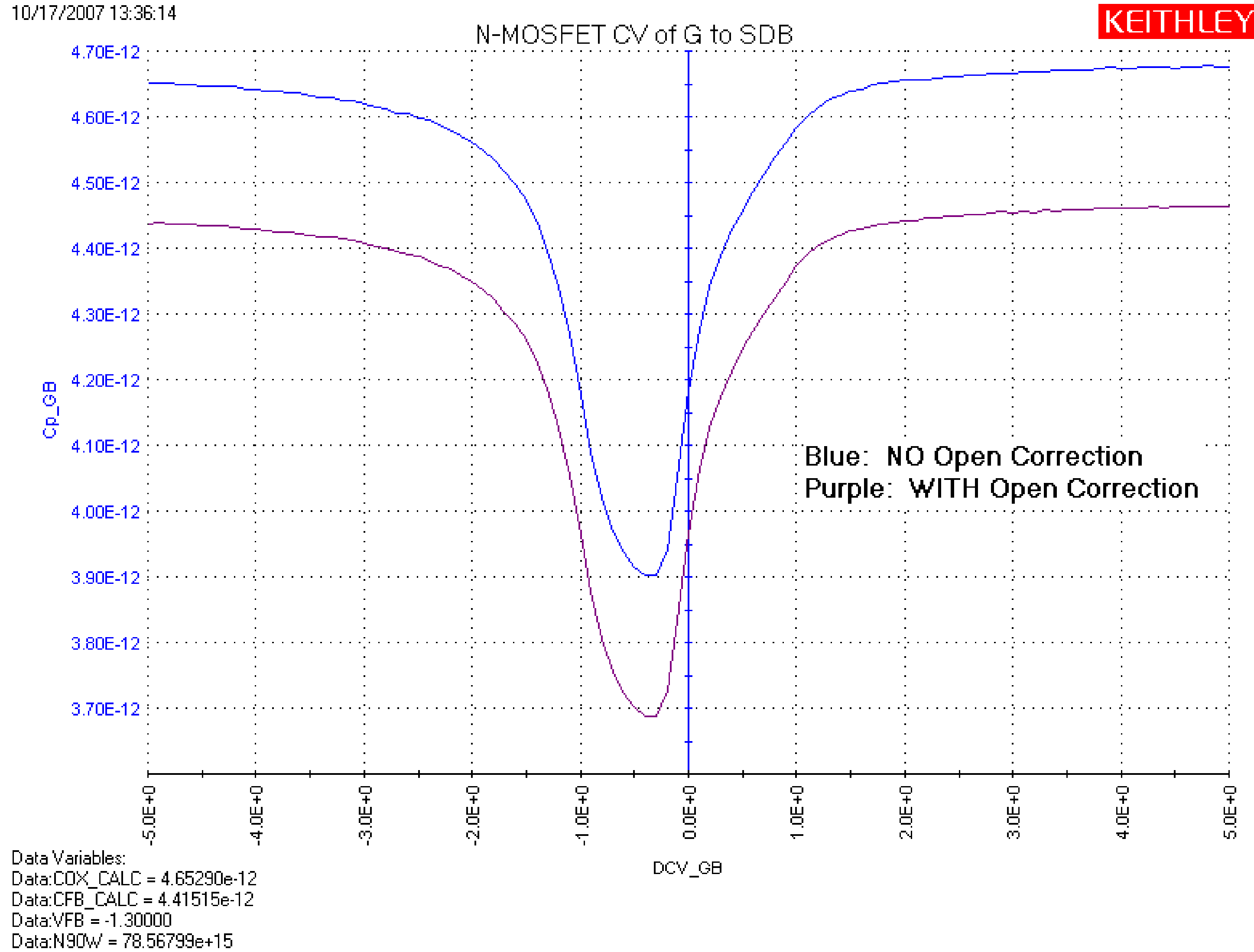
C-V Curve Before and After Open Correction on MOSFET Demo DUT



C-V Curve Before and After Correction on 100 nF Capacitor (low impedance device)