

Using the Ramp Rate Method for Making Quasistatic C-V Measurements with the 4200A-SCS Parameter Analyzer

APPLICATION NOTE



Introduction

Capacitance-voltage (C-V) measurements are generally made using an AC measurement technique. However, some capacitance measurement applications require a DC measurement technique. These are called *quasistatic* C-V (or QSCV) measurements because they are performed at a very low test frequency, that is, almost DC. These measurements usually involve stepping a DC voltage and measuring the resulting current or charge. Some of the techniques used for quasistatic C-V measurements include the *feedback charge method* and the *linear ramp method*. The 4200A-SCS Parameter Analyzer uses a new method, the ramp rate method, which employs two 4200-SMUs Source-Measure Units (SMUs) with two 4200-PA Preamps. The optional 4200-PA Preamps are required because this test involves sourcing and measuring current in the picoamp range. The SMUs are used to source current to charge the capacitor, and then to measure the voltage, time, and discharge current.

The software calculates the capacitance as a function of voltage from the measured parameters and shows the curve on the 4200A-SCS's display. This application note describes how to implement and optimize quasistatic C-V measurements using the 4200A-SCS and the ramp rate method. It assumes the reader is familiar with making I-V measurements with the Keithley 4200A-SCS at the level outlined in the 4200A-SCS Reference Manual.

Ramp Rate Method

Figure 1 illustrates the basic connection diagram for the ramp rate method. This configuration requires two 4200-SMUs with 4200-PAs connected to either side of the device under test. Because the ramp rate method works over a limited range, the capacitance of the device under test should be in the range of 1pF to about 400pF.

Basically, the ramp rate method works by charging up the device under test to a specific DC voltage using an SMU as a current source. Once the device is charged up, a current of the opposite polarity is forced to discharge the device as the SMU measures voltage as a function of time. A second SMU measures the discharge current. From the measured voltage (V), current (I) and time (t) values, the capacitance (C) is derived as a function of voltage and time:

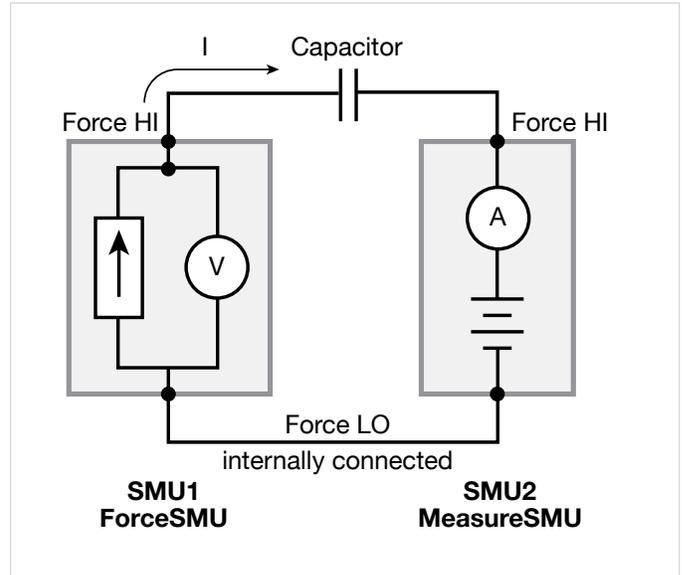


Figure 1. Connections for Capacitance Measurements Using Ramp Rate Method

$$C = \frac{dQ}{dV}$$

$$Q = \int Idt$$

The ramp rate method included with the 4200A-SCS follows these steps when making QSCV measurements:

1. **Charge the Device:** A precharge current of 100pA is applied to the DUT by an SMU, called *ForceSMU*, until the compliance voltage is reached. The compliance voltage is user specified and is called *VStart*. The polarity of the precharge current is the same as the polarity of the *VStart* voltage. If the precharge current is not sufficient to force the device to *VStart*, then a timeout error will be generated.
2. **Bias the Device for Specified Time Prior to Sweep:** The device is biased at the *VStart* voltage for a user specified time (*PreSoakTime*) prior to the sweep.
3. **Apply Ramp Current to Discharge Device:** Once the device is biased for a specified time, a ramp rate current is applied to the device to discharge the device. The ramp rate current is of the opposite polarity as the precharge current. The value of the ramp current is:

$$I_{ramp} = CVal \times RampRate$$

where:

$CVal$ = the estimated capacitance value input by the user in farads (F).

$RampRate$ = user input slope of stimulus voltage (dV/dt) in V/s.

4. **Simultaneously Trigger SMUs to Take**

Measurements: The SMU that is the *ForceSMU* measures voltage (V1, V2, V3 ... Vn) and time (T1, T2, T3 ... Tn). The SMU that is the *MeasureSMU* measures the current (I1, I2, I3 ... In). The voltage, time, and current measurements are made until the opposite polarity of the *VStart* voltage is reached.

5. **Calculate Voltage, Time, and Capacitance Output**

Values: In real time, parameters are extracted from the measurements and will appear in the Sheet or Graph. These parameters are V_{out} = voltage, T_{out} = time, and C_{out} = capacitance, and are calculated as follows:

$$V_{out} = \frac{(V2 + V1)}{2} \text{ (the average of two measured voltages)}$$

T_{out} = T2 (the time when the second measurement is made)

$$C_{out} = \frac{I2}{(dV/dt)}$$

where $dV = V2 - V1$ and $dT = T2 - T1$.

How to Make QSCV Measurements Using the Clarius Software

The system's Clarius software includes a user module to make quasistatic C-V measurements using the ramp rate method. This user module, *meas_qscv*, located in the *QSCVulib* user library, can be opened up as a custom test from within a project.

Setting up the Parameters in the *meas_qscv* User Module

Once you've created a test using the user module, you need to input a few parameters. The adjustable parameters for the *meas_qscv* user module are listed in **Table 1**.

Table 1. List of Adjustable Parameters in *meas_qscv* User Module

Parameter	Range	Description
ForceSMU	1-8	SMU number that will force current through capacitive load. This SMU must have a preamp.
MeasureSMU	1-8	SMU number that will measure current. This SMU must have a preamp.
VStart	-200 to 200	Starting and ending voltages (V) for C-V sweep.
CVal	1E-12 to 400E-12	Approximate capacitance of device under test in Farads (F).
RampRate	0.1 to 1	Slope of stimulus voltage (dV/dt) in V/s.
PreSoakTime	0 to 60	Additional time delay in seconds to allow DUT, fixture, and cables to charge up.
TimeOut	10 to 60	Time allowed in seconds to charge up prior to time out.

Here's a more detailed description of the input parameters:

ForceSMU: The SMU that will force current to the device under test and measure the voltage as a function of time. This SMU must have a preamp because it will be sourcing current in the picoamp range.

MeasureSMU: The SMU that will measure the current flow in the circuit. This SMU must have a preamp because it will be measuring current in the picoamp range.

VStart: This is both the starting and ending voltage of the C-V sweep because the C-V sweep is always symmetrical about 0V.

CVal: Enter at least the approximate maximum capacitance value of the device under test. This value is used to determine the magnitude of the source current to charge the device.

RampRate: The slope of the stimulus voltage in V/s. If the ramp rate is too fast, there will not be enough data points in the sweep. If the ramp rate is too slow, the readings may be noisy. Some experimentation may be needed to find the optimal setting for a particular device.

PreSoakTime: The length of time in seconds to apply the *VStart* voltage to the device prior to the start of

the C-V sweep. Specify sufficient time for the device to charge up and reach equilibrium.

TimeOut: The amount of time allowed to charge the device to the *VStart* voltage until the test module times out. In some cases, such as when a device is shorted, the device may not reach the *VStart* voltage; this parameter enables the module to stop automatically and generate an error message. By default, this is set to 10 seconds.

Executing the Test

The *meas_qscv* user module can be opened up in a project by selecting a new Custom Test in the Test Library. Then select Configure in the top left corner of the screen and in the right hand pane select the *QSCVulib* user library and the *meas_qscv* user module. You can then enter the appropriate values based on your application.

However, Keithley has already created a test and a project that comes in the Library that makes quasistatic C-V

measurements using the *meas_qscv* user module. Choose Select in the top left corner of the screen and then from either the Test or Project Library, enter *qscv* in the search bar and select Search. The *qscv* Test or Project will automatically appear in the center pane.

The project tree for the *Quasistatic C-V Using Ramp Rate Project (ramprate-cvsweep)* is shown in **Figure 2**.

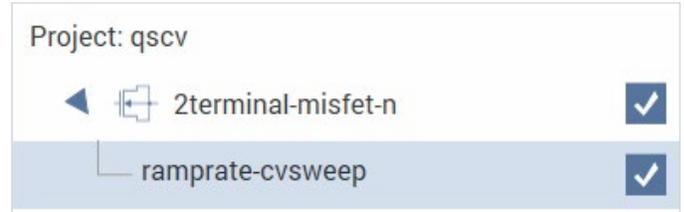


Figure 2. Project Tree for *Quasistatic C-V Using Ramp Rate Project (qscv)*

This project contains a test called *ramprate-cvsweep* for making measurements on a MOSFET device. The configuration pane for setting up the test parameters is shown in **Figure 3**.

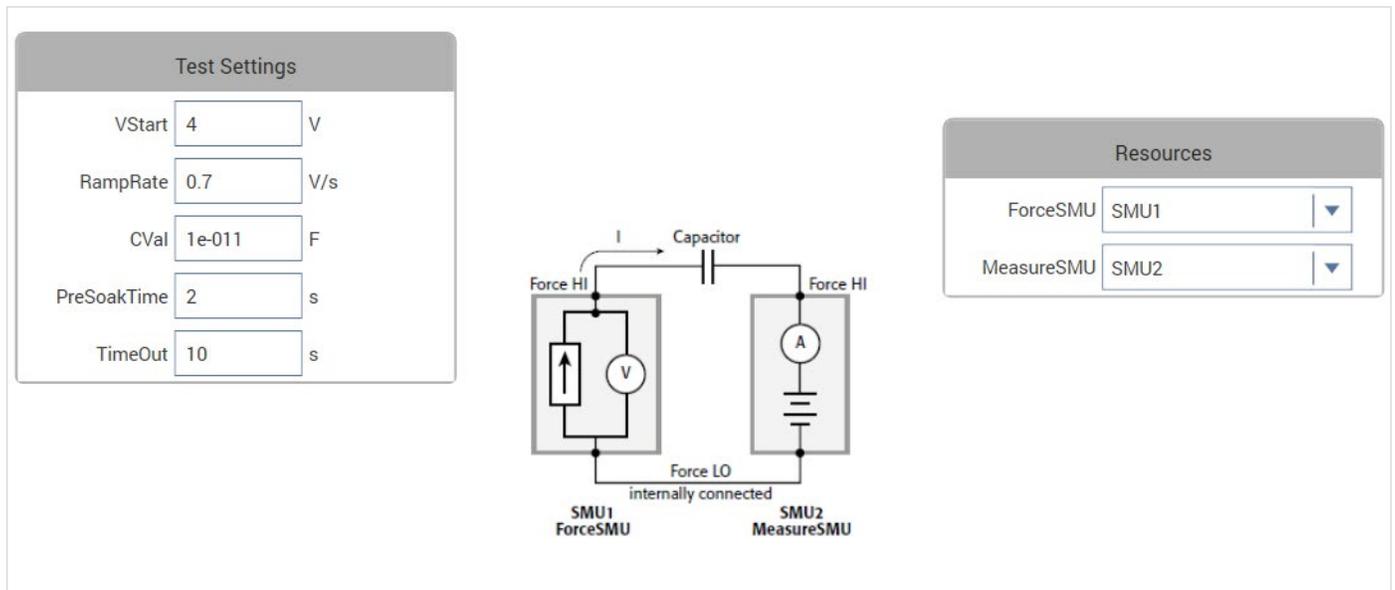


Figure 3. Configuration pane for *ramprate-cvsweep* test

In this test, SMU1 (*ForceSMU*) and SMU2 (*MeasureSMU*) are used to make the C-V measurements. The *VStart* value is set to 4V, so this will generate a voltage sweep from -4V to 4V. The approximate capacitance value is 10pF, so this was entered as the *CVal* parameter. This *CVal* capacitance value will be used to determine the ramp rate current. If this number is too low (for example, 1E-12 instead of 10E-12), then the capacitance measurements will appear noisy. The *RampRate* value was set to 0.7V/s. In this case, a *RampRate* that is larger (1V/s) will produce a somewhat quieter curve but will have fewer data points. A *RampRate* that is smaller (0.1V/s) will produce a much noisier curve with lots of data points. You will need to experiment in order to determine the optimal settings for a particular device under test.

Once the device is connected to the two SMUs and the test is created with the desired input parameters, the C-V sweep can be executed. The results of such a sweep are shown in **Figure 4**.

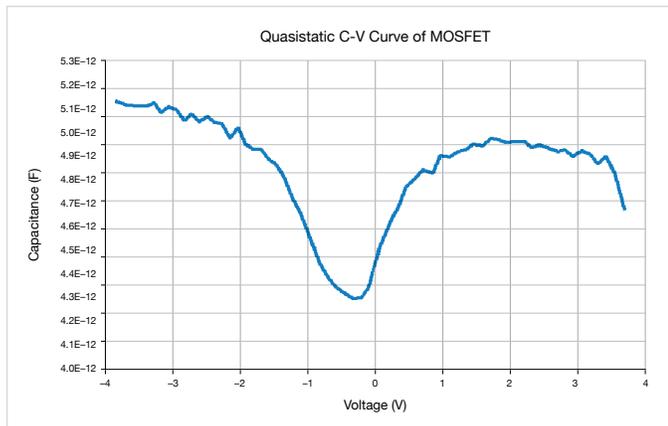


Figure 4. Quasistatic C-V Sweep of MOSFET device

Optimizing Measurements

When making quasistatic C-V measurements using the ramp rate method, various techniques must be used to optimize measurement accuracy. These techniques include implementing low current measurement practices and choosing the appropriate settings in the software.

Because using the ramp rate method involves sourcing and measuring picoamp-level current, low current measurement

techniques must be implemented. Use the triax cables that come with the 4200A-SCS, which are shielded and will allow making a guarded measurement. To reduce noise due to electrostatic interference, make sure the device is shielded by placing it in a metal enclosure with the shield connected to the Force LO terminal of the 4200A-SCS. Detailed information on low current measurement techniques can be found in Keithley's Low Level Measurements Handbook.

The parameter settings in the *meas_qscv* module that will most affect the measurements are *CVal* and *RampRate*. *CVal* is the approximate value of the device under test. If you input a value that is larger than that of the actual device, then the *RampRate* will be larger and there will be fewer data points. Conversely, if the capacitance value entered is smaller than the actual device capacitance, the *RampRate* will be lower and there will be more data points in the curve. Use the largest *RampRate* possible, but ensure the device curve appears settled. However, if the *RampRate* is too fast, there may not be enough points in the sweep.

To reduce the noise level of the curve, the moving average (MAVG) function in the Formulator can be used. Try using a moving average of three readings to see if this helps. Do not set the moving average number so large so that you lose the shape of your C-V curve.

To subtract the offset due to the cables and probe station, generate a C-V sweep using the *meas_qscv* module with the probes up or with an open circuit in the test fixture. Using the Formulator, take an average of the readings. Subtract this average offset value from capacitance measurements taken on the device under test.

Conclusion

Quasistatic C-V measurements can be made with the 4200-SMUs with pre-amps using the ramp rate method. This technique is implemented in software in the *meas_qscv* module of the *QSCV_uslib* user library of the Clarius software. Using low level measurement techniques and choosing the appropriate parameter settings in the software will ensure optimal results.

Contact Information:

Australia* 1 800 709 465
Austria 00800 2255 4835
**Balkans, Israel, South Africa
and other ISE Countries** +41 52 675 3777
Belgium* 00800 2255 4835
Brazil +55 (11) 3759 7627
Canada 1 800 833 9200
Central East Europe / Baltics +41 52 675 3777
Central Europe / Greece +41 52 675 3777
Denmark +45 80 88 1401
Finland +41 52 675 3777
France* 00800 2255 4835
Germany* 00800 2255 4835
Hong Kong 400 820 5835
India 000 800 650 1835
Indonesia 007 803 601 5249
Italy 00800 2255 4835
Japan 81 (3) 6714 3010
Luxembourg +41 52 675 3777
Malaysia 1 800 22 55835
**Mexico, Central/South America
and Caribbean** 52 (55) 56 04 50 90
Middle East, Asia, and North Africa +41 52 675 3777
The Netherlands* 00800 2255 4835
New Zealand 0800 800 238
Norway 800 16098
People's Republic of China 400 820 5835
Philippines 1 800 1601 0077
Poland +41 52 675 3777
Portugal 80 08 12370
Republic of Korea +82 2 6917 5000
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Spain* 00800 2255 4835
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Switzerland* 00800 2255 4835
Taiwan 886 (2) 2656 6688
Thailand 1 800 011 931
United Kingdom / Ireland* 00800 2255 4835
USA 1 800 833 9200
Vietnam 12060128

* European toll-free number. If not accessible, call: +41 52 675 3777

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