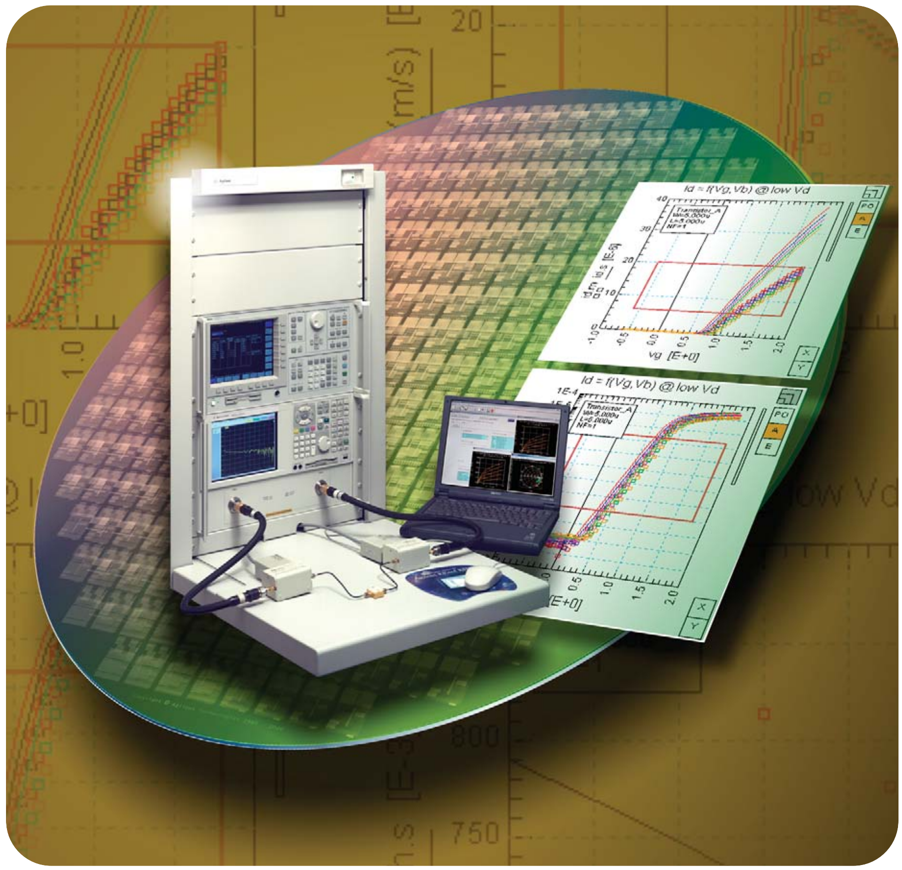
Agilent 85194K IC-CAP BSIM4 Modeling Package

Technical Overview



The BSIM4 Modeling Package

The BSIM4 Modeling Package offers a complete DC-to-RF CMOS modeling toolkit for U.C. Berkeley's BSIM4 model. Developed within the open and flexible IC-CAP software environment through partnership with AdMOS, the 85194K BSIM4 Modeling Package provides a complete CMOS device modeling solution. The package offers:

- Turnkey extraction routines with an easy-to-use interface.
- Reliable and accurate DC, CV, and RF measurements with effective de-embedding methods.
- Accurate extraction and optimization capability for fully scalable DC, CV, and RF models.
- Easy-to-configure binned models with no discontinuity problems.
- An open and flexible extraction package with DC and RF model extensions for enhanced accuracy.

Features at a glance

- A complete package for highly accurate DC, CV, RF, and temperature extraction routines for the industry-standard BSIM4.4 model with STI mechanical stress effect.
- A user interface that guides you step-by-step through complete device measurements, parameter extraction, and optimization.
- A redefined Plot Optimizer and tuners for quickly setting up custom optimization tasks,which are easily incorporated into the automatic extraction flow.
- An automatic HTML report generator, for complete results documentation.

The BSIM4 model

The U.C. Berkeley BSIM4 model is an industry-standard model for MOSFET devices. The BSIM4 model addresses many important modeling issues for sub-0.13 micron CMOS technology and RF high-speed applications. One of the major effects covered in the BSIM4 model is the process-induced stress effect, or the STI effect, which models the device performance based on the active area geometry and the location of the device in the active area. The major improvements and additions over the BSIM3v3 include:

- Scalable stress effect model for process induced stress effect;
- Unified current-saturation model that includes all mechanisms of current saturation - velocity saturation, velocity overshoot, and source end velocity limit;
- Temperature model format that allows convenient prediction of temperature effects on saturation velocity, mobility, and S/D resistances;
- Non-Quasi-Static (NQS) model;
- Gate direct tunneling current model for multiple-layer gate dielectrics;
- Gate Induced Drain Leakage (GIDL) current model;
- Induced gate noise model;
- Quantum mechanical charge-layer-thickness model;
- Enhanced accuracy and flexibility of holistic thermal noise model;
- Improved accuracy of forward body bias model;
- Model of the intrinsic input resistance for RF, high-frequency analog and high-speed digital applications;
- Layout dependent parasitic model for multi-finger devices;
- A flexible substrate resistance network for RF modeling.

The BSIM4.4 model was specifically developed to addresses trap-assisted tunneling and recombination current that occurs at reverse biased P-N junction where the doping on both sides of the junction is relatively high due to the halo-doping technology. It also makes improvements to the BSIM4.3 model that include:

- A new trap-assisted tunneling and recombination current model that is applicable to gate-edge side-wall, STI-edge side-wall and bottom junctions.
- A new parameter VFBSDOFF, to improve the gate overlap tunneling current.
- A new parameter LINTNOI which is an offset to the length reduction parameter. (It improves the accuracy of the flicker noise model.)

Accurate DC-to-RF measurements made easy with the IC-CAP BSIM4 Toolkit

IC-CAP controls the standard modeling systems such as the Agilent 85225G for complete measurement of DC, CV and up-to-67-GHz RF measurements. The BSIM4 toolkit provides an interactive user interface that makes it very easy to configure the instruments, the input and output for all DC device-under-test (DUT), capacitance, DC diode and S-parameter measurements.

DC Measurements:

With the user interface shown in Figures 1 and 2, setting up the instruments and taking device measurement is easy with IC-CAP's BSIM4 toolkit.

Follow these steps to complete the DC, CV and DC diode measurements:

1. Configure the Starts, Stops, and the Steps for DC transistors, Capacitance, and DC Diode.
2. Add the temperatures at which you would like to measure the device for Temperature modeling.
3. Configure the switch matrix you want to use.
4. Add the devices you want to measure for geometry scaling and STI effect modeling.
5. Then perform the DC Transistors, Capacitance, or DC Diode measurement.

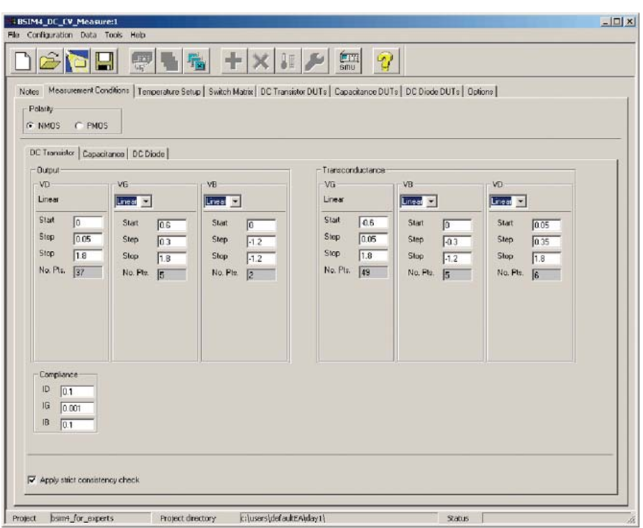


Figure 1: Enhanced measurement user interface for step-by-step measurement tasks. DC Transistor, Capacitance, and DC Diodes can be measured at discrete steps using LIST mode.

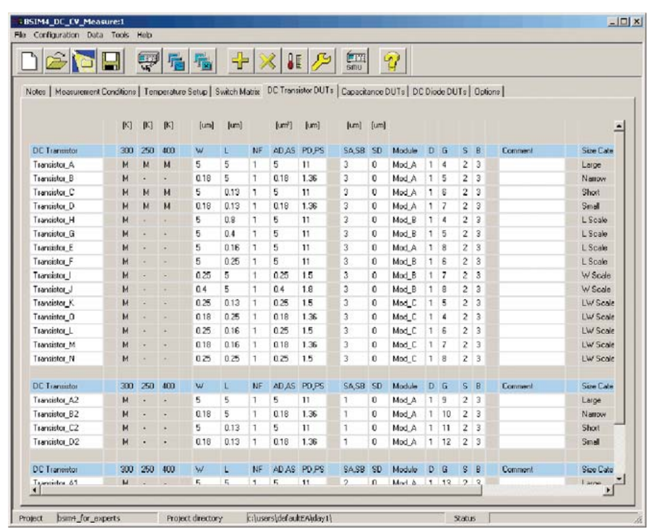


Figure 2: Enhanced measurement user interface for STI effects. Click on Add to add a number of new devices, change the name, and specify their dimensions and STI instance parameter values for SA, SB, and SD. Click SET to specify device size categories (Large, Small, Narrow, Short, L Scale) and STI category (SA ref, SA1, SA2). Click MEASURE to perform the device measurement in single device model or batch mode.

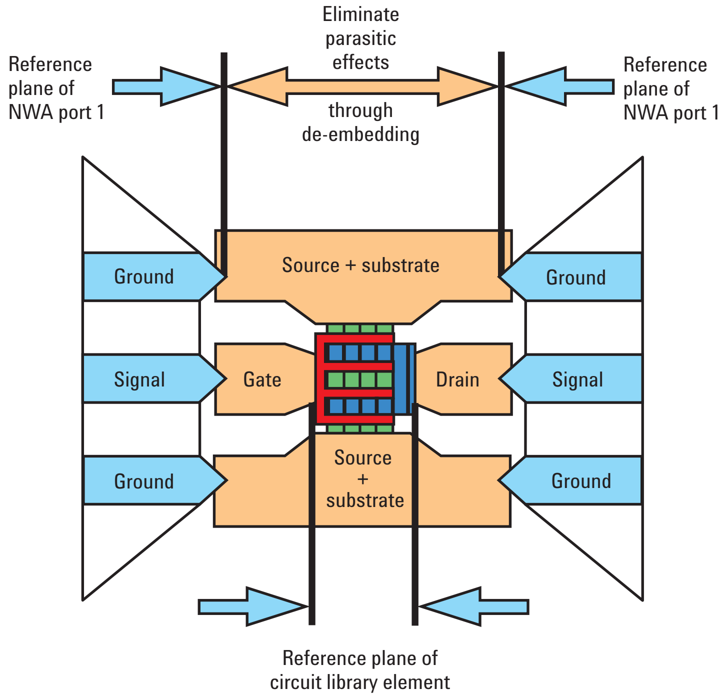
S-parameter measurements:

Although S-parameter measurements for RF modeling require a bit more experience, the BSIM4 toolkit guides you through this process. The steps to get the most accurate RF measurement data include:

1. Calibrate the system very well to remove all DC and RF losses up to the tip of the probes (this is your new reference plane) as shown in Figure 3. Through direct interface with Cascade Microtech's probe stations, Agilent modeling systems can be well calibrated by Cascade's automatic WinCal software using proprietary LRRM calibration techniques.

2. De-embed the parasitic due to pads and interconnects that surround the device to get the true measurement of the device-under test such as a MOSFET transistor. The BSIM4 toolkit (shown in Figure 3) guides you through the two-step de-embedding method with Open-Short, and verifies the data with Through. Your S-parameter measurement data should be thoroughly de-embedded from the surrounding parasitic, and the data can be used for very accurate RF model extraction.

3. Add devices and test structures with specific dimensions, as shown in Figure 4. Click on Calibrate to perform the automatic calibration. Click on Measure to start the DUT measurements. Click De-embed All to start automatic de-embedding procedures. The data is ready for RF model extraction.



Calibration moves the reference plane of the circuit library element closer to the DUT.

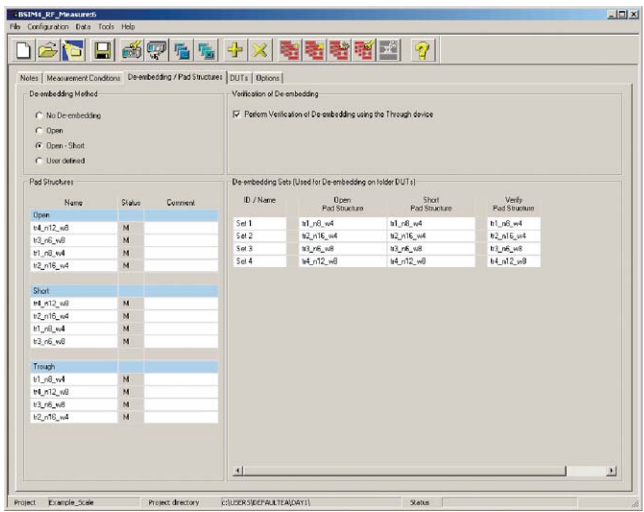


Figure 3: RF Measurement user interface for easy de-embedding or removing of parasitic.

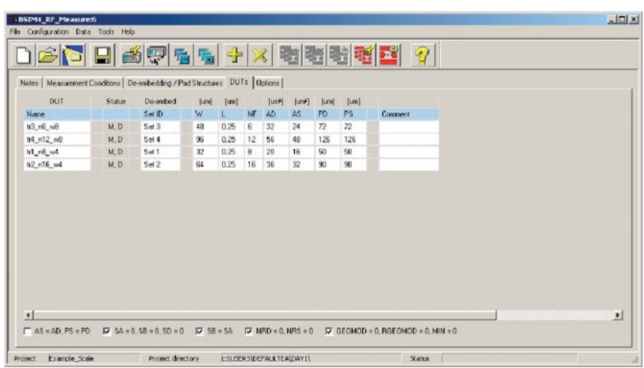


Figure 4: RF Measurement user interface for quickly adding new RF devices into the template.

Easy DC to RF BSIM4 model extraction, step by step:

Through extensive testing and verification with customer CMOS processes, the IC-CAP BSIM4 toolkit starts with very robust DC/CV parameter extraction methodologies that yield highly physical results and excellent fit for ultra-short channel devices below 0.13-µm technologies. The extraction procedures are highly automated, with built-in direct extraction followed by robust optimization tasks, thus reducing the engineering time required to manually fine-tune model parameters at every step. You can use BSIM4 model extraction out-of-the box, without modification.

Extracting the BSIM4 model parameters is easy. Follow these steps:

1. Load the measurement data, initialize known or required process parameters, and set the BSIM4 model flags and device symmetries, as shown in Figure 5.

2. Follow the extraction procedures step by step or check the box to turn off all manual tuners and let IC-CAP perform automatic extraction and optimization of the model for you, as shown in Figure 6.

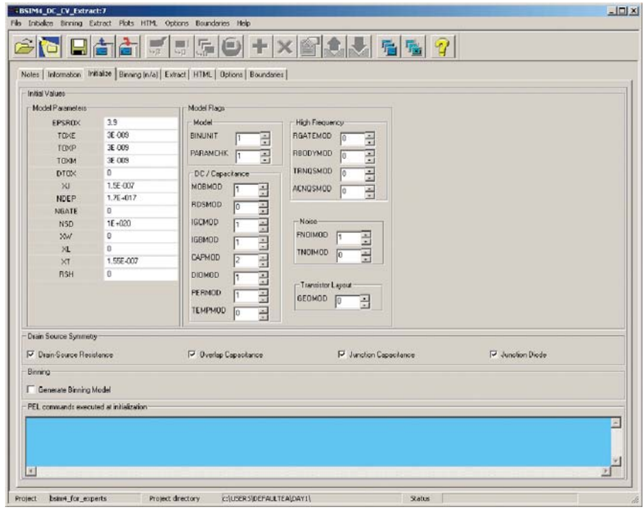


Figure 5: Extraction user interface for easy model parameters initialization. To initialize of the BSIM4 process parameters, click to Add Parameter, select the parameters from the list, and enter their values. Click on the arrow keys or fill in the proper values to set the BSIM4 model flags. Check the appropriate boxes to define Drain/Source symmetry.

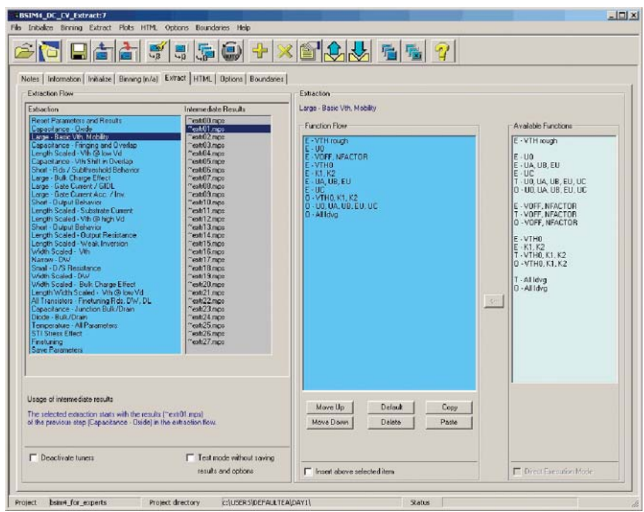


Figure 6: The BSIM4 extraction package provides everything you need to extract the whole set of BSIM4 DC, CV, and RF model parameters.

3. Use the predefined plot optimizer and tuners to follow the standard extraction flow or set up your own custom optimization task. The Plot Optimizer lets you quickly set up a fine-tuning step, which can then be added into the extraction flow outlined in step 2, as shown in Figure 7.

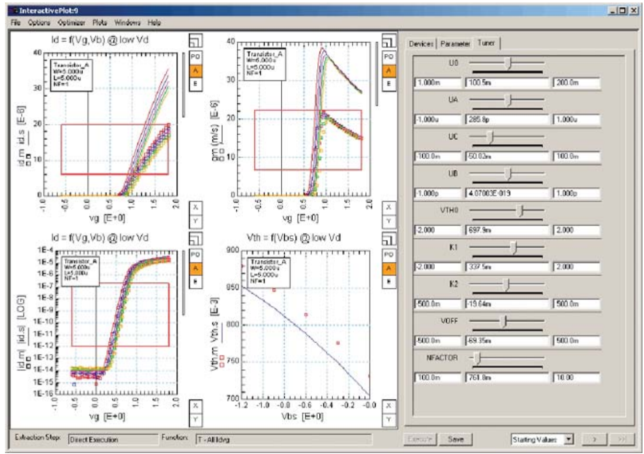


Figure 7: With the predefined plot optimizers and tuners. you can run multiple trials, save the trial results, and then select the parameters that best fit your extraction. Once chosen, those parameters are passed on to the next step of the extraction. You can select from a list of 13 optimizers, shown in Table 1.

Table 1: IC-CAP Optimization Algorithms

Algorithm	Description
Levenberg-Marquardt	Non-linear search method with least-squares error function.
Random	Random search method with stochastic gradient error function.
Hybrid (Random/LM)	Combination of Random and Levenberg Marquardt algorithms and error functions.
Sensitivity Analysis	Single-point or infinitesimal sensitivity analysis of a design variable. Prints partial derivatives with respect to each parameter.
Random (Gucker)[1]	Random search method with least-squares error function.
Gradient[1]	Gradient search method with least-squares error function.
Random Minimax[1]	Random search method with minimax error function.
Gradient Minimax[1]	Gradient search method with minimax error function.
Quasi-Newton[1]	Quasi-Newton search method with least-squares error function.
Least Pth[1]	Quasi-Newton search method with least Pth error function.
Minimax[1]	Two-stage, Gauss-Newton/Quasi-Newton method with minimax error function.
Hybrid (Random/Quasi-Newton)[1]	Combines the Random and Quasi-Newton search methods.
Genetic[1]	Direct search method using evolving parameter sets.

[1] Uses full working precision of 15 digits during simulation and error calculation while optimizing. The IC-CAP Status window displays results based on the WORKING_PRECISION variable, which is 6 by default. At the end of the optimization, RMS and MAX error are calculated at the default precision. Therefore, results displayed at the end of the optimization may differ from those obtained during the optimization steps.

Binned models:

The BSIM4 toolkit lets you create fully binned models. You can also choose to select only a few key parameters to be binned, and the rest can be extracted using the scalable modeling approach. The binning approach in the IC-CAP BSIM4 toolkit does not create any discontinuity problems, thus reducing the time it takes to verify continuity across bin boundaries.

Follow these steps:

- Click on show devices to show available measured devices.
- Create a box covering four adjacent devices, as shown in Figure 8.
- Click on Set Bin to create a new bin.

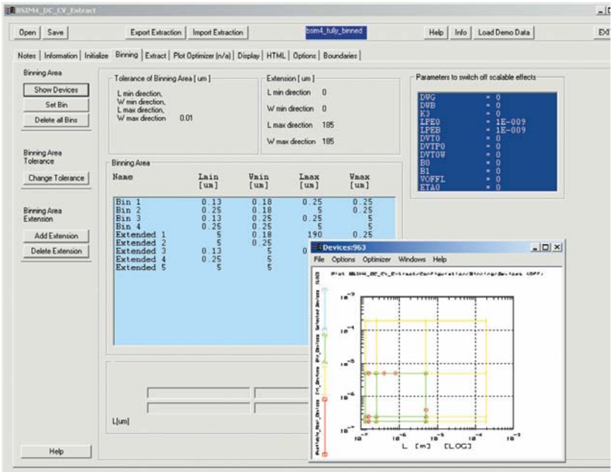


Figure 8: To configure devices for binned models, create a box for devices and click to set bin.

- Open the Extract page and follow the binning extraction step-by-step or use automatic binned model extraction, as shown in Figure 9.

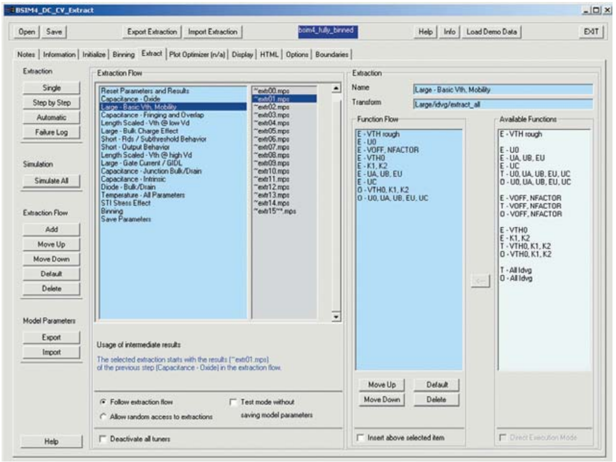


Figure 9: The automated binned model extraction flow.

HTML report generator:

An automated HTML report generator is available for creating a full HTML report of your modeling results, as shown in Figure 10.

BSIM4 RF model parameters extraction simplified:

The BSIM4 extraction module includes built-in extraction routines for all gate, substrate, overlapping, and external parasitic elements that are critical to RF and microwave designs. In addition, the BSIM4 RF extraction routines provide scaling equations for the substrate resistance network, enabling a single set of RF model parameters to fit a wide range of device geometries.

1. To extract a complete set of RF BSIM4 model parameters, start with initialization of required or known model parameter values, and choose the appropriate model flags, as shown in Figure 11.

2. Go to the extract page and follow the extraction sequence provided. You can extract groups of parameters step by step, or turn off all manual tuners and let IC-CAP run the full model extraction and optimization, as shown in Figure 12.

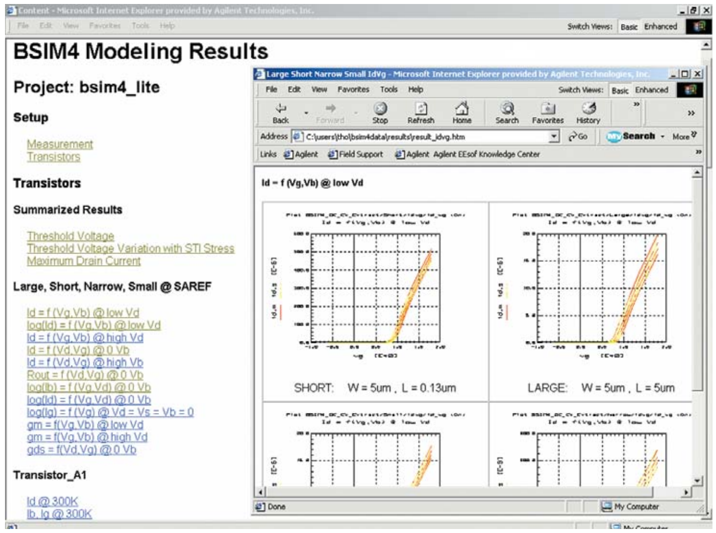


Figure 10. The fully automated HTML report generator gives complete DC, CV, and RF model results.

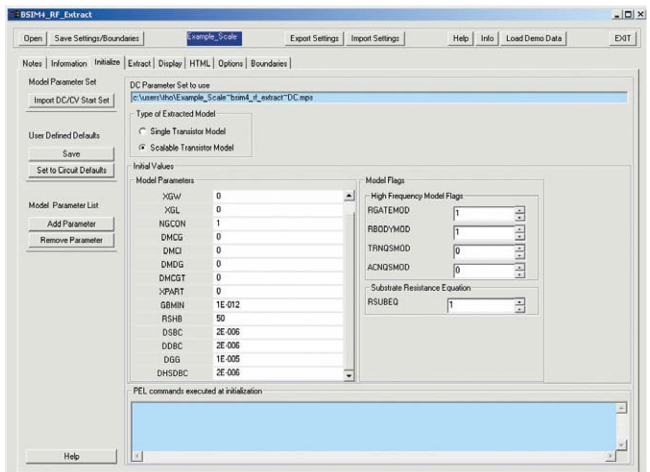


Figure 11: The IC-CAP BSIM4 toolkit allows a single or scalable RF transistor modeling approach. Check the box and let IC-CAP perform the necessary task.

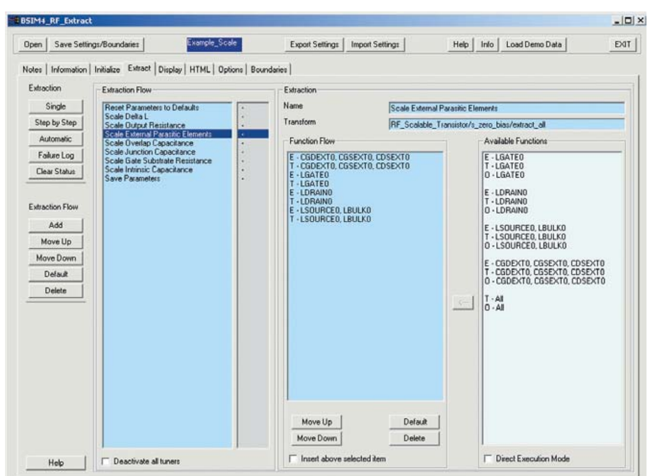


Figure 12: The out-of-the-box RF model extraction flow. No further modification is required. For specific processes for which the standard BSIM4 model does not provide adequate RF modeling, users can enhance the sub-circuit model, and extract and optimize the extended RF model parameters.

AdMOS stands for Advanced Modeling Solutions, a recognized leader in MOS extraction, offering products in device simulation and modeling consulting. AdMOS has a close partnership with Agilent EEsof EDA, and Agilent EEsof EDA has the exclusive distribution rights to the BSIM4 Modeling Package. For more information about AdMOS visit the AdMOS web site at **www.admos.de.**

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