KEITHLEY

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Keithley DC/RF Technology Implementation Backgrounder

Introduction to Keithley's DC/RF Test Solutions

Keithley's RF APT Systems provide a fully automated solution for wafer-level RF measurements:

- They eliminate the need for an expert to analyze and filter the data before use by the general engineering and manufacturing community.
- They eliminate the need for special probers to make high frequency measurements.
- They are so much faster than prior solutions that they make statistical model generation and real-time statistical process control of RF parameters possible.

These systems add a Vector Network Analyzer (VNA) to our standard APT systems to allow both DC and RF measurements:

- The DC and RF interconnects are separate, so both can be optimized. DC performance isn't degraded by the addition of the RF measurement capability.
- The bandwidth of the RF interconnect is 40GHz on both the S400 and S600 systems. This makes it possible for you to purchase a lower cost, lower performance entry-level RF measurement option, and then upgrade later as new test needs evolve.
- The RF measurement capability can be added to any S400 or S600 you currently own or included in a new APT system purchase.

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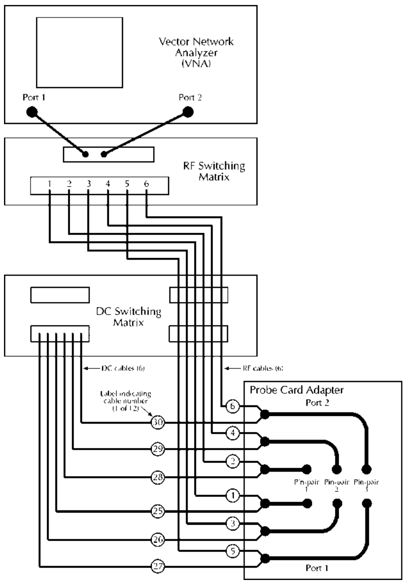
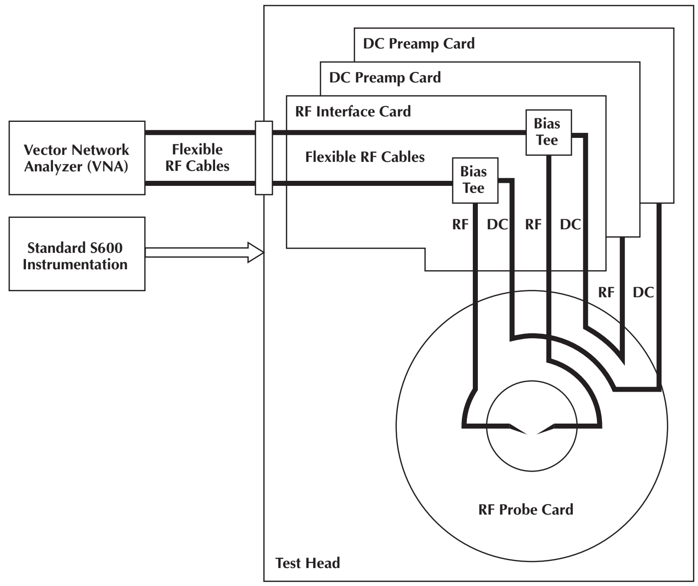
• The basic measurement the VNA makes is “s-parameters.” Keithley software automates the setup, execution, and analysis of these measurements more thoroughly than ever before possible.





S400 with RF added and optional RF switching matrix ***S600 with RF added***

Who Needs the S400DC/RF and S600DC/RF Systems?

Whether you work in a device modeling lab or in a production wafer fab, if you need to make high integrity, wafer-level RF measurements and understand the results of these test quickly, then you could benefit from these systems. If you are new to making RF measurements, you’ll appreciate these GUI-based systems, because they treat RF data according to industry standards. That means you can focus on product performance, rather than on trying to become an RF measurement expert. If you have many years of RF experience, you’ll appreciate the data browser utility, which makes it easy to get a complete analysis of your RF data and associated DC bias information. The data output can be configured for compatibility with all modeling packages and design automation systems. Both S400- and S600-based systems provide automation that’s sophisticated enough to allow you to focus on product issues, rather than system integration problems.

Certain process technologies absolutely require the type of RF measurement support that the S400DC/RF and S600DC/RF Systems provide. Silicon Integrated Device Manufacturers (IDMs) employing BiCMOS, high performance analog, SiGe CMOS, SOI CMOS, and sub-150nm standard CMOS processes will find these systems a good fit for their RF measurement needs, as will III-V IDMs using GaAs MESFET technologies.

How Are Wafer Level RF Measurements Made?

An RF measurement is only as good as the quality of the reference plane the user establishes. This reference plane is established at the probe tips by **calibration** and moved to the DUT by **de-embedding**.

The **calibration** is performed by measuring known standards. These measurement standards are precision manufactured to give fixed, repeatable values of complex impedance, which are used to correct systematic errors in the RF measurement system. The elements of the impedance standard and correction algorithm may vary (SOLT, TRL, LRM, TRM, LRL, etc.), but the goal remains the same— establishing a 0dB magnitude and 0° phase reference at the probe tips. Connectors, test cables, matrix switches, probe card, and the prober contribute the errors, which need to be corrected to accomplish this. They affect *transmission* and *reflection frequency response*, *source* and *load match*, *directivity*, and *isolation* (cross-talk). These six terms on both ports are used to generate a 12-term vector error corrected calibration. Random error sources such as connector repeatability, cable stability, environmental changes, and frequency repeatability must be addressed in the hardware design of the system. Random sources of measurement error can't be corrected.

De-embedding is performed using a structure on the same wafer as the measurement DUT, which allows correction of the parasitic elements related to connecting the DUT to the probe tips. These parasitic elements include probe contact resistance, probe pad shunt capacitance, and DUT lead inductance among others. While the ideal de-embedding solution would involve an Open, Short and Thru de-embedding structure for each DUT type, practical implementations use shared de-embedding structures to reduce the size of the area required. One way of improving the effectiveness of these shared structures is to shield the signals of the DUT and dummy signals on the de-embedding structures. The shield is a conductive layer, connected to ground, isolating the signal lead from the substrate. The accuracy with which the de-embedding structures represents the complete interconnect without the DUT determines how well the user can establish a 0dB magnitude and 0° phase reference at the DUT.

S-parameter measurements are made using the vector network analyzer (VNA); they return an array of complex impedances with respect to frequency. After these impedances are corrected using the de-embedding data, extractions are performed.

Typical Practices Before Keithley RF APT

Today's Solution: Device modeling labs are the center of excellence for wafer level RF measurement in most companies, regardless of their market segment or technology focus.

Unfortunately, their effectiveness can be hampered by the lack of solutions that can provide reliable data quickly, consistently, and cost-effectively. Their installed equipment is usually a rack and stack solution with a VNA, two or more DC bias instruments, DC coax and RF phase-matched cabling, various connectors and bias tees appropriate for the frequency capability, and a semiautomatic prober.

Critical Problems in Lab RF Measurements. With systems like those described, integrity is too often poor and the sample size is too small to achieve valid, statistical RF models.

- Inconsistent Interconnect Quality—The cables and connectors can vary considerably, depending on the rack builder's expertise and budget. The resulting performance varies accordingly. Typically, bias tees are located at the VNA, which reduces the system's effective dynamic range. The probes are manual, so the port separation will vary slightly from touchdown to touchdown, as will contact resistance. Both add variability to the measurement.
- Non-Standard Software for Calibration and Measurement and Parameter Extraction—Calibration is manual and typically must be repeated two or three times before accurate measurements can be taken. The calibration software is often developed internally, unless the budget allows enough money for standarized third-party calibration software. The measured parameters are corrected and analyzed by homemade or third-party software. De-embedding data is taken, but s-parameters are corrected after the measurements are all completed. Parameter extraction from the corrected s-parameters is often not performed using any industry standard, but rather the method favored by the local expert.
- The low volume of data this type of system provides often makes data analysis qualitative and subjective. True statistical models based on the process capability limits are rarely realized due to the high cost of obtaining valid data.

Critical Problems in Fab RF Measurements: In addition to the problems in the lab, the cost of ownership for today's solution is prohibitive for use in statistical process control of the fab.

- Fanning out the solution to other company facilities isn't practical because vendors can't support "home grown" systems and the internal support cost of this system is high.
- Consumable costs are high because manual probing methods accelerate wear-out of calibration standards and probe needles.

- Sample sizes are typically too small to make proactive changes to the process, which require substantial data to justify.
- Escalation off-shift is impossible because of the level of expertise required to make successful measurements and interpret the data correctly.

These challenges mean the data quality is subjective and varies based on the user's expertise. Also, the quantity of data doesn't support delivering a statistically robust RF model or effective process control. Statistical RF models, when used in an automated design environment, have been shown to improve yield by more than five percent. Sample sizes are currently on the order of one to five devices from one wafer to produce a scalable model. Effective design-to-process capability requires ten samples from at least three device sizes, each of which comprehends process extremes. In rare cases where the need to meet product goals was overwhelming, this semi-automated system has been introduced to the fab for process monitoring. The primary complaints about this solution include data integrity and frequency limitation (20GHz).

Keithley's Approach to RF Parametric Testing

Automation, pre-packaged measurement algorithms, throughput, and signal integrity improvements distinguish Keithley's solution from prior art. For the first time, a single vendor offers a complete solution and provides comprehensive systems support worldwide.

A New Approach to Lab RF Measurements. High data integrity with ground-breaking throughput achieves statistically valid RF models with much less time and expertise.

- **Consistent, Robust Interconnect Quality—**Matched cabling and connectors with 40GHz bandwidth for port matching, along with bias tees close to the DUT, offer the lowest noise floor and greatest dynamic range possible.
- **Vender Supported Standard Software for Calibration and Measurement and Parameter Extraction—**GUI driven environment with working defaults leads the operator painlessly from setup to execution and analysis.
- **High Throughput Systems Supports True Statistical Models—**Automation allows use of high speed, fully automatic probers to improve calibration and measurement time. Calibration is fast enough to be performed between lots (transparent to user) and is stable

for at least three days. Dramatically reduced measurement overhead, combined with competitive raw measurement speed, results in production worthy throughput.

A New Approach to Fab RF Measurements: With Keithley's systems, no knowledge of RF is required to make repeatable RF measurements on wafers with sufficient data volume to drive process control. By contrast, with competitive solutions, in addition to the problems experienced in the lab, the level of maintenance and operator supervision required to use them makes the cost of ownership prohibitive for statistical process control of the fab.

Keithley's advantages:

- Vendor supported solution with worldwide service and support.
- Automated measurements extend the useful life of consumables by 10X.
- High throughput allows sample sizes large enough to make proactive changes to the process.
- The simplicity of Keithley's solution makes off-shift use possible because RF measurements are as easy to make and analyze as DC.

Calibration is automated and supports all fully automatic probers in current use by semiconductor manufacturers. Calibration standards are manufactured in a wafer form factor, so they can be loaded, aligned, and profiled just like other production wafers. The RF set-up GUI guides the technician or engineer through all aspects of the calibration setup. The results can be stored in a revision-controlled environment (KRM Option). Calibration can also be customized to a greater extent than previously possible. Up to ten pairs of port power and attenuation settings can be calibrated in a single pass, which allows custom calibration by device type. Discrete frequencies can be added to the calibration that don't fall on the regular Intermediate Frequency (IF) bandwidth interval. This allows matching the use case frequency without suffering the longer calibration time needed for a smaller IF bandwidth. The two most common calibration methods are fully supported by the software (SOLT and LRM). Our calibration wafers includes enhanced reflection standards that extend the accuracy of both calibration methods.

The Auto-Z (SofTouch) software utility extends the life of consumables by minimizing over-travel through electrical contact Z-height verification. Probes aren't scrubbed as hard, so they last longer and accumulate less contamination. The automation also detects contamination and automatically initiates probe cleaning. Probe contact resistance, leakage, and s-parameter limits are all set in the calibration GUI to ensure a high integrity calibration.

De-embedding has also been automated to allow setup by DUT for OPEN, OPEN_SHORT, OPEN_THRU, ALL or AUTO de-embedding. De-embedding data taking can be set up for by device, by wafer or by lot occurrence. The system is fully compatible with other significant automation options like 300mm factory control, Adaptive Test, Probe Card Manager, and Recipe Manager.

An RF parlib is included that produces raw, corrected, and extracted parameters for MOS, bipolar, capacitor, inductor, varactor, and other device types. No knowledge of RF is required to make repeatable RF measurements on wafers. The data can be selectively stored and/or processed by other utilities in KTE. The RF data browser allows interactive or post-processed data analysis.

Data integrity and throughput are improved by hardware design. Bias tees are located at the probe card for the lowest possible noise floor and greatest possible dynamic range. Proprietary connector technology ensures that the calibrated insertion loss is less than 0.25dB. The measurement uncertainty characteristics of the system are nearly identical to the VNA. Probe needle designs and cleaning protocols have been developed for the most common interconnect systems (aluminum, copper, gold).

Worldwide support is provided for all aspects of Keithley's RF APT systems.

Product Information

Superior instrumentation (Anritsu Lightning VNA and S40/41) makes the Keithley RF APT systems more accurate and more productive than the competition. The Anritsu Vector Network Analyzer (VNA) makes the s-parameter measurements that are corrected with RF parameters subsequently extracted by our automation. The key features of the VNA that support production s-parameter measurement are:

- Internal auto-calibration with scheduling features for stability.
- Locking on each frequency point in a synthesized sweep for accuracy.
- Internal diagnostics for ease of integration.
- Cleanroom cal/verify fixtures for annual on-site calibration.
- Binary data transfer mode for high throughput.

The Keithley RF switch can be customized to apply this capability to any number of pins (sequentially). While the measurement error budget is slightly degraded, this provides flexibility and a further throughput advantage. The RF upgrade includes the most recent version of KTE and Solaris. KRM, PCM, and Adaptive Testing are available.

The software components critical to effective wafer level RF measurements are **calibration/verification**, **de-embedding**, **RF parlib**, and the **RF data browser**.

Calibration/Verification

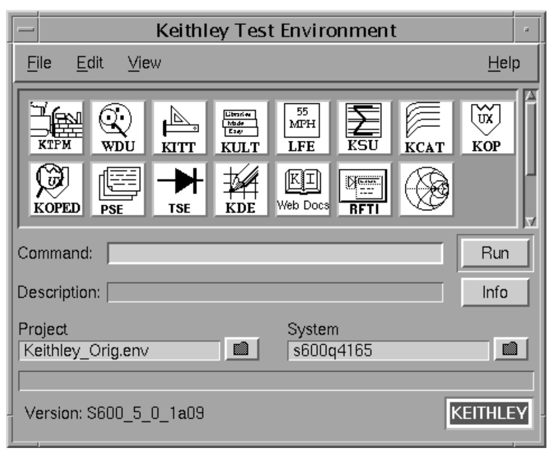
Typically, calibration is performed every day, although our system characterization shows that once our system is calibrated, it produces accurate data for at least three days. Calibration cancels errors contributed by test cables, matrix switches, and the prober. The standard calibration devices (short, open, load, and thru) are provided on a calibration substrate wafer. This allows calibration to be performed right at the substrate to cancel error sources that exist between the VNA and the wafer. There are three options for the calibration program: (1) calibrate and verify, (2) calibrate only, or (3) verify only. With the use of an automatic prober, calibration and verification can typically be done in two to 30 minutes. The time it takes to calibrate/verify depends on the number of frequencies and amplitudes used for the tests.

SofTouch is a valuable feature of the calibration system. To achieve valid calibration/verification, the prober chuck must be set to a height position that provides good electrical contact between the prober pins and the pads of the calibration devices. When using SofTouch with an automatic prober, the height position for the chuck is set automatically. The prober chuck moves up until electrical contact (as verified by a current measurement) is established. This height position is then used for all calibration devices. DC contact limit tests are then performed to verify electrical contact between the prober pins and the calibration devices. Passing these tests ensures that any subsequent calibration/verification failures aren’t due to poor electrical contact. Calibration (if enabled) is then performed using the calibration devices for every specified frequency and amplitude.

Following calibration, verification (if enabled) is performed for every specified frequency and amplitude. The devices used for calibration and verification are provided on the calibration substrate. The device layout for Keithley’s 9430-CW-02 calibration substrate contains seven rows of six structures. The structures are Open, Short, Load, Thru, Open-Short, and Short-Open. The Open-Short and Short-Open structures are referred to as enhanced reflection standards and allow the SOLT calibration method to support higher frequencies than it could without these extra structures. The software also supports the LRM calibration method (Line Reflect Match). TRL (Thru Reflect Line) isn't supported, because it requires variable signal pin separation. Probes have a fixed position on a probe card, which eliminates the ability to do a TRL calibration.

Settings for calibration/verification are contained in a Calibration Configuration File and the Calibration Global Data Definition File. Calibration/verification setting changes are made by modifying these set-up files. Due to wear-and-tear of the substrate pads that occurs from prober-pin contact, each site can only be used for a finite number of calibrations. Each of the seven sites provides approximately 32 calibrations. Therefore, one calibration substrate wafer will provide approximately 224 calibrations. Verification tests are performed on s-parameter measurements to ensure they are within limits set by the user. The S11, S12, S21 and S22 parameters are measured on the Open, Thru, and Load devices of the calibration substrate. The report for verification appears in the Test Program Messages window while verification is in process. The same information is also saved in the verification log file. The name of the log file is specified in the calibration configuration file. A failure report will include the frequency at which it fails, the value of the real and imaginary s-parameter values, and other information. A target value can be 1.0, 0.0, or –1.0, depending on the device (open-short, load-load, thru, short-open) being verified, and the parameter type (S11, S12, S21, S22). For these amplitudes, the standard SLOT (short, load, open, and thru) calibration devices fully reflect, fully absorb, or fully transmit the RF signal. After the calibration and verification software is run, the measurement is calibrated to 0dB magnitude and 0° phase at the probe tips. This is referred to as "establishing the reference plane" at the probe tips.

The following screen captures illustrate the simplicity of calibrating an S400- or S600-based DC/RF test system.

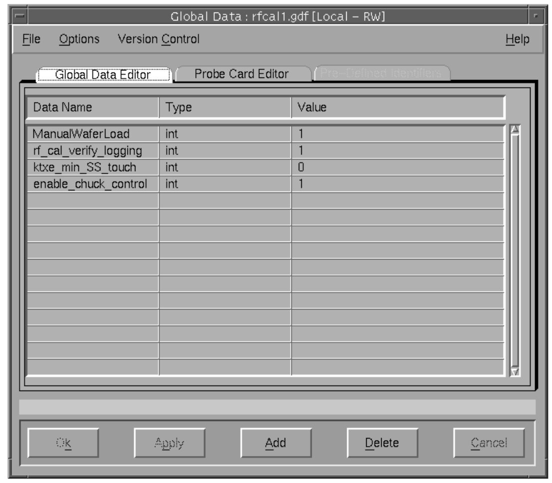


RF Test GUI Updates

Calibration, de-embedding and test execution are integrated into the existing DC parametric test executive. Collecting and refining this information by technology and storing it in a revision-controlled environment are crucial to achieving the highest repeatability calibration and test results. That's why Keithley strongly recommends using the Keithley Recipe Manager (KRM) option for recipe management and revision control.

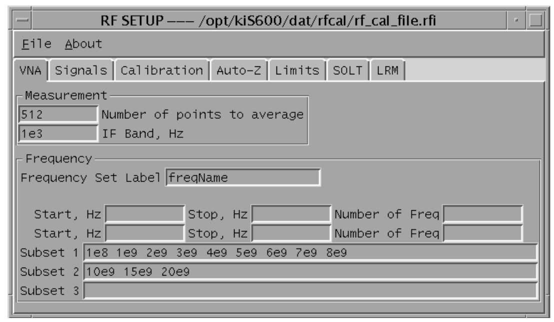
Global Data Entry

Automating wafer loading and contact resistance control allows a test operator to make wafer level s-parameter measurements, rather than an engineer or technician. Keithley applications engineers can set up the initial protocols.



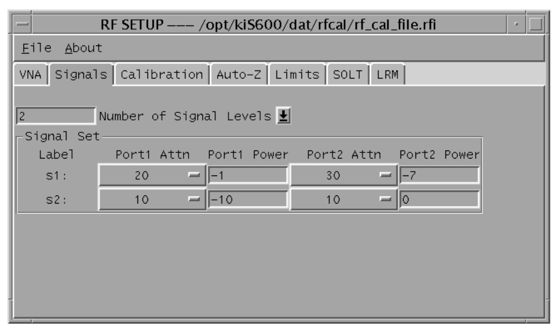
RF Setup—VNA

Increasing averages and reducing IF band will increase the precision of the calibration, but lengthen the calibration time. To improve calibration accuracy without increasing test time, selectively add subset frequencies that are relevant to the use condition, but which may not occur on the calibration interval.



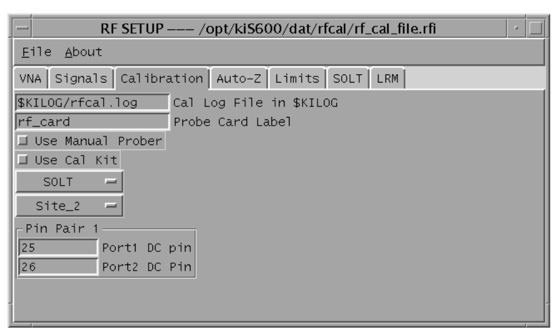
RF Setup—Signals

The system allows calibration at separate port power and attenuation values for each DUT type in a single operation. This allows optimal correction of the raw s-parameter data for active, passive, and complex DUTs. The system allows up to ten signal levels in a single calibration.



RF Setup—Calibration

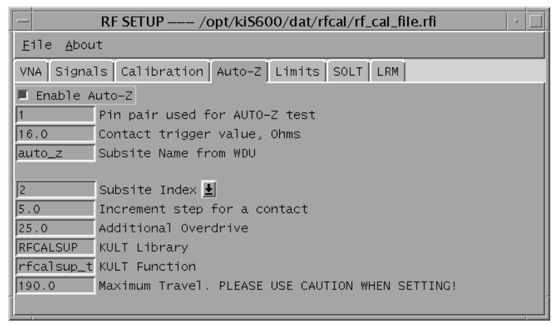
Calibration results are stored in a log file that associates the data with a specific probe card and calibration method. The default mode is an automatic prober, but manual probers are also supported. The calibration method to be used can be set to SOLT or LRM. The test sequencing for



SOLT calibration is Open-Open, Open-Short, Short-Open, Load-Load, Thru. The calibration is verified using the Short-Short structure. Contact resistance is calculated at that time. The calibration standard contains seven rows (sites) of structures. When a row (site) fails cal/verify, then the operator must choose the next available site. Two DC pins are dedicated to the RF measurement for bias. They must be specifically identified.

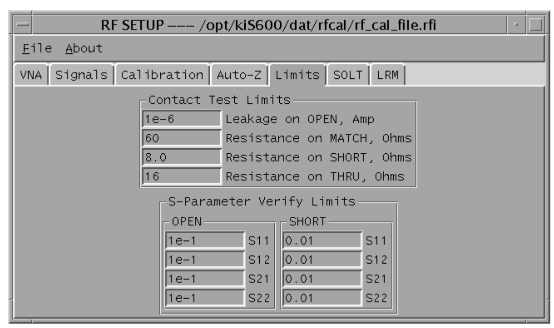
RF Setup—Auto-Z

Automated Z height adjustment (Auto-Z) allows *electrical verification and optimization of contact resistance* on single or multiple RF pin pairs. Acceptable contact resistance levels are then saved by technology (metal type). This feature allows detection of calibration structure wear-out (increased resistance) and sub-site increment to the next set of calibration structures.



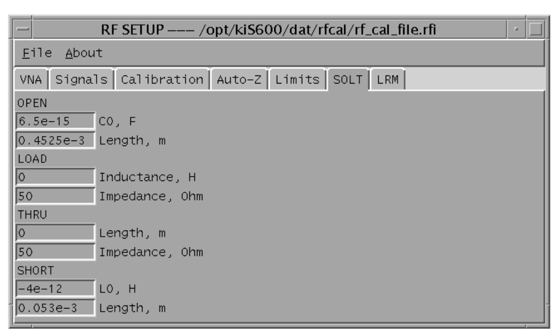
RF Setup—Limits

DC limits are used to verify probe contact. The s-parameter verification limits are used for pass/fail of the calibration. Open leakage is an indication of DC measurement capability on an RF pin.



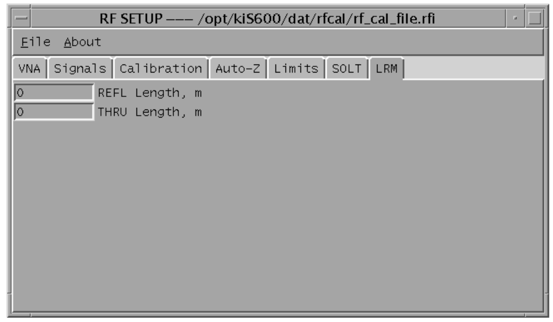
RF Setup—SOLT

Probe-pad parasitic parameters are provided by the vendor for manual input. If the probe card vendor provides these parameters in the form of barcodes, the system can also accept them, which has the advantage of eliminating operator input errors.



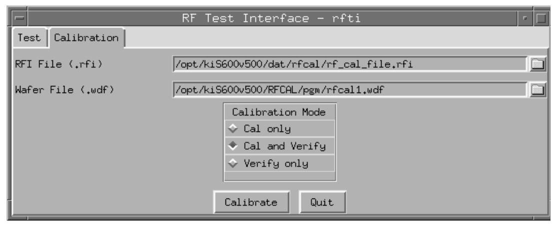
RF Setup—LRM

SOLT and LRM are both suitable for use with fixed position probes measuring s-parameters to 110GHz. TRL requires variable position probes and is not useful with automated systems. The default calibration method is SOLT, which Keithley has enhanced with improved reflection standards to include the best calibration features of other methods.



Calibration Execution

Calibration, once set up, is executed by the operator based on conditions stored by engineering, rather than through a process of successive approximation.



De-embedding

De-embedding is the process of moving the reference plane to the DUT by eliminating the parasitic effects of the probe pads and interconnects from the pads to the DUT. There are seven de-embedding modes supported by the RF software: auto, none, open, short, open-short, open-thru, and all. The raw s-parameter values in a *device.dat* file implicitly contain offsets due to parasitic capacitances, parasitic inductances, and minor phase errors at the device interface previously described. The raw s-parameter values in *open.dat*, *short.dat*, and *thru.dat* files are effectively measurements of the offsets. Therefore, the analysis program de-embeds by subtracting *open.dat*, *short.dat,* or *thru.dat* s-parameter offsets from *device.dat* s-parameters. That occurs in this order:

- The raw s-parameters in the *device.dat* file are converted to normalized admittances (y) or normalized impedances (z).
- The s-parameter offsets in an *open.dat*, *short.dat*, or *thru.dat* file are converted to normalized admittances (y) or normalized impedances (z).
- The y or z forms of the *open.dat*, *short.dat*, or *thru.dat* s-parameter values are subtracted from the y or z forms of the *device.dat* s-parameter values.

- The y or z forms of the results (the now de-embedded s-parameters) are converted back to the S forms.
- The de-embedded s-parameters are stored in the corresponding *extract.dat* file (and are subsequently used in the extracted-parameter calculations)

De-embedded s-parameter values are similar to the values that would be obtained if the device were interfaced directly with the VNA. In the "auto" mode, the program automatically picks the best available de-embed mode, depending on which of the possible de-embed files (*open.dat*, *short.dat*, *thru.dat*) accompany the raw data file (*device.dat*). If all three de-embed files are present, the program picks the open-thru mode (described at the end of the table). If no de-embed files are present, no de-embed calculations are performed—only calculations of extracted parameters from the raw data. Otherwise, de-embed calculations are performed using the de-embed files that are present. For example, if *open.dat* and *short.dat* are present, then open and short mode de-embed calculations are performed. When "none" is selected, de-embed calculations aren't performed. Parameters are extracted directly from the raw data. "Open" mode subtracts the offsets that were measured in the open and then calculates extracted parameters. If an *open.dat* file doesn't exist, de-embed calculations aren't performed, and s-parameters are extracted directly from the raw data. "Short" and "thru" modes work similarly to the open mode on *short.dat* and *thru.dat* respectively. "Open-thru" mode subtracts the offsets that were measured in the open and thru test modes, if both *open.dat* and *thru.dat* exist. If only *open.dat* exists, only the open de-embed calculations are performed. If only *thru.dat* exists, only the thru de-embed calculations are performed. If neither *open.dat* nor *thru.dat* exist, de-embed calculations aren't performed, and parameters are extracted directly from the raw data. "Open-short" mode works similarly to open-thru mode using *open.dat* and *short.dat*. The four left-most buttons at the bottom of the Keithley RF Data Display window configure, initiate, and control de-embed and extraction operations.

The RF Parlib

The RF parlib consists of industry standard extractions of the most common RF parameters from the devices typically used in RF circuits. This user library contains four pre-programmed C modules, similar to DC parlib modules. These modules allow an entire test to be performed simply by calling the module with the appropriate arguments. The modules test bipolar, cmos, capacitive, and inductive type devices. The names of the four supplied test modules correspond to the types of devices they evaluate: *bipolar_RF*, *cmos_RF*, *capacitor_RF*, and *inductor_RF*.

- *Bipolar_RF* extracts Ft, Fmax, Rbb, Gmax, Gtu and U. Ft is the gain-bandwidth frequency at which the short-circuit gain approximates unity. Fmax is the maximum frequency of oscillation at a maximum available power gain of 1. Rbb is the base resistance. Gmax is maximum gain. Gtu is unilateral gain. U is unilateral figure of merit.
- *Cmos_RF* extracts Ft, Fmax, Gmax, Gtu and U. The parameter definitions are the same.
- *Capacitor_RF* extracts C (capacitance), R (resistance), and Q (quality factor).
- *Inductor_RF* extracts L (Inductance), R (resistance), and Q (quality factor).

Additional libraries containing component C modules allow creating custom test macros. These nineteen modules control measurements and files at the VNA. The technical literature contains many variations on RF parameter extraction from s-parameters. All of these methods are supported by Keithley's program development approach. Keithley RF applications engineers can adapt the RF parlib macros to implement these methods.

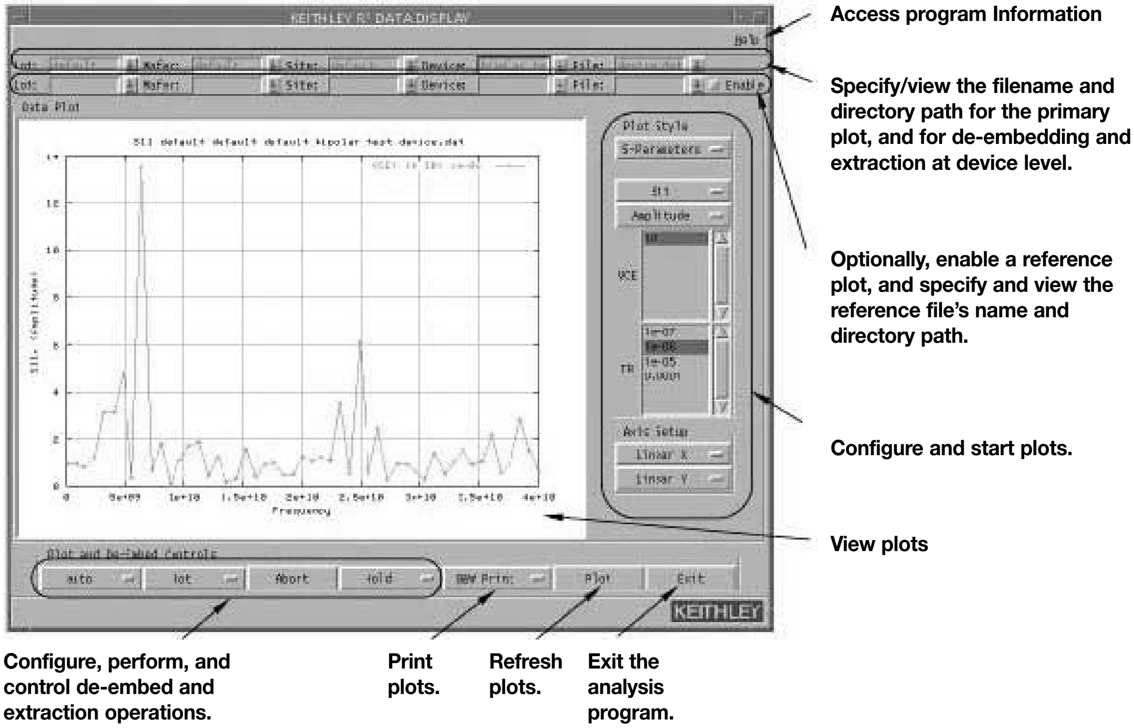
RF Data Browser

The Keithley RF Data Browser plots raw and de-embedded/extracted data in a variety of formats. Most of the window buttons are double acting, as follows:

- When the window button is left-clicked and held, the program displays a menu of actions/configurations.
- When the mouse button is released after selecting an action/configuration, the program immediately initiates that action/configuration.

Once an action is performed, the button used is labeled with the most recent selection. More information about a specific window button can be found by placing the cursor, without clicking, over the button. Similarly, more information is also available about the fields at the top of the window, where filenames and origins of plot files can be specified/viewed, by placing the cursor, without clicking, over the button or window. It's also possible to view the full text of names too long to fit in a field.

The four left-most buttons at the bottom of the Keithley RF Data Display window configure, initiate, and control de-embed and extraction operations as previously described.

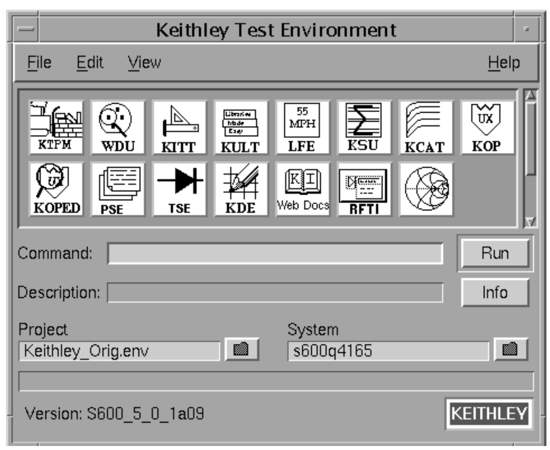


The Keithley RF Data

The data browser supports interactive analysis, debug, and optimization of bias and de-embedding.

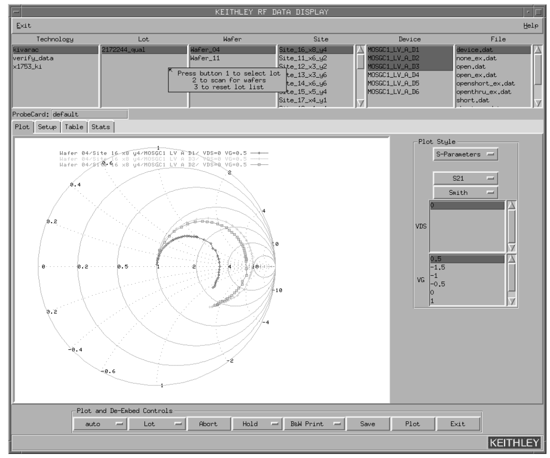
RF Test GUI Updates

You can invoke a data display for RF parameters from either the KTE screen or command line.



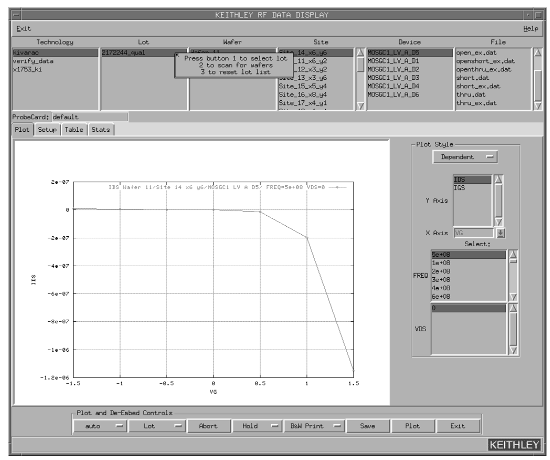
Smith Chart

Data from a single lot or a comparison of data from multiple lots can be displayed. The system imposes no fixed limits on the number of samples displayed in a plot.



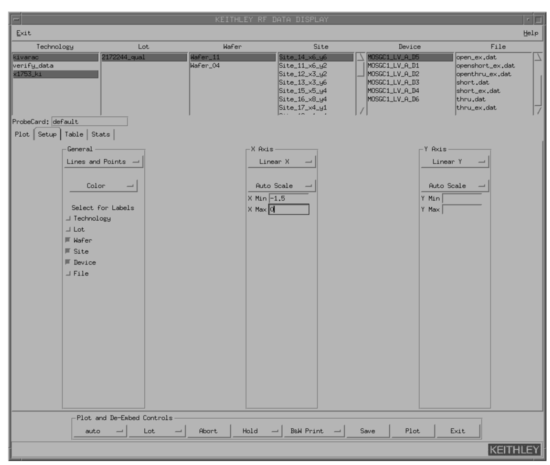
DC Bias

Displaying the DC bias conditions allows confirmation of DC behavior during RF testing.



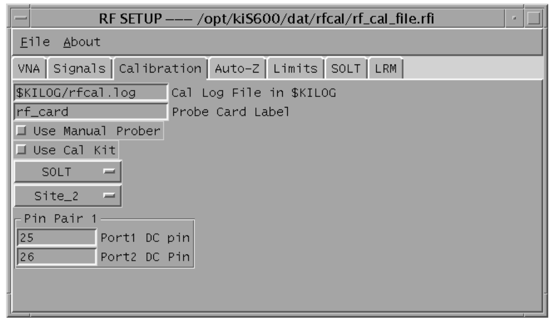
Plot Setup

Either arbitrary limits or auto-scaling can be used to set up plots, which can have either logarithmic or linear axis. It's also simple to customize a plot's colors, labels, and other aspects of its appearance.



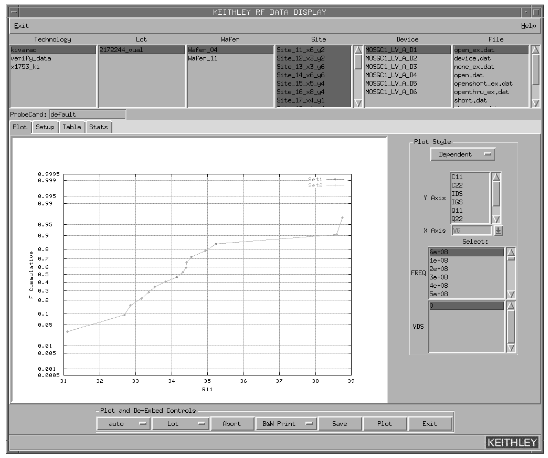
Tabular Data

To increase the precision of graphical representations, the system can generate statistics for any device type at specific bias and frequency conditions.



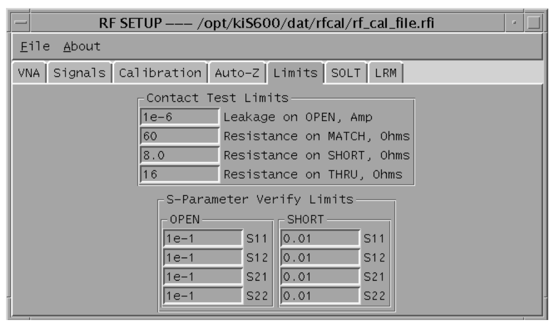
Cumulative Probability

Cumulative probability plots display the distribution characteristics necessary for establishing SPC limits.



Comparative Statistics

To make the results of process experiments easier to understand, comparative statistics are available at the click of a button.



Life with Keithley's DC/RF Test Systems

Tomorrow's Solution: Device modeling labs can now do simulation model fitting in one-tenth the time required previously. The stability of the probing environment and built-in data integrity features allow 24x7 data collection. The RF data browser reduces the time needed for data analysis from days to minutes.

Critical Problems in Lab RF Measurements are Gone: Data integrity is high and the sample size is huge. Statistical models are generated routinely. Recipe management is required to deal with the proliferation of projects. Historical reference data can be preserved by extracting modeling data using the Keithley Data Browser.

- Each statistical device model for each technology will be based on dramtically more data. This allows for a radical improvement in confidence in the validity of the models created
- The data browser will be deployed as an offline tool on every modeling engineer's PC.
- The Keithley Recipe Manager (KRM) option will be required to manage the proliferation of projects, each with unique calibration, de-embedding, and test execution setups.

Critical Problems in Fab RF Measurements Are Gone: In addition to the productivity improvements in the lab, the cost of ownership for tomorrow's solution is reduced to levels at or near those of traditional DC testing.

- Fan-out of the solution to other company facilities is routine and internal support costs of this system are low.
- Consumables costs (for calibration standards and probe needles) are low enough to allow RF statistical process control. As industry consumption of these consumables increases, growing economies of scale and improved learning should continue to drive down consumables costs, much as they have in the past for other semiconductor test applications.
- Sample sizes are large enough to make proactive changes to the process and yield leverage is obvious.
- The adaptive testing option for KTE automates first-level disposition of failing wafers. That means that during shifts when engineers are off duty, there's no need to pull non-conforming wafers from the lot for later retesting because they are retested immediately, while still on the prober. This eliminates retest queues and the costs associated with excessive work-in-process inventories.

As a result of these improvements, the data quality is consistent and doesn't vary based on the user's expertise. The quantity of data supports delivering a statistically robust RF model and effective process control. The statistical sample size, combined with the automated design environment, produces improved yields.

Frequently Asked Questions

What type of interconnects is used to achieve 40GHz bandwidth?

The connectors are K-type (2.92mm), except for the SMB type connectors on the S400RF probe card. This gives the system 40GHz bandwidth. The same interconnect is used on the 13.5GHz, 20GHz and 40GHz options, which results in calibrated insertion losses of 0.07dB, 0.1dB and 0.2dB respectively. The RF cables are Gore phase-matched, phase-stable cables with electrical characteristics that don't change when the cables are moved. The bias tees are Kelvin and placed on the probe card adapter for the S400 and on the RF UIU for the S600. This placement ensures the lowest possible noise floor, which is –91dBm for both systems.

How are RF probe cards handled and what is the expected performance and lifetime?

Probe cards for the S400 are changed using a torque wrench to ensure consistent electrical connection at the screw-on SMB connectors. Probe cards are changed on the S600 the same way they are for DC testing due to a Keithley proprietary connector scheme that doesn't require screw-on attachment. The probes are either GGB self-leveling ground-signal-ground (GSG) probes (Model 40a) or Cascade membrane GSG probes. The GGB probes are qualified to 40GHz. The Cascade membrane card is qualified to 20GHz. Probe performance is changing quickly, so improved performance is expected. The life of a cantilever type RF probe (GGB) is expected to be 250,000 touchdowns vs. more than one million touchdowns for the membrane type card.

How are the probes used and cleaned?

1. Over-travel not to exceed 100µm from first ground tab contact. Average over-travel should be 70–80µm.
2. Probe card is cleaned on cleaning pad on prober as required to minimize debris buildup.
3. Probe card has preventative maintenance after every 50,000 touchdowns. Preventative maintenance includes:
    - Cleaning probes with a chemical cleaning agent such as Gensolve 2004 or Asahiklin AK225. These solvents are available at www.techspray.com.
    - Probe tip alignment check and adjustment.
    - Probe planarization check and adjustment.

4. Abrasive clean of probe tips on the ceramic substrate or a fine abrasive pad (3M or Tungsten Carbide Pad) as required to keep contact resistance to an acceptable level.

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