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SWTW 2002

RF S-Parameter Wafer Probing – A Production Solution

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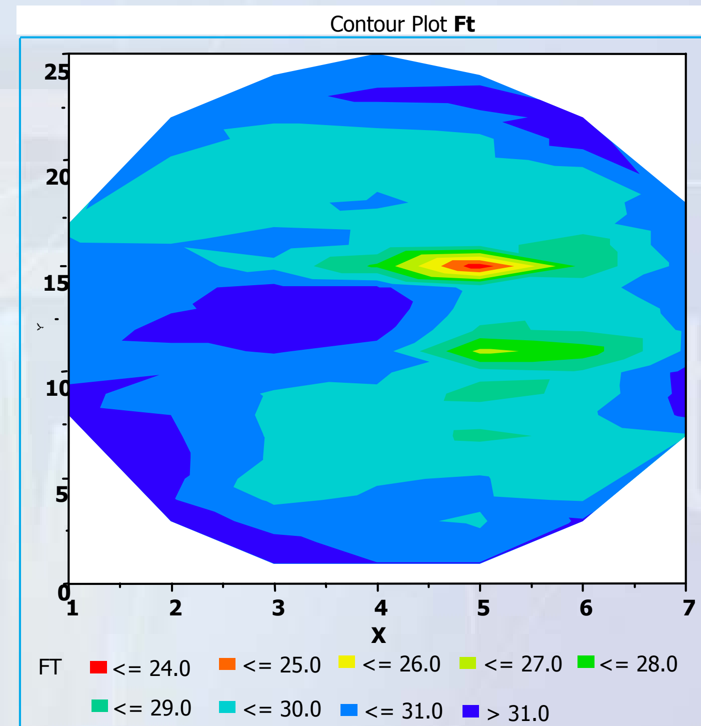

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Agenda

- The Need for Fully Automated, On-Wafer S-Parameter Measurement
- Test System Requirements
- System Calibration / Diagnostics
- Device Layout Considerations / De-Embedding
- Considerations for Probe Selection
- Probe Cleaning
- Data Extraction Techniques

The Need for Fully Automated S-Parameter Measurement

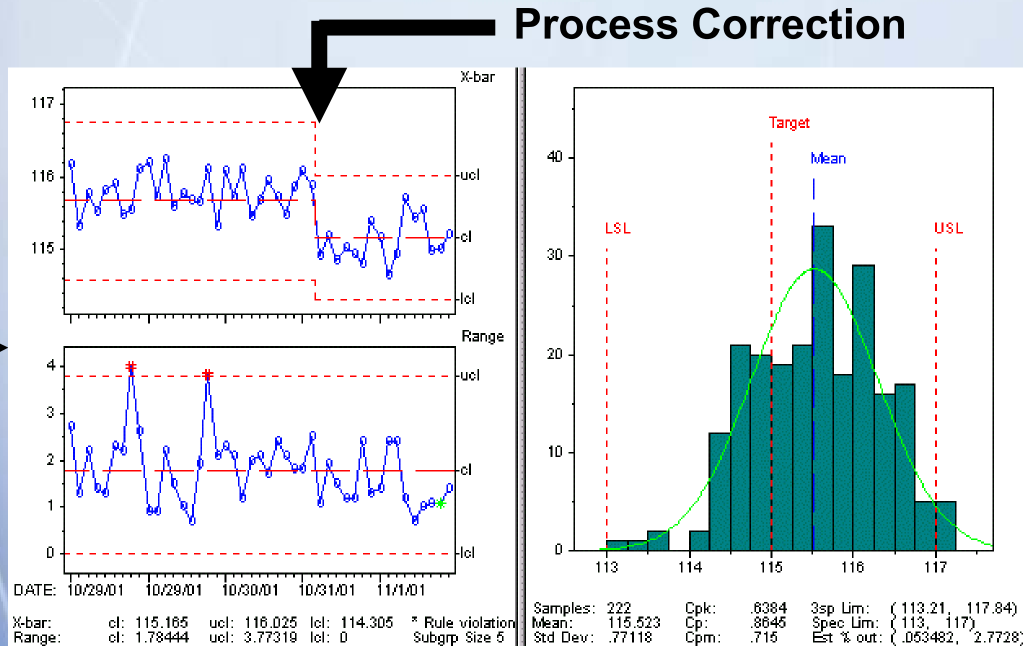
- Statistical Model Generation
- Manufacturing SPC of high frequency device characteristic
- Yield Analysis

Mixers
Rx LNA
Tx PA
Baseband Filter
Digital Control
FSK Demodulator

Need – Statistical Process Control

Process Correction

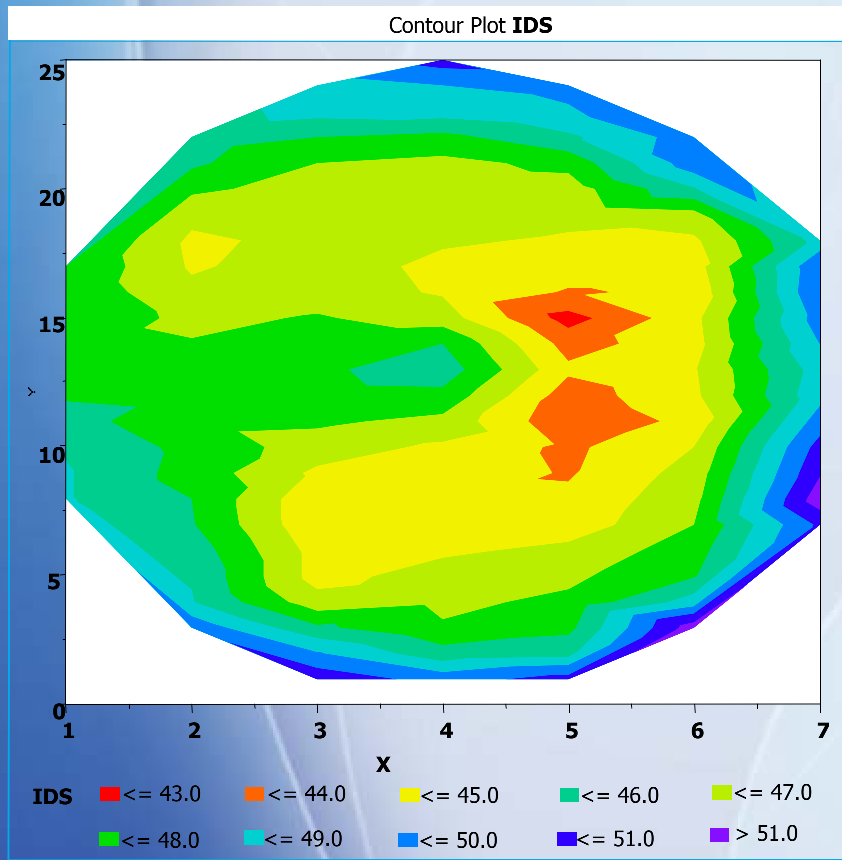
RF SPC Data

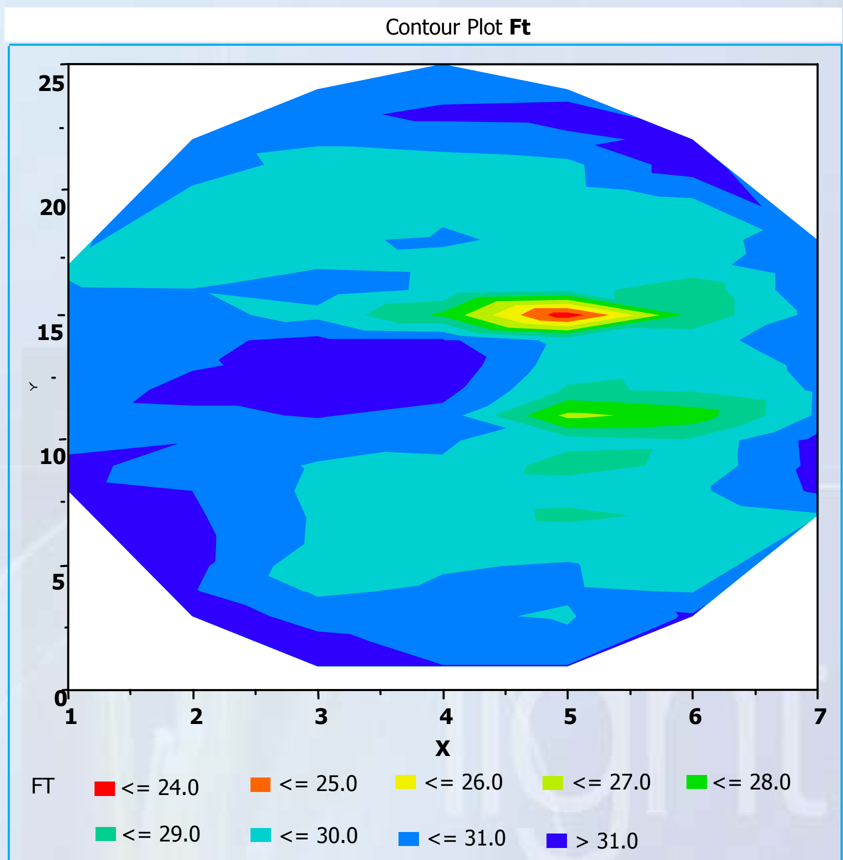


RF Product Performance Improves

DC is Necessary but not Sufficient.

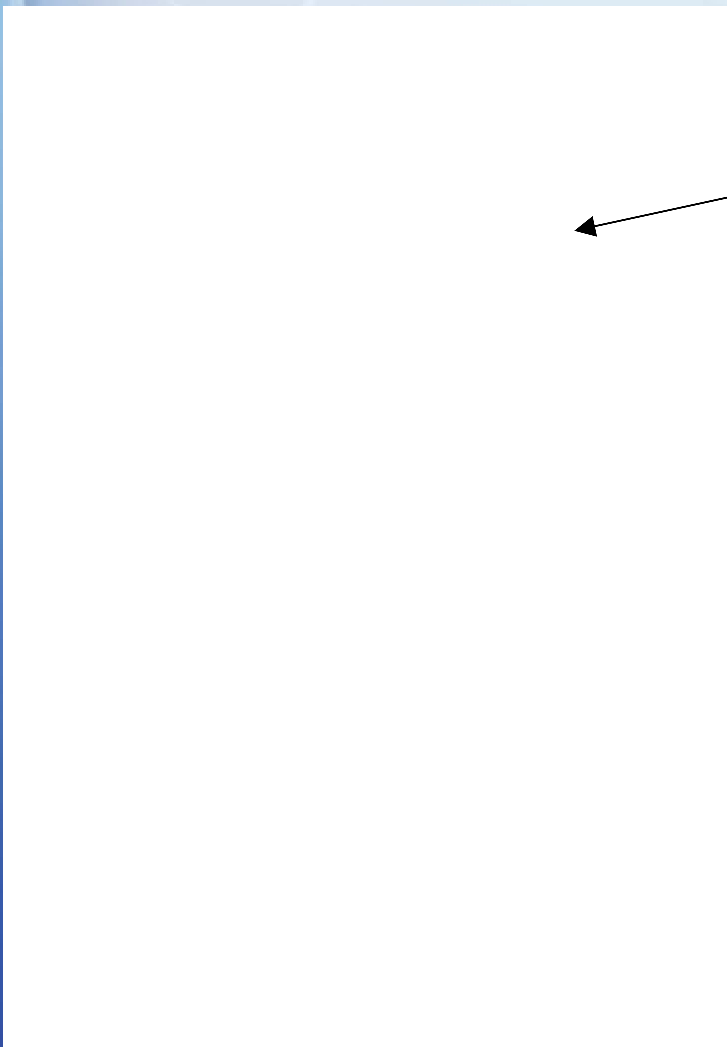
Need – Yield Analysis



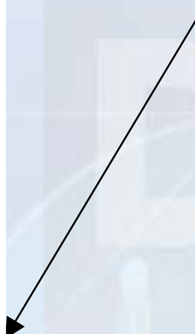


Overlay of DC and RF Wafer Maps Makes Systematic Defects Visible.

Three Main Aspect of Requirements

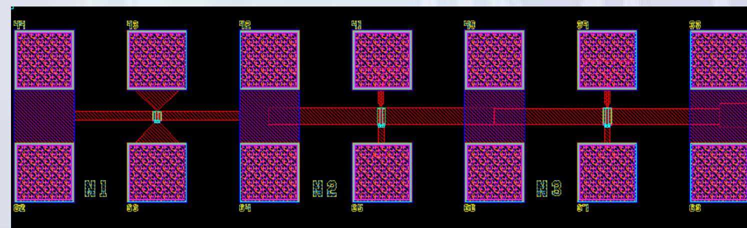


Vector Network Analyzer (VNA), Cable and Connector calibration



Probe Card Stability

Wafer Test Structures and De-embedding



System

Parametric tester with
DC and RF interconnect
To a automatic prober

Probe Card And Prober

System interconnect showing cables, bias tees, probe card interconnect, and probe card adapter mounted in an automatic prober.

RF Test GUI

Keithley Test Environment

File Edit View Help

KTPM WDU KITT KULT LFE KSU KCAT KOP

KOPED PSE TSE KDE Web Docs RFTI

Command:

Description:

Run

Info

Project

Keithley_Orig.env

System

s600q4165

Version: S600_5_0_1a09

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RF Test Setup

RF Data Display

Global Data Entry

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Global Data Entry

Global Data : rfcal1.gdf [Local – RW]

File Options Version Control Help

Global Data Editor | Probe Card Editor | Pre-Defined Identifiers

Data Name	Type	Value
ManualWaferLoad	int	1
rf_cal_verify_logging	int	1
ktxe_min_SS_touch	int	0
enable_chuck_control	int	1

Ok Apply Add Delete Cancel

- Control Wafer Loading
- Optimize Probe Contact
- Verify Contact Resistance
- Minimize Probe Wear
- Set Control limits by technology
- Log all events and associate with data
- Enable Tester SPC

RF SETUP - VNA

RF SETUP --- /opt/kiS600/dat/rfcal/rf_cal_file.rfi

File About

VNA | Signals | Calibration | Auto-Z | Limits | SOLT | LRM

Measurement

512 Number of points to average

1e3 IF Band, Hz

Frequency

Frequency Set Label freqName

Start, Hz Stop, Hz Number of Freq

Start, Hz Stop, Hz Number of Freq

Subset 1 1e8 1e9 2e9 3e9 4e9 5e9 6e9 7e9 8e9

Subset 2 10e9 15e9 20e9

Subset 3

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RF SETUP - Signals

RF SETUP ––– /opt/kiS600/dat/rfcal/rf_cal_file.rfi

File About

VNA | Signals | Calibration | Auto-Z | Limits | SOLT | LRM

2 Number of Signal Levels

Signal Set

Label	Port1 Attn	Port1 Power	Port2 Attn	Port2 Power
s1:	20	-1	30	-7
s2:	10	-10	10	0

RF SETUP - Calibration

RF SETUP --- /opt/kiS600/dat/rfcal/rf_cal_file.rfi

File About

VNA | Signals | Calibration | Auto-Z | Limits | SOLT | LRM

$KILOG/rfcal.log Cal Log File in $KILOG

rf_card Probe Card Label

Use Manual Prober

Use Cal Kit

SOLT

Site_2

Pin Pair 1

25 Port1 DC pin

26 Port2 DC Pin

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RF SETUP– Auto-Z

RF SETUP --- /opt/kiS600/dat/rfcal/rf_cal_file.rfi

File About

VNA | Signals | Calibration | Auto-Z | Limits | SOLT | LRM

Enable Auto-Z

Value	Setting
1	Pin pair used for AUTO-Z test
16.0	Contact trigger value, Ohms
auto_z	Subsite Name from WDU
2	Subsite Index
5.0	Increment step for a contact
25.0	Additional Overdrive
RFCALSUP	KULT Library
rfcalsup_t	KULT Function
190.0	Maximum Travel. PLEASE USE CAUTION WHEN SETTING!

RF SETUP– Limits

RF SETUP ---- /opt/kiS600/dat/rfcal/rf_cal_file.rfi

File About

VNA | Signals | Calibration | Auto-Z | Limits | SOLT | LRM

Contact Test Limits

1e-6	Leakage on OPEN, Amp
60	Resistance on MATCH, Ohms
8.0	Resistance on SHORT, Ohms
16	Resistance on THRU, Ohms

S-Parameter Verify Limits

OPEN		SHORT	
1e-1	S11	0.01	S11
1e-1	S12	0.01	S12
1e-1	S21	0.01	S21
1e-1	S22	0.01	S22

RF SETUP– SOLT

RF SETUP ––– /opt/kiS600/dat/rfcal/rf_cal_file.rfi

File About

VNA | Signals | Calibration | Auto-Z | Limits | SOLT | LRM

OPEN

Value	Parameter
6.5e-15	C0, F
0.4525e-3	Length, m

LOAD

Value	Parameter
0	Inductance, H
50	Impedance, Ohm

THRU

Value	Parameter
0	Length, m
50	Impedance, Ohm

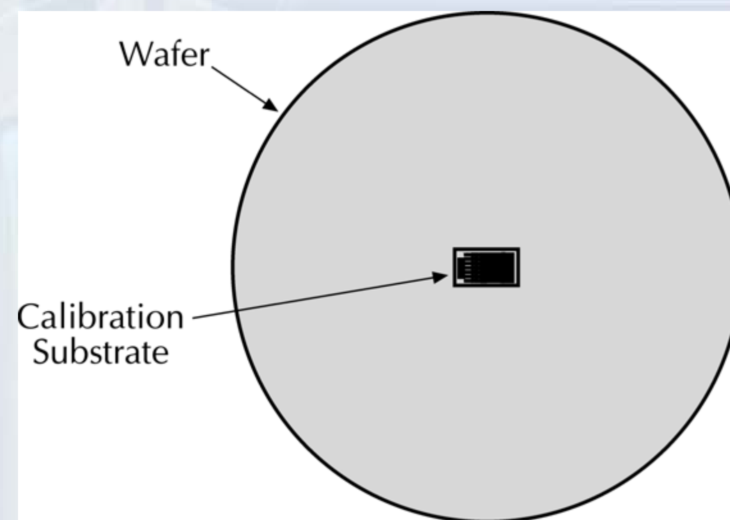
SHORT

Value	Parameter
-4e-12	L0, H
0.053e-3	Length, m

Requirements - VNA Calibration

- **Calibration is required to correct for systematic errors in the VNA and cabling.**
- **The fixed probe spacing of a production probe card limits the choice error correction methods to SOLT (two port, 12 term error corrected).**
- **Automatic calibration is performed by inserting a calibration standard onto a silicon wafer.**

A Calibration Substrate has gold test structures on alumina substrate.



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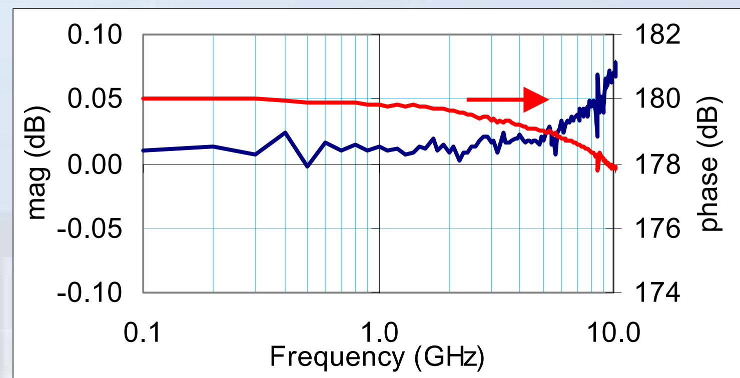
VNA Calibration SOLT

Measurement **Structure** **Response**

Short

Sxx

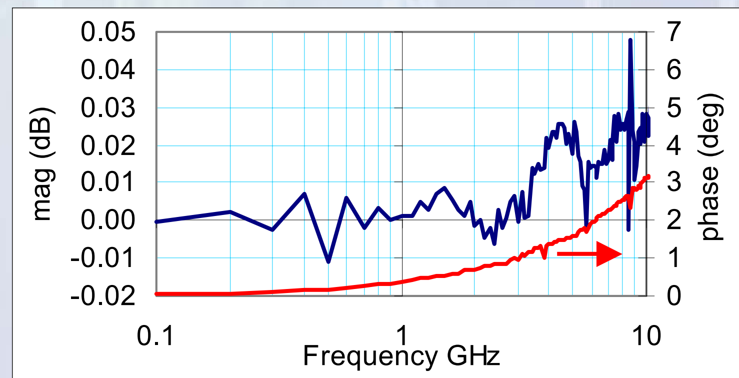
Ideal: Unity Reflection(0dB), 180 Phase Shift



Open

Sxx

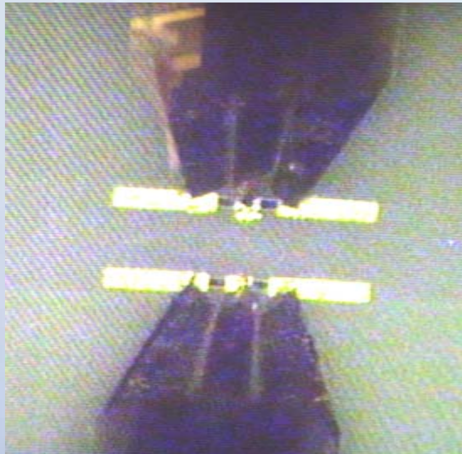
Ideal: Unity Reflection(0dB), 0 Phase Shift



VNA Calibration SOLT (cont.)

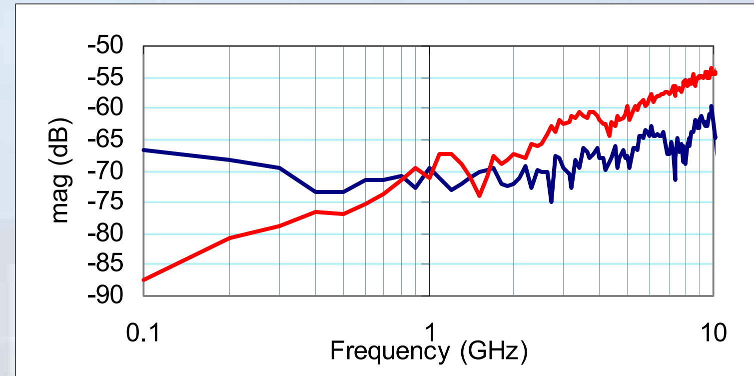
Measurement **Structure** **Response**

Load

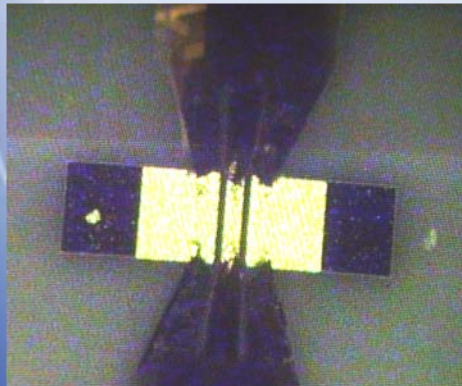


Ideal: 0 Reflection, 0 Transmission port 1 to port 2

Sxy

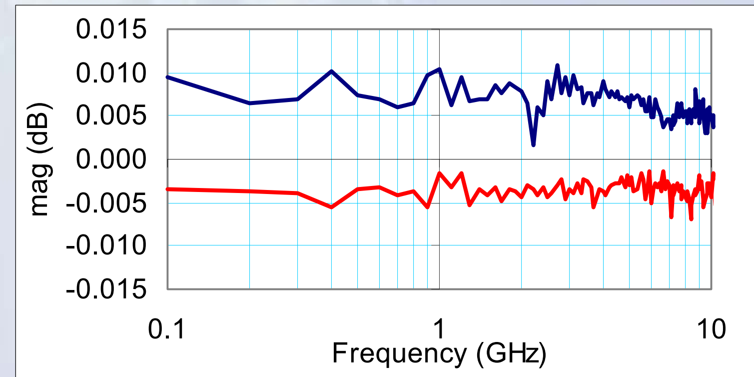


Thru



Ideal: Unity Transmission port 1 to port 2

Sxy



Calibration Considerations

Calibration Frequency

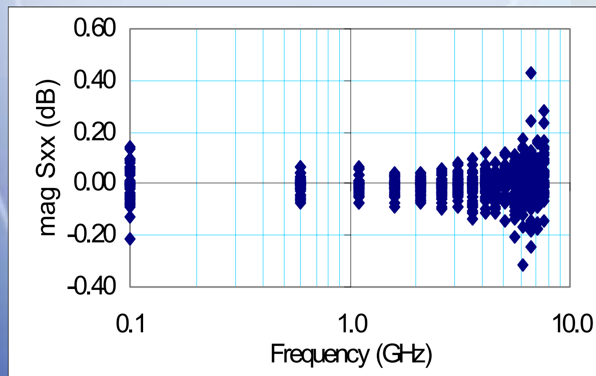
- With each probe card change (when test head docks)
- Periodic by time, DUT type or number of sites probed
- As part of needle cleaning and contact verification

Calibration Pass/Fail Criteria

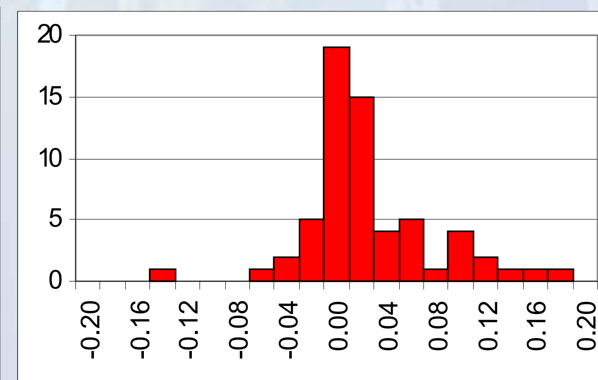
- Dependent on user requirements (device size, frequency etc)
- Calibration Repeatability Expectations
- Critical factors are probe card docking and probe cleanliness

S11 and S22 Open

Frequency Response



Statistics at 7.6 GHz



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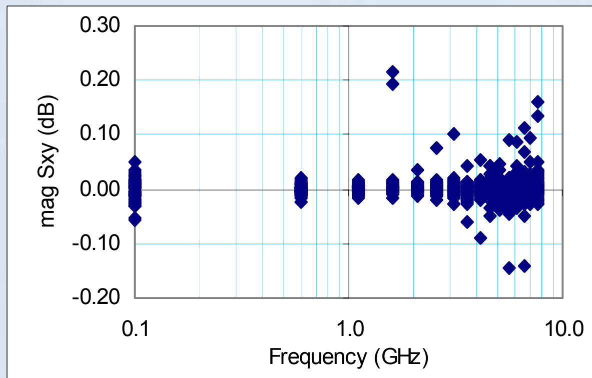
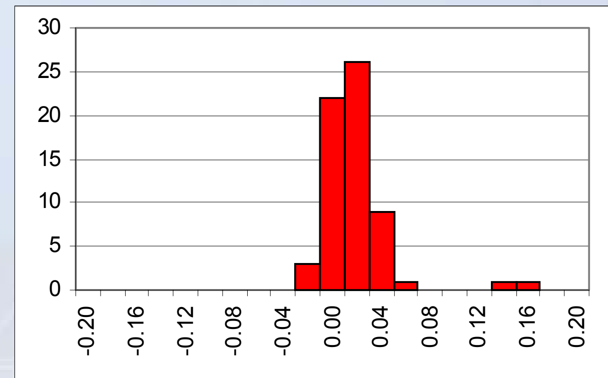
Calibration Pass/Fail Criteria

S12 and S21 Thru

Frequency Response



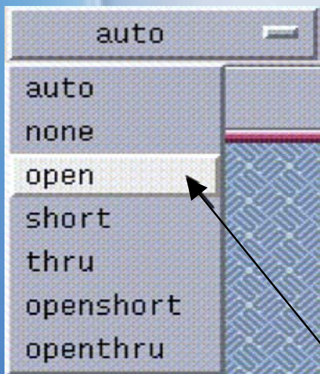
Statistics at 7.6 GHz



Typical Pass/Fail Criteria for MOSFET S Parameter Testing

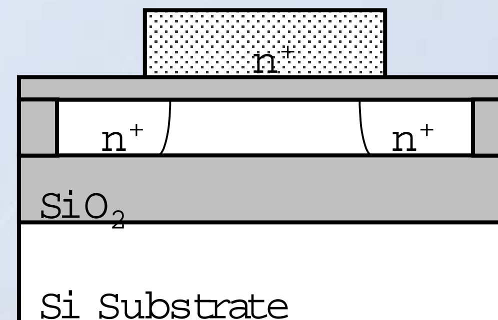
	OPEN	THRU
S11	0 ± 0.15 dB	< -50 dB
S12	< -50 dB	0 ± 0.10 dB
S21	< -50 dB	0 ± 0.10 dB
S22	0 ± 0.15 dB	< -50 dB

Requirements – Test Structures and De-Embedding

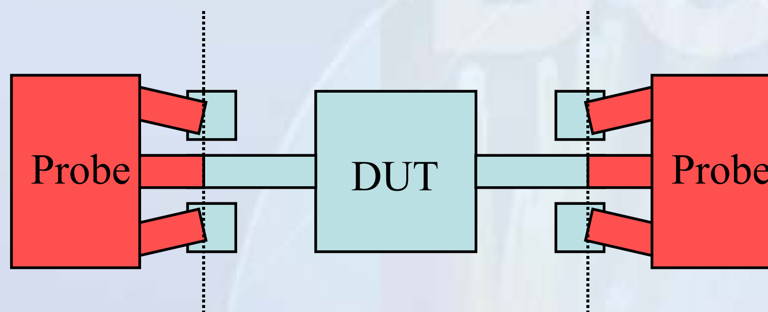


What Type of De-Embedding?

How Frequently?



Technology Considerations?



DUT Considerations?

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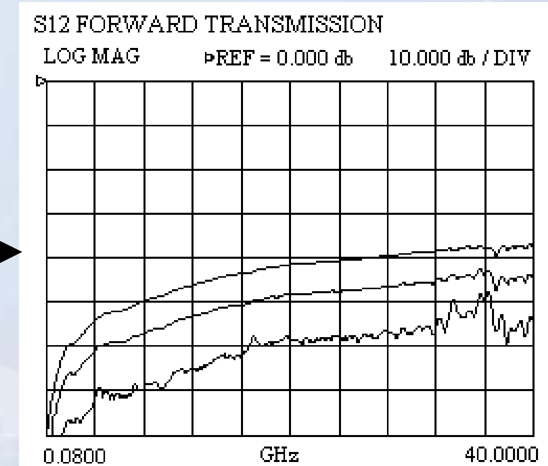
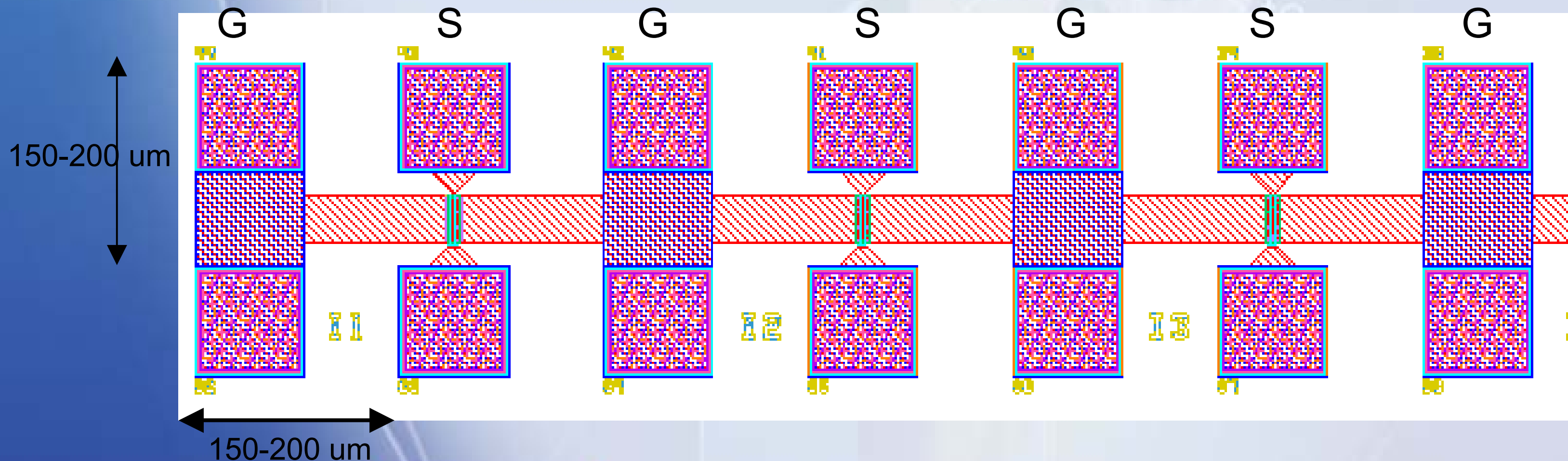
Device Layout Considerations - DUT

Device Under Test (DUT)

GSG Configuration

- **Fixed Pitch**
  typically 100-200um S to G
  100-300um S to S
- **Shared Ground for Improved Area Utilization**
- **Pad size - typically 55x55 to 100x100 um**
- **Top layer metal only is best**





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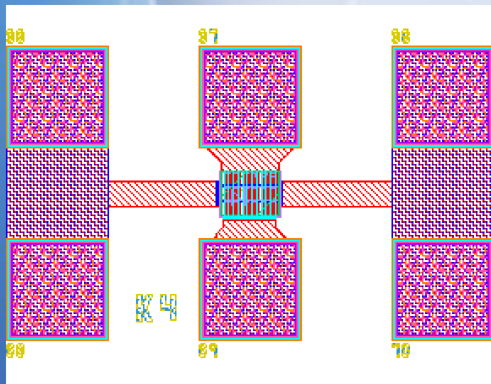
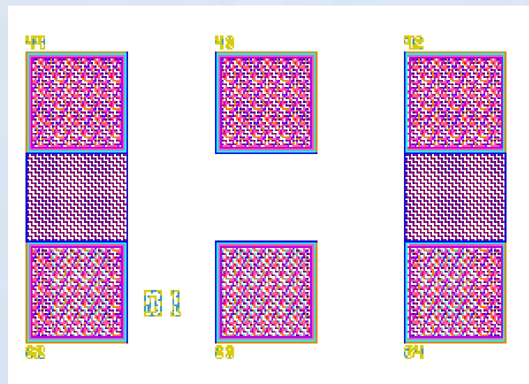
2002

Layout for De-Embedding

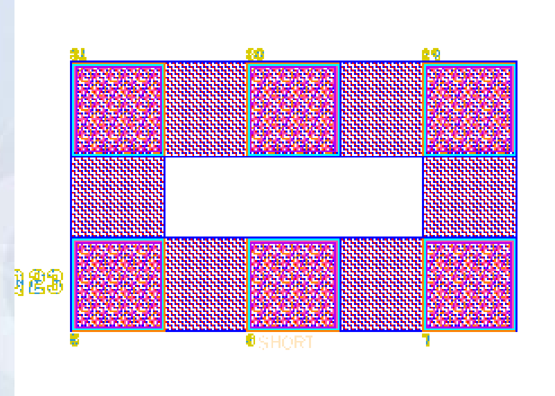
DUT



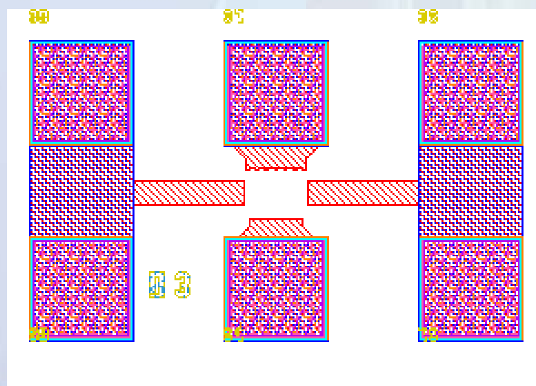
Generic OPEN



SHORT



Ideal OPEN



RF Probe Card

Considerations for Probe Selection

- **50 Ohm impedance match G-S-G construction**
- **Mechanical Design for Fine Pitch Probing (fine point and steep pitch)**
- **Metallurgical match to probe pad requirements**
- **Balance Contact Force and Co-Planarity match to DC probes for mixed DC/RF probe card**
- **Durability and low cost**

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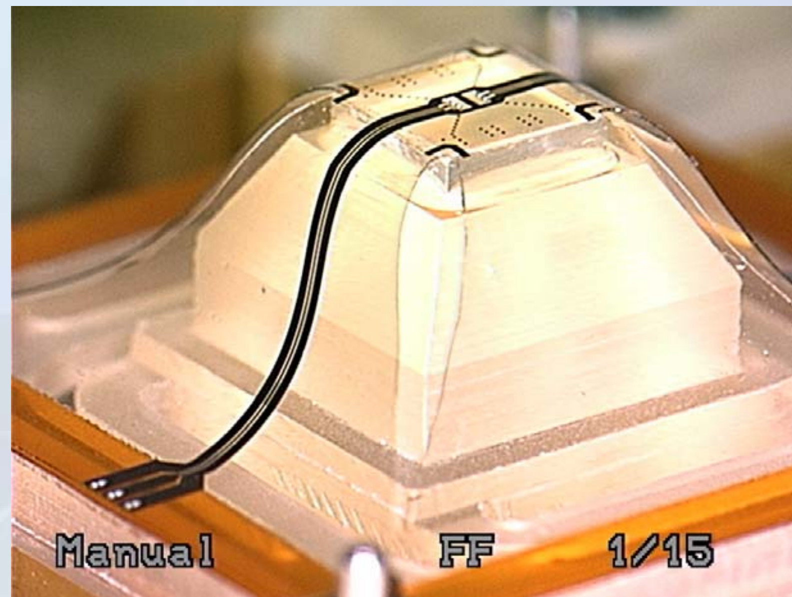
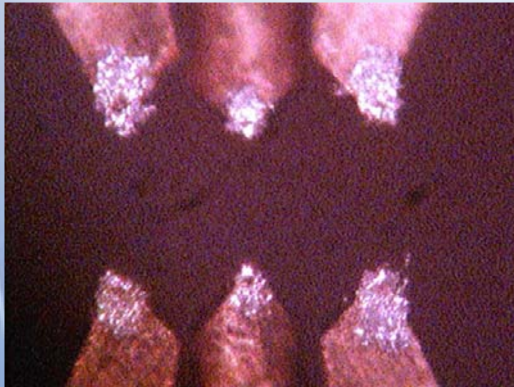
Available Probe Technologies



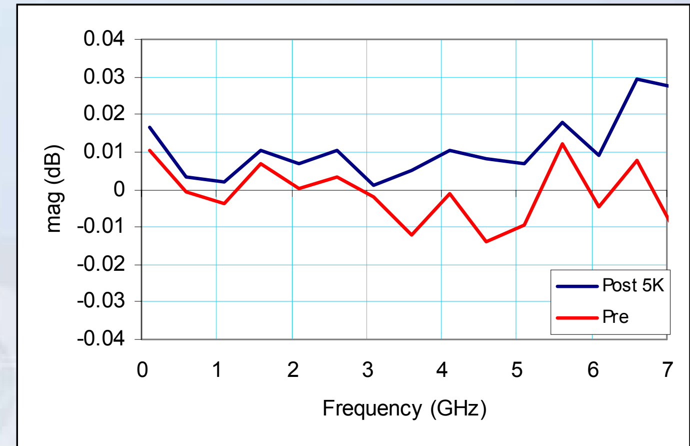
Requirements – Probe Card Stability

Two types of contamination are most often observed

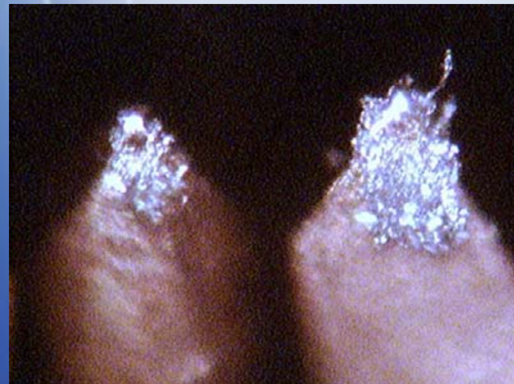
Small particulates which systematically build up over many hundreds or thousands touchdowns.



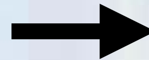
S11 OPEN cal before and after 5000 touchdowns

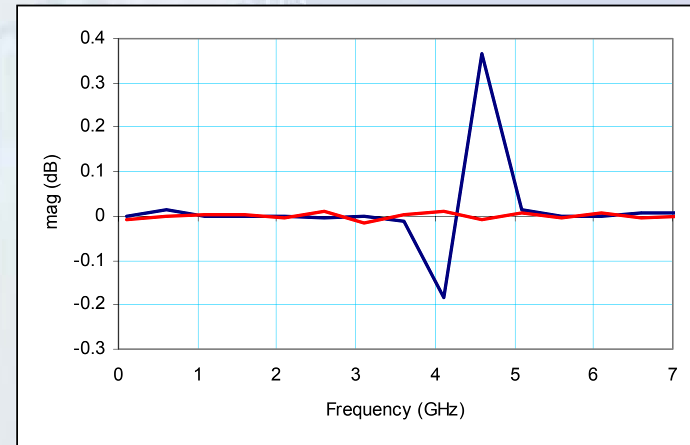


Large particulates which are generated on a random basis



S11 OPEN cal before and after particle contamination





Probe Contamination Monitor

- S11 measured during prober indexing
- Deviation from 0dB plotted
- Probe pattern:

Contour Plot

Y: 0, 5, 10, 15, 20, 25

X: 1, 2, 3, 4, 5, 6, 7

S11_dB1: <= 0.0775, <= 0.0800, <= 0.0825, <= 0.0850, <= 0.0875, <= 0.0900, <= 0.0925, <= 0.0950, <= 0.0975, > 0.0975

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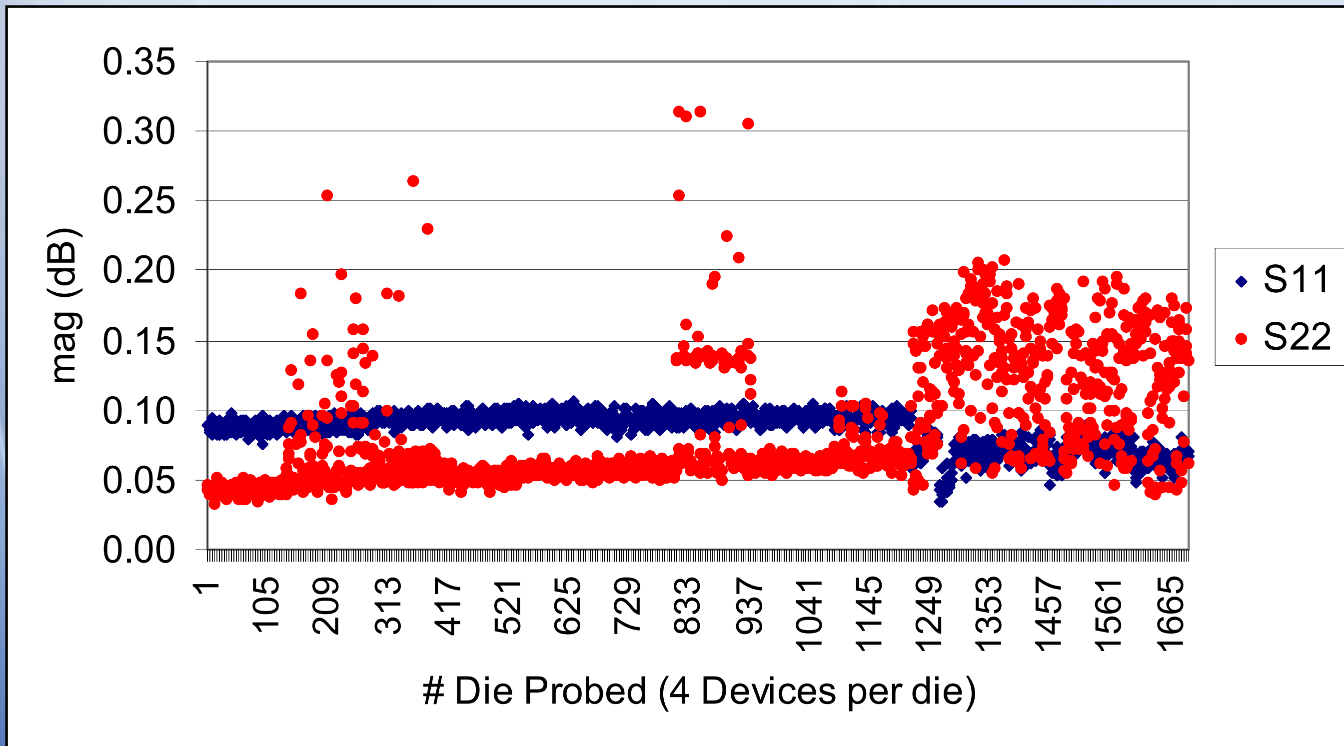
Contamination Monitor Results



SPC of Probes Up S11 and S22 During a Test with 5000 Devices Measured On Two Sequential Wafer Lots

Real-Time Probe Cleaning, Re-Cal

- **Measured Data or Probes Up Sxx Fails Limits.**
- **Probe Clean and Re-Test at Current or Adjacent Site.**
- **Probe Clean and Re-Test at Current or Adjacent Site Fails.**
- **Re-Clean and Re-Test Previously Good Site.**
- **Re-Clean and Re-Test Previously Good Site Fails.**
- **Stop Testing, Re-Load Calibration Wafer and Re-Cal.**

1
2
3
1
2
3
Re-Cal
1
2

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RF Data Display

KEITHLEY RF DATA DISPLAY

Exit Help

Lot: TEST6 Wafer: Count_1 Site: Site_5_x2_ Device: MIM_CAP_D1 File: device.dat

Lot: Wafer: Site: Device: File: Enable

Product: 125ovd Technology: avg_64mos_512cap ProbeCard: default

Data Plot

64mos 512cap 125ovd TEST6 Count 1 Site 5 x2 y3 MIM CAP D1 device.dat

1 0.6 2 0.4 4 0.2 10 0 0.2 0.5 1 2 4 10 -10 0.2 -4 -0.4 -2 -0.6 1

Plot Style

- S-Parameters
- S11
- Smith

Axis Setup

- Linear X
- Linear Y

Lines Style

- Lines & Points
- Lines
- Points

Plot and De-Embed Controls

auto | lot | Abort | Hold | B&W Print | Save | Plot | Exit

auto
none

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Data Browser - Ft

KEITHLEY RF DATA DISPLAY

Exit | Help

Apr_01_CAP_MOS
Atest_4090_3runs_ovd35
CALX512
Cle_Varac

0008745-07
0008745-09

C3_x1_y4
F4_x4_y1
A4_x4_y6

pnp
npn

open_ex.dat
device.dat
open.dat

Technology: | ProbeCard: default

Plot | Setup | Table

FT 0008745-07/C3_x1_y4/pnp/ FREQ=1e+09 VCE=10
FT 0008745-07/C3_x1_y4/pnp/ FREQ=3e+09 VCE=10
FT 0008745-07/F4_x4_y1/pnp/ FREQ=1e+09 VCE=10
FT 0008745-07/F4_x4_y1/pnp/ FREQ=3e+09 VCE=10

FT: 0, 5e+08, 1e+09, 1.5e+09, 2e+09, 2.5e+09, 3e+09, 3.5e+09, 4e+09, 4.5e+09
IC: 0.0001, 0.001, 0.01, 0.1

Plot Style: Dependent
Y Axis: FMAX, FT, GMAX, GTU
X Axis: IC
Select:
FREQ: 1e+09, 3e+09, 2.5e+08, 5e+08
VCE: 10

Plot and De-Embed Controls
auto | lot | Abort | Hold | B&W Print | Save | Plot | Exit

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Data Browser - FMAX

KEITHLEY RF DATA DISPLAY

Exit Help

Apr_01_CAP_MOS
Atest_4090_3runs_ovd35
CALX512
Cle_Varac

0008745-07
0008745-09

C3_x1_y4
F4_x4_y1
A4_x4_y6

pnp
npn

open_ex.dat
device.dat
open.dat

Technology: ProbeCard: default

Plot | Setup | Table

FMAX 0008745-07/C3 x1 y4/pnp/ FREQ=1e+09 VCE=10
FMAX 0008745-07/C3 x1 y4/pnp/ FREQ=3e+09 VCE=10
FMAX 0008745-07/F4 x4 y1/pnp/ FREQ=1e+09 VCE=10
FMAX 0008745-07/F4 x4 y1/pnp/ FREQ=3e+09 VCE=10

FMAX: 0, 2e+09, 4e+09, 6e+09, 8e+09, 1e+10, 1.2e+10, 1.4e+10, 1.6e+10, 1.8e+10

IC: 0.0001, 0.001, 0.01, 0.1

Plot Style: Dependent

Y Axis: FMAX, FT, GMAX, GTU

X Axis: IC

Select:

FREQ: 1e+09, 3e+09, 2.5e+08, 5e+08

VCE: 10

Plot and De-Embed Controls

auto | lot | Abort | Hold | B&W Print | Save | Plot | Exit

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KEITHLEY A GREATER MEASURE OF CONFIDENCE

Data Browser - Capacitance

Data showing 3 measured capacitors

KEITHLEY RF DATA DISPLAY

Exit Help

Apr_01_CAP_MOS
Atest_4090_3runs_ovd35
CALX512
Cle_Varac

0008745-07
0008745-09

C3_x1_y4
F4_x4_y1
A4_x4_y6

pnp
npn

open_ex.dat
device.dat
open.dat

Technology: ProbeCard: default

Plot Setup Table

C11 0313769 13/Site 4 x7 y2/MIM CAP D3/
C11 0313769 13/Site 4 x7 y2/MIM CAP D2/
C11 0313769 13/Site 4 x7 y2/MIM CAP D1/

C11: 2.2e-12, 2e-12, 1.8e-12, 1.6e-12, 1.4e-12, 1.2e-12, 1e-12, 8e-13, 6e-13

FREQ: 0, 2e+09, 4e+09, 6e+09, 8e+09, 1e+10, 1.2e+10

Plot Style
Dependent
Y Axis: FMAX, FT, GMAX, GTU
X Axis: IC
Select:
FREQ: 1e+09, 3e+09, 2.5e+08, 5e+08
VCE: 10

Plot and De-Embed Controls
auto | lot | Abort | Hold | B&W Print | Save | Plot | Exit

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Data Browser – DC; IC vs. VBE

KEITHLEY RF DATA DISPLAY

Exit Help

Apr_01_CAP_MOS
Atest_4090_3runs_ovd35
CALX512
Cle_Varac

0008745-07
0008745-09

C3_x1_y4
F4_x4_y1
A4_x4_y6

pnp
npn

open_ex.dat
device.dat
open.dat

Technology: ProbeCard: default

Plot | Setup | Table

VBE 0008745-07/C3 x1 y4/pnp/ FREQ=1e+09 VCE=10
VBE 0008745-07/F4 x4 y1/pnp/ FREQ=1e+09 VCE=10

VBE: 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1
IC: 0.0001, 0.001, 0.01, 0.1

Plot Style
Dependent
Y Axis: FMAX, FT, GMAX, GTU
X Axis: IC
Select:
FREQ: 1e+09, 3e+09, 2.5e+08, 5e+08
VCE: 10

Plot and De-Embed Controls
auto | lot | Abort | Hold | B&W Print | Save | Plot | Exit

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Conclusions

- The need for large amounts of s-parameter data for statistical modeling and process control is becoming increasingly significant.
- The considerations for a solution and the effectiveness of that solution have been demonstrated.
- Using this approach enables automated yield optimization tools to support products with DC to Broadband performance parameters.

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