Probe Tip Characterization Using Self-Calibration

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Overview

- equipment
- how to determine probe S-parameter and parasitics (probe specific calibration coefficients) for different probes with only one impedance standard substrate (ISS)
- GSG and GS results
- verification
- conclusions

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Equipment

port1 / reference plane 1

e.g. coaxial 2.92 mm connector

port2 / reference plane 2

coplanar (GSG) or

dual stripline (GS)

problem:determine TwoPort S-Parameter from reference plane 1 to reference plane 2 including "contact parasitics"

available probes at FH

Cascade Microtech
- ACP GSG 150 µm
- ACP GS/SG 150 µm
- HPC GSG 100 µm

Picoprobe
- GGB 40A 150 µm

Suss
- |Z|-Probe 40 N 125 µm

5 differnet ISS are necessary for calibration

measurement equipment

NWA Agilent 8720 D

cables Huber+Suhner, 3.5 mm

Agilent 3.5 mm calibration kit (85052D)

Impedance Standard Substrate (ISS)

Cascade 101-190 B

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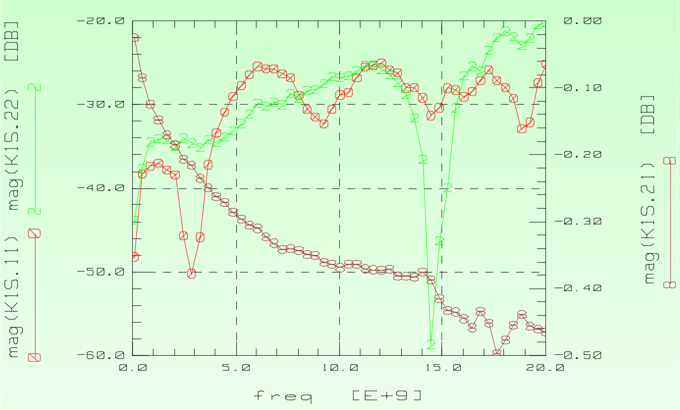
Simple Solution

- perform 3.5 mm one port SOL-calibration at port 1
- measure at the calibrated port 1 the on wafer load, open and short Standards connected at port 2
- calculate the probes S-parameters using the shown ICCAP Transform "K1S" (SOL One Port Calibration)

Example |Z|-Probe




```
UPDATE_MANUAL
n=size(freq)
complex x.22[n]
GL=LO/SOLT.m.11                  !measured reflection coefficient of the load
GO=OL/SOLT.m.11                  !measured reflection coefficient of the open
GS=SL/SOLT.m.11                  !measured reflection coefficient of the short
RL=sc101_190B/l1/S11             !known reflection coefficient of the load
RO=sc101_190B/o1/S11             !known reflection coefficient of the open
RS=sc101_190B/s1/S11             !known reflection coefficient of the short
N12=(GL-GO) / (RL-RO)
N13=(GL-GS) / (RL-RS)
i=0
while i < n
  x.22[i]=(N12[i]-N13[i]) / (RO[i]*N12[i]-RS[i]*N13[i])              !Source Match Error
  x.12[i]=sqrt(N12[i]*(1-x.22[i]*RL[i])*(1-x.22[i]*RO[i]))           !Source Tracking Error
  x.21[i]=x.12[i]
  x.11[i]=GL[i]-RL[i]*x.21[i]**2 / (1-x.22[i]*RL[i])                 !Directivity Error
  i=i+1
end while
return x
```

problem1: "in on-wafer probing the electrical behavior of the standards are dependent upon the probe and how it is placed" [1]

problem 2: probe manufacturers deliver probe specific standard definitions only for their own ISS

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Self-Calibration with TRL[2]

Standard	Known Parameter	Unknown Parameter-determined by self-calibration
short line ("Thru")	length	line propagation constant
long line ("Line")	length	
on wafer load	DC resistance / Ω	skin effect loss, load inductance, characteristic line impedance
on wafer open ("Reflect")	-	reflection coefficient; open capacitance
on wafer short	-	reflection coefficient; short inductance

result: calculation of the 12 TERM error coefficients

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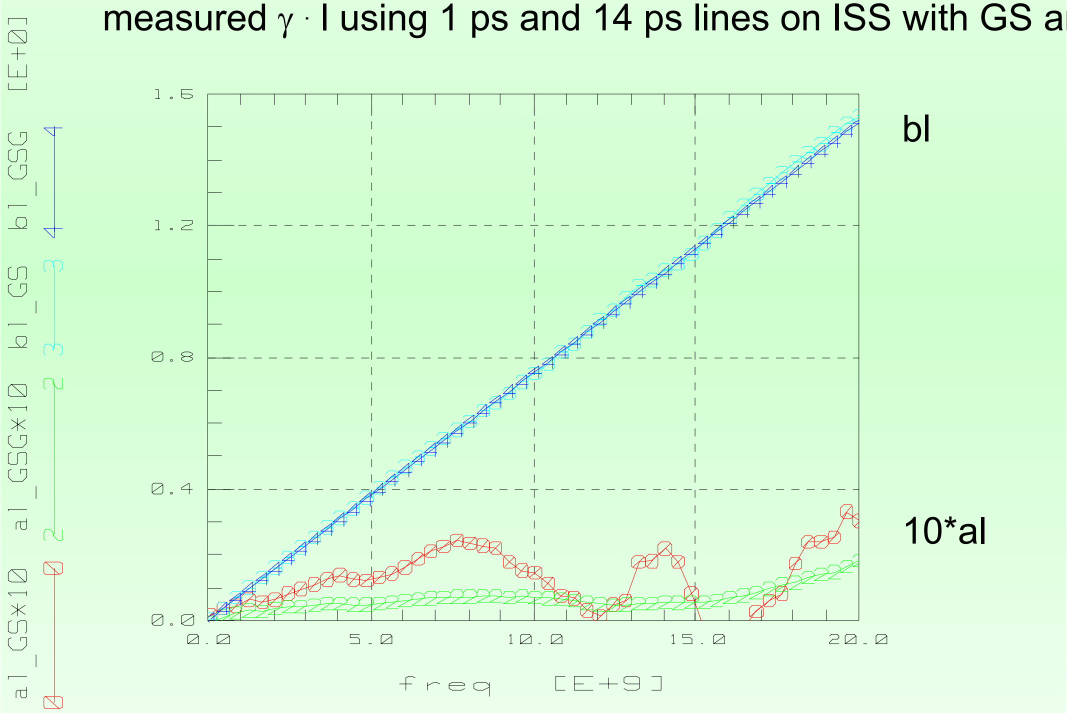
Line Parameters - Propagation Constant

$$\gamma \cdot l = (\alpha + j \cdot \beta) \cdot l = al + j \cdot bl$$

measured $\gamma \cdot l$ using 1 ps and 14 ps lines on ISS with GS and GSG Probes



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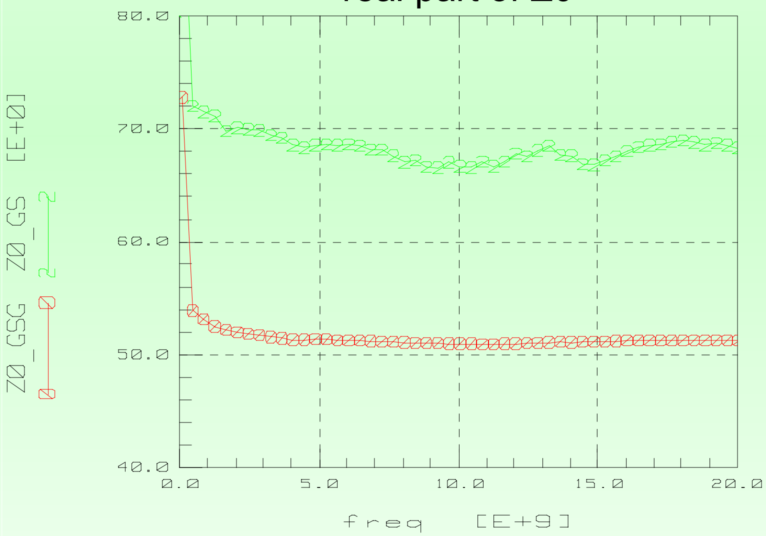
Characteristic Line Impedance Z0 [3]

- measure uncalibrated S-parameter of the load and calculate the reflection coefficient Γ_{Load} using the TRL solution
- measure DC resistance of the load $R_{Load,dc}$
- calculate the line capacitance
- calculate the characteristic impedance

$$C \approx \frac{\gamma \cdot l}{j \cdot \omega \cdot R_{Load,dc}} \cdot \frac{1+\Gamma_{Load}}{1-\Gamma_{Load}}$$

$$Z0 \approx \frac{\gamma \cdot l}{j \cdot \omega \cdot C}$$

real part of Z0



$R_{Load,dc,GS} = 100\ \Omega$

$R_{Load,dc,GSG} = 50\ \Omega$

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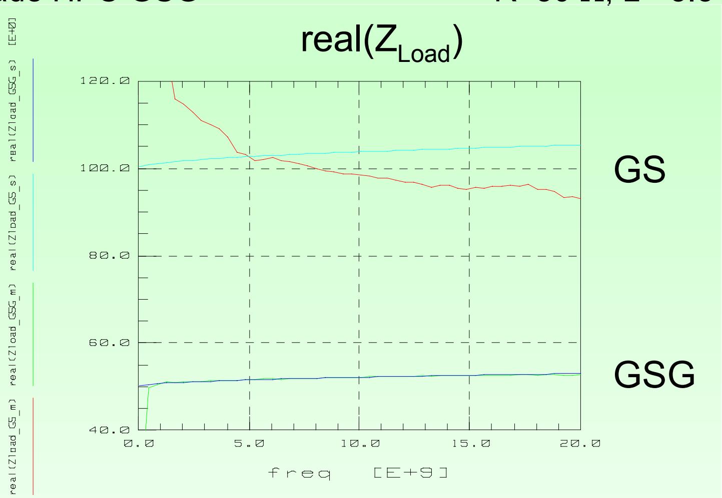
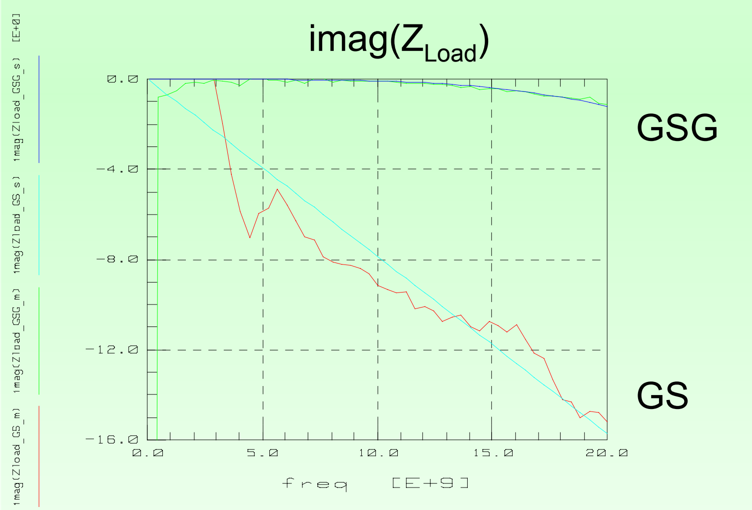
Modeling of the LOAD

- measure uncalibrated S-parameter of the load and calculate the reflection coefficient Γ_{Load} using the TRL solution and Z0

$$Z_{Load} = Z0 \cdot \frac{1+\Gamma_{Load}}{1-\Gamma_{Load}} = R \cdot \left(1 + \alpha \cdot \left(\frac{freq}{1GHz}\right)^{0.5}\right) + j \cdot \omega \cdot \left(\frac{L_0}{10^{-12}} + \frac{L_1 \cdot freq}{10^{-24}} + \frac{L_2 \cdot freq^2}{10^{-33}} + \frac{L_3 \cdot freq^3}{10^{-42}}\right)$$

model parameter GSG:	R=50 Ω, α=0.012, L_0=0 H, L_1=0 H/Hz, L_2= 0 H/Hz^2, L_3= -1.2 H/Hz^3
model parameter GS:	R=100 Ω, α=0.012, L_0=-125 H, L_1=0 H/Hz, L_2= 0 H/Hz^2, L_3= 0 H/Hz^3
Cascade ACP GS	R=50 Ω, L=57.8 pH
Cascade HPC GSG	R=50 Ω, L=-3.5 pH





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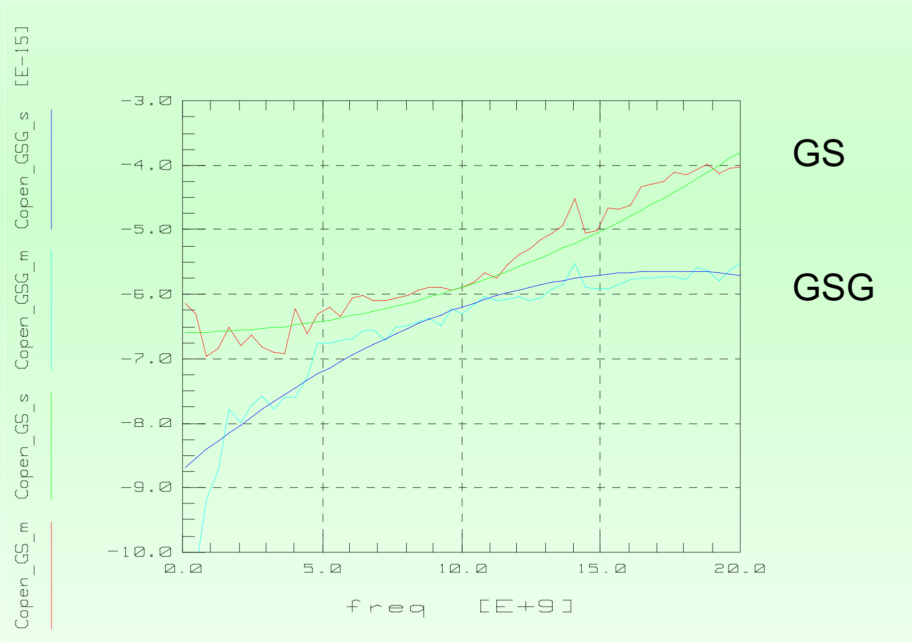
Modeling of the OPEN

- measure uncalibrated S-parameter of the open and calculate the reflection coefficient Γ_{Open} using the TRL solution and Z0

$$Y_{Open} = \frac{1}{Z0} \cdot \frac{1-\Gamma_{Open}}{1+\Gamma_{Open}} = j \cdot \omega \cdot \left(\frac{C_0}{10^{-15}} + \frac{C_1 \cdot freq}{10^{-27}} + \frac{C_2 \cdot freq^2}{10^{-36}} + \frac{C_3 \cdot freq^3}{10^{-45}} \right)$$

model parameter GSG:	C_0=-8.7 F,C_1=350 F/Hz,
	C_2=-10 F/Hz^2, C_3= 0 F/Hz^3
model parameter GS:	C_0=-7 F,C_1=0 F/Hz,
	C_2= 7 F/Hz^2, C_3= 0 F/Hz^3
Cascade ACP GS	C=-11 fF
Cascade HPC GSG	C=-9.3 fF



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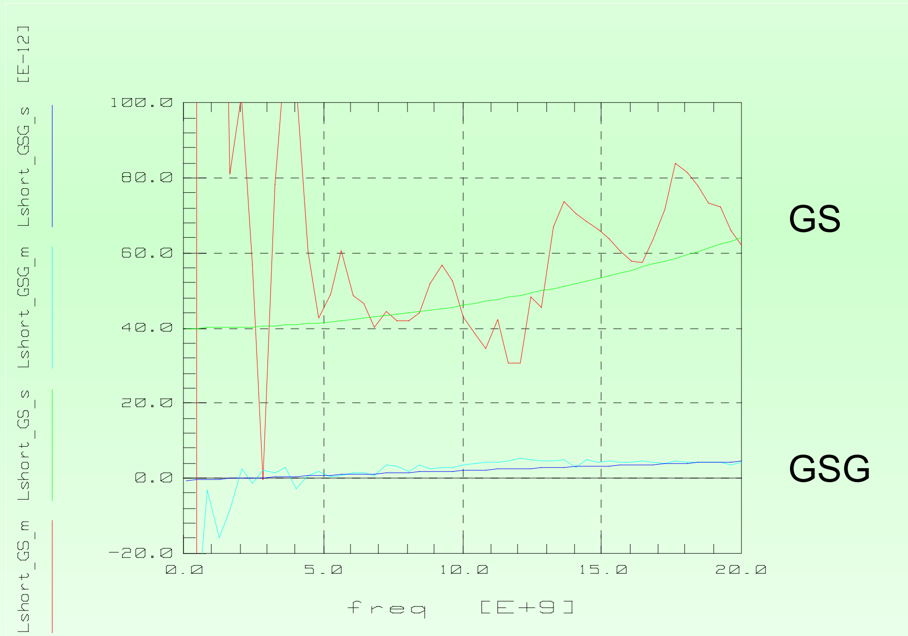
Modeling of the SHORT

- measure uncalibrated S-parameter of the open and calculate the reflection coefficient Γ_{Short} using the TRL solution and Z0

$$Z_{Short} = Z0 \cdot \frac{1+\Gamma_{Short}}{1-\Gamma_{Short}} = j \cdot \omega \cdot \left(\frac{L_0}{10^{-12}} + \frac{L_1 \cdot freq}{10^{-24}} + \frac{L_2 \cdot freq^2}{10^{-33}} + \frac{L_3 \cdot freq^3}{10^{-42}} \right)$$

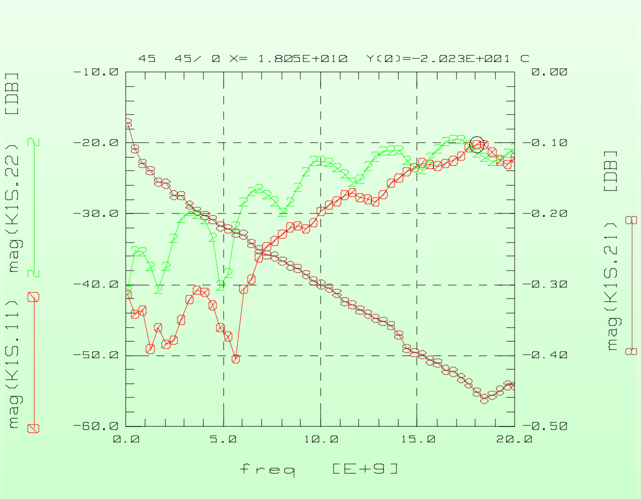
model parameter GSG:	L_0=-0.5 H,L_1=250 H/Hz,
	L_2= 0 H/Hz^2, L_3= 0 H/Hz^3
model parameter GS:	L_0=40 H,L_1=0 H/Hz,
	L_2= 60 H/Hz^2, L_3= 0 H/Hz^3
Cascade ACP GS	L=49.8 pH
Cascade HPC GSG	L=2.4 pH



GS

GSG

Example Datasheet of ACP40-Probe



Kalibriersubstrat C101-190B
Pitch 150 µm
SN:434907

Messung vom 30.07.2008

data provided by Cascade:

Copen = -9.7 fF

Lshort = 4.8 pH

Lload = 0.2 pH

delay = 1 ps

$Copen_0 = -11.5 fF$

$Copen_1 = 267 \cdot 10^{-27}$ F/Hz

$Copen_2 = -6.5 \cdot 10^{-36}$ F/Hz^2

$Lshort_0 = 7$ pH

$Lshort_1 = 350 \cdot 10^{-24}$ H/Hz

$Rload = 50.0 \Omega$

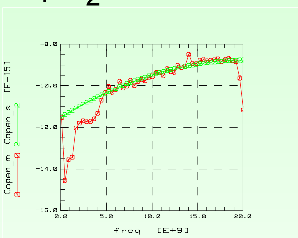
alpha = 0.012

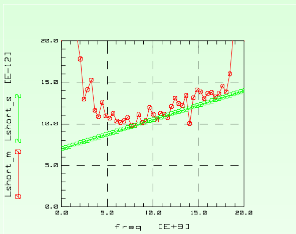
$Lload_0 = 3$ pH

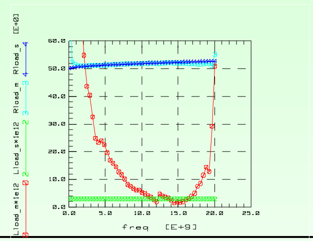
Line Z0 $= 50 \Omega$

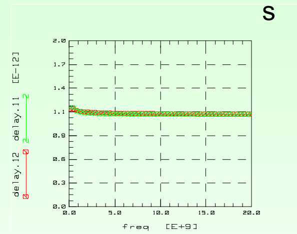
delay = 1.105ps

loss@1GHz $= 29 \frac{G\Omega}{s}$









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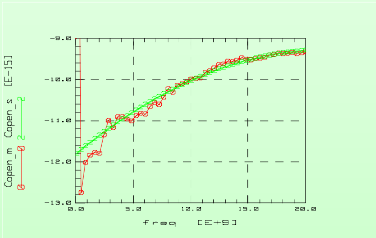
Calibration Standards on GaAs Wafer

ACP40 GSG Pitch 150 µm SN:434907 Messung vom 30.07.2008

$Copen_0 = -11.5\ fF$

$Copen_1 = 267 \cdot 10^{-27}\ F/Hz$

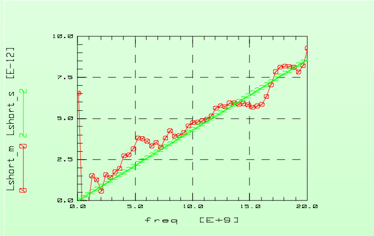
$Copen_2 = -6.5 \cdot 10^{-36}\ F/Hz^2$

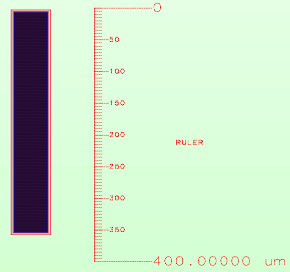


probe in air

$Lshort_0 = 0\ pH$

$Lshort_1 = 430 \cdot 10^{-24}\ H/Hz$



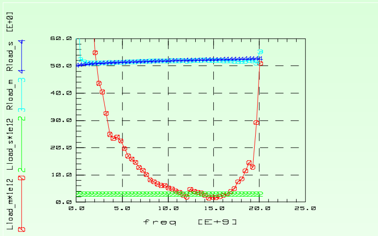


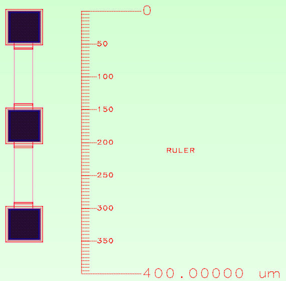
$Rload = 50.55\ \Omega$

$alpha = 0.0115$

$Lload_0 = 0\ pH$

$Lload_1 = -300 \cdot 10^{-24}\ H/Hz$

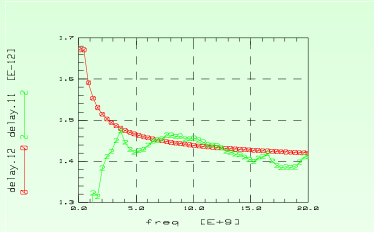


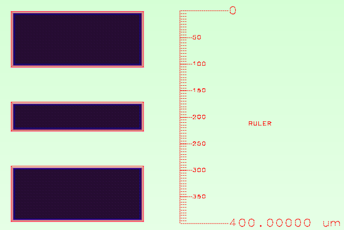


$Line1\ \ Z0 = 61\ \Omega$

$delay = 1.35\ ps$

$loss@1GHz = 110\ \frac{G\Omega}{s}$





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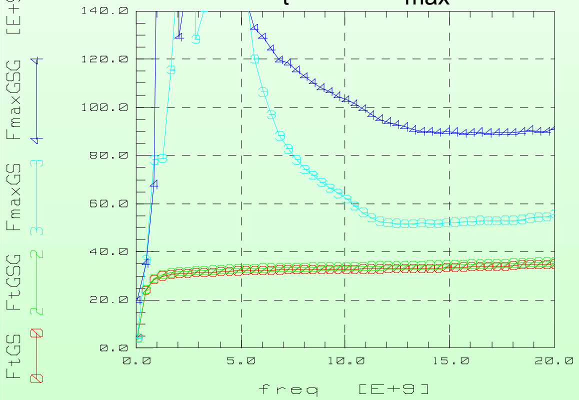
Specification of measured Probes to 20 GHz

Probe	Pitch/µm	max(S11)/dB	max(S22)/dB	min(S21)/dB
Suss Z-Probe 40 N GSG Ni	125	-25	-20.5	-0.5
GGB EDPW 40 GSG W	150	-25	-22	-0.65
ACP40 GSG W	150	-18	-20	-0.5
ACP40 GSG W	150	-21	-26	-0.38
HPC40 GSG BeCu	100	-24	-20	-0.3
HPC40 GSG BeCu	100	-26	-26	-0.34
ACP40 GS W	150	-19	-13	-0.76
ACP40 SG W	150	-18	-14	-0.76
Suss Z-Probe GSG Ni 1mm	100	-25	-25	-0.39

Comparing GS with GSG measurements

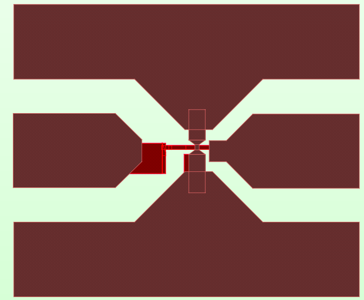
F_t and F_{max}



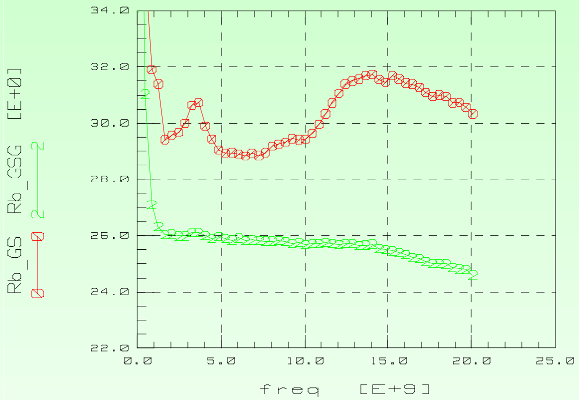
GaAs HBT 2x10 µm^2

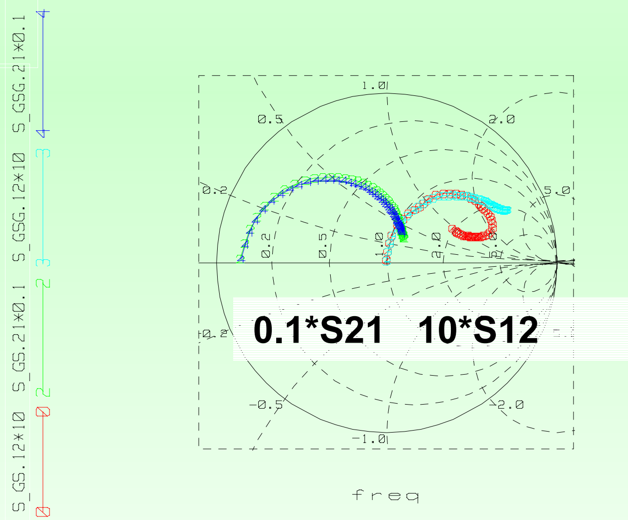
V_{ce}=3 V; I_c = 10 mA

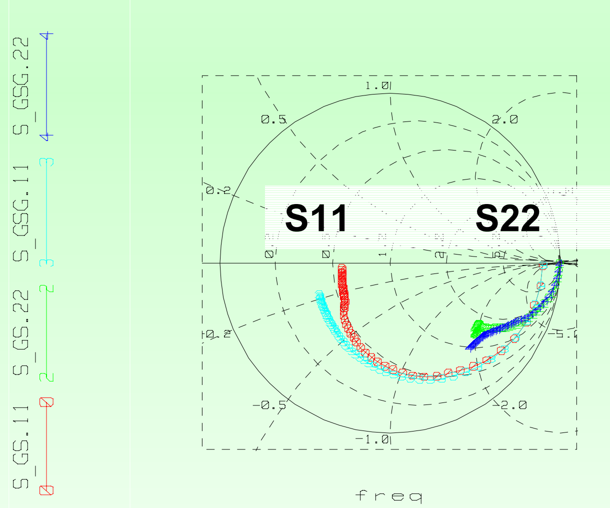
Frequency 0.05...20.05 GHz



base resistance







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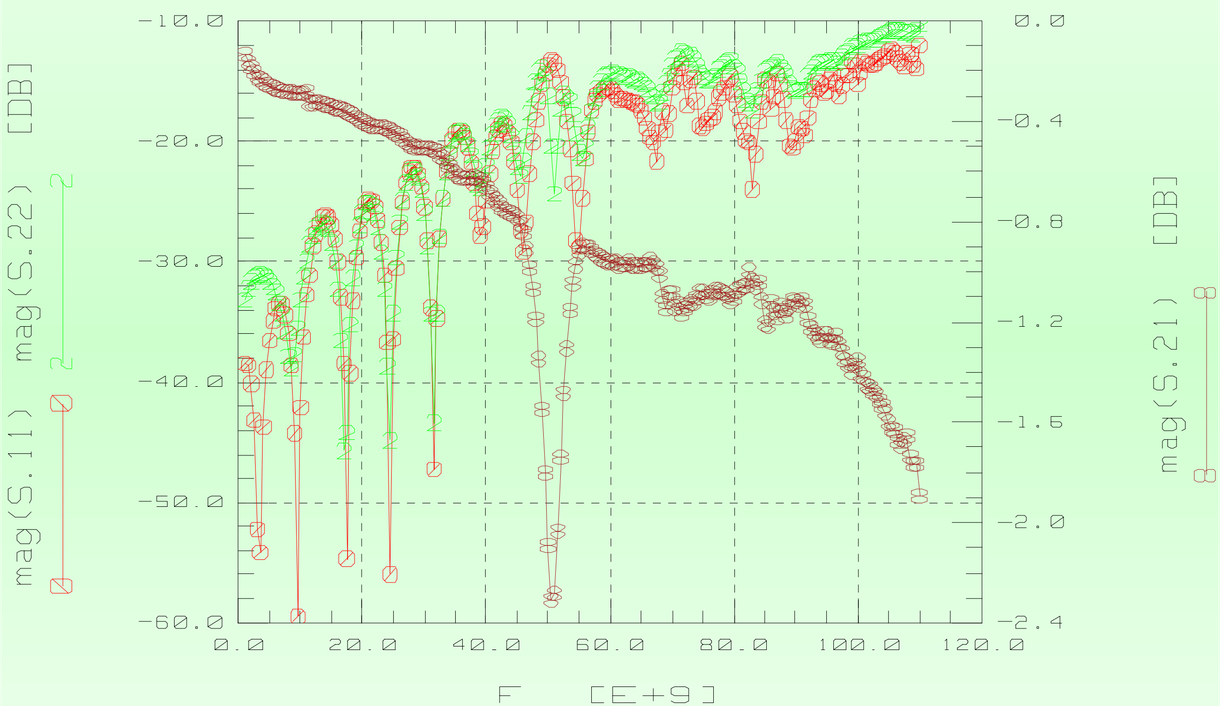
1mm Z-Probe to 110 GHz

uncalibrated measurements at IMS-Bordeaux



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Conclusions

a method for self calibration of on wafer probe parasitics is shown using TRL

this is necessary if a ISS with unknown standard definitions is used (e.g. 101-190B with GS probes)

known standard parameters are length of two transmission lines with equal charcteristic line impedance and dc resistance of a load

the method can be further improved using NIST multiline TRL algorithm

with the TRL solution the S-parameters of short, open, load and thru standards are measured and modeled using the parameters available in e.g. 8510 NWA to achieve a broadband solution without ripple in SOLT/SOLR calibrations

the load model is extended by inclusion of the skin effect

it is possible to characterize a self built on wafer calibration kit

using the probe tip contact parasitics for the availalble calibration standards the probes S-parameter are calculated with the SOL algorithm

GS and GSG measurements deliver different results for transistor modeling (e.g. Fmax and Rb)

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References

[1] Cascade Microtech Inc. Impedance Standard Substrate description of P/N 101-190

[2] G.F.Engen, C.A. Hoer,*"Thru-Reflect-Line": An Improved Technique for Calibrating the Dual Six-Port Automatic Network Analyzer*, MTT-27, No12, Dec 1979, pp.987-993.

[3] D.F. Williams and R.B. Marks, *Transmission Line Capacitance Measurement,* IEEE MICROWAVE AND GUIDED WAVE LETTERS, VOL 1, NO. 9, SEP 1991,pp.243-245.

Thank You for Your attention

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