"PA Load Pull Error Limits using Delta G_t Contours"

by Jim Paviol, Eric Kueckels*, Ravi Varanasi** & Larry Dunleavy**

Presented by Jim Paviol, Sr. Principal Systems Engineer, GlobespanVirata - PRISM Wireless
2401 Palm Bay Rd. NE, MS62B-017; Palm Bay, FL 32905 (321)-724-7081

*Maury Microwave; Ontario, CA 91764-4804
(518)-857-6224; Maury: (919)-987-4715

**University of South Florida (USF); EE-WAMI Center, Tampa, FL 33620 (813)-974-2574

Delta G_t Contours Introduction

- Load Pull tuners sweep all reflection coefficient space.
  - Maury Load Pull Tuner Systems are used for this presentation.
- Tuners characterizations are used in gain contour calculations:
  - Accuracy of S-Parameter characterization is critical.
  - Repeatability of connectors and cables are important.
  - The Power Block Diagram needs to be set up properly.
- Delta G_t can be used to confirm the system accuracy.
  - Insert a characterized low loss through between tuners.
  - Sweep out the reflection coefficients for the tuner.
    - Initially the outside ring with 45° points and the center.
    - Over-night sweeps of all reflection space and frequencies.
  - Both Source and Load tuners should be verified.
  - Start with a simple coax system and then progress to more complex on-wafer and diplexer or triplexes setups.

Delta G_t Contours: Formula's

- The three types of RF Gain:
  - **Available Gain =(available output power)/(available input power)**

$$G_a = f(\Gamma_S, [S]) = \frac{(1-|\Gamma_S|^2)|S_{21}|^2}{|1-S_{11}\Gamma_S|^2(1-|\Gamma_2|^2)} \; where, \Gamma_2 = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}$$

  - **Power Gain =(delivered output power)/(delivered input power)**

$$G_p = f([S], \Gamma_L) = \frac{|S_{21}|^2(1-|\Gamma_L|^2)}{(1-|\Gamma_1|^2)|1-S_{22}\Gamma_L|^2} \; where, \Gamma_1 = S_{11} + \frac{S_{21}S_{12}\Gamma_L}{1-S_{22}\Gamma_L}$$

  - **Transducer Gain=(delivered output power)/(available input power)**

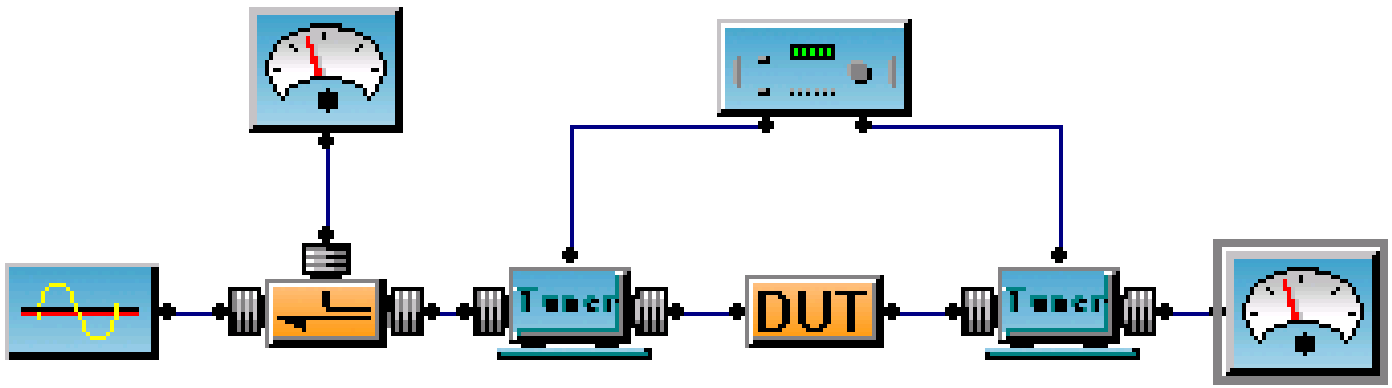
$$G_t = f(\Gamma_S, [S], \Gamma_L) = \frac{(1-|\Gamma_S|^2)|S_{21}|^2(1-|\Gamma_L|^2)}{|1-S_{11}\Gamma_S|^2|1-\Gamma_2\Gamma_L|^2}$$

A function of Both Γ_S & Γ_L.

[1]

Delta G_t Minimum Configuration

- Delta G_t (dB)= G_t{measured} (dB)- G_t[S] {calculated} (dB).
- DUT *Available Input Power* can be calculated rigorously:
  - Using Pre-Calibrated Tuner S-Parameters and Z_{source} .
- *Delivered Output Power* is measured by the Power Sensor.
- A low loss thru is used for the DUT in Delta G_t errors testing.
- Delta G_t error is minimum near Z_o, maximum at high VSWR.



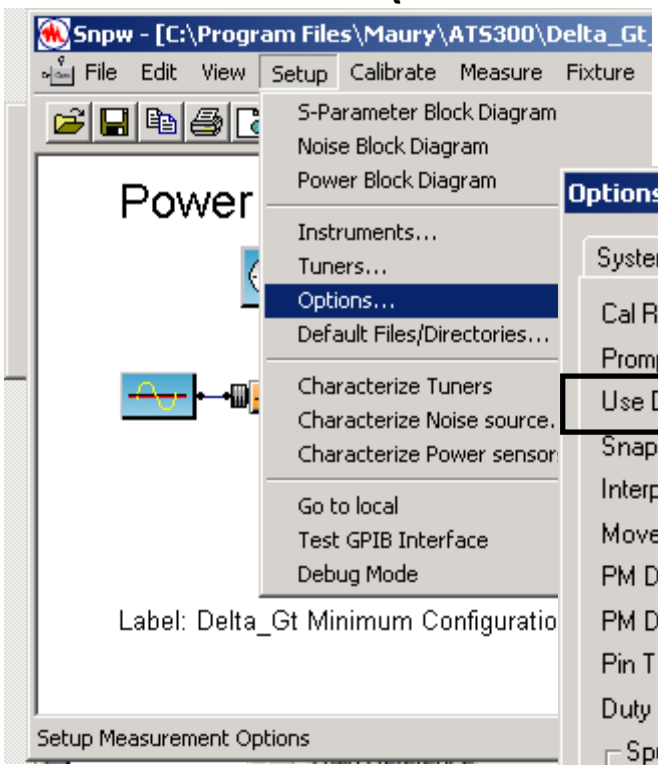
Label: Delta_Gt Minimum Configuration Test

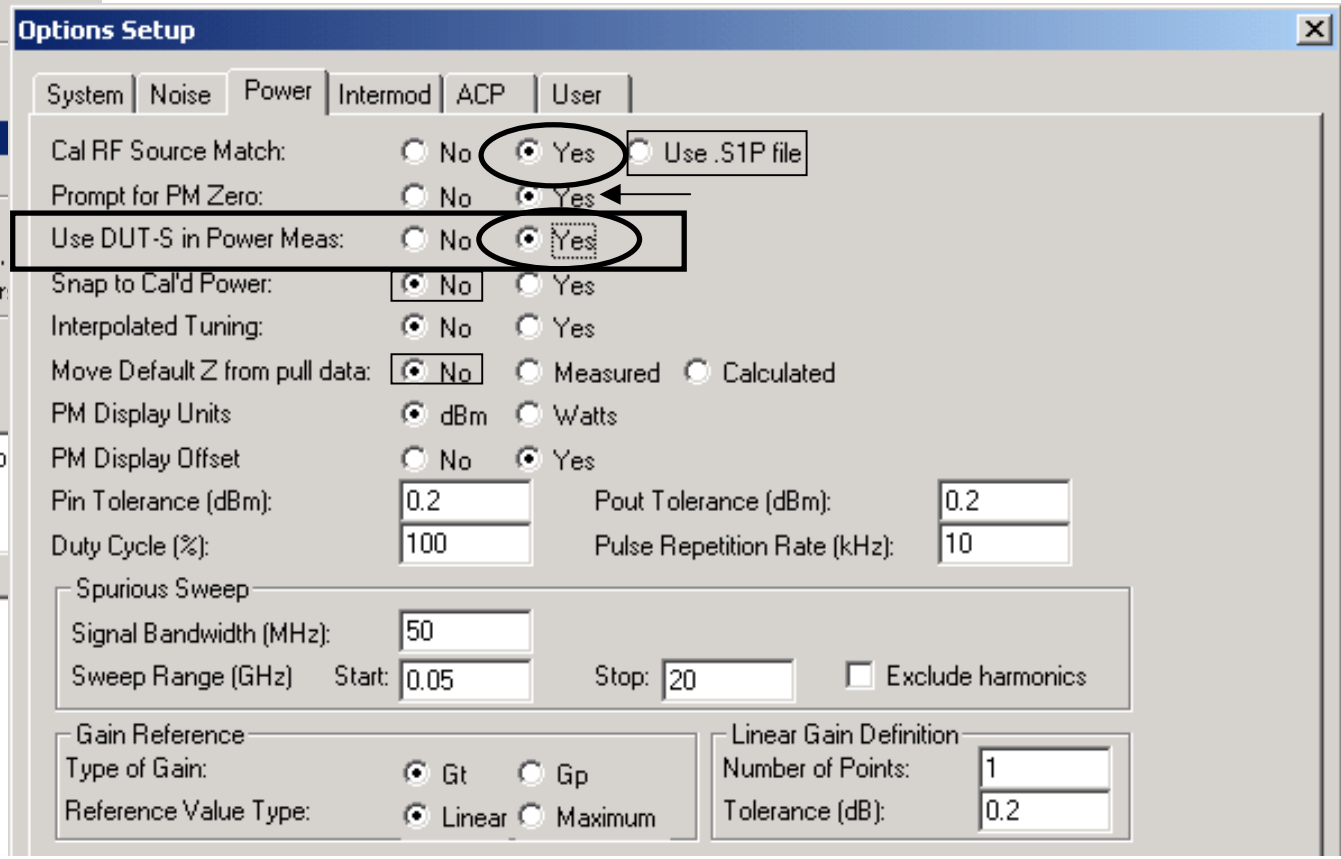
[2]

Delta G_t'Setup Options

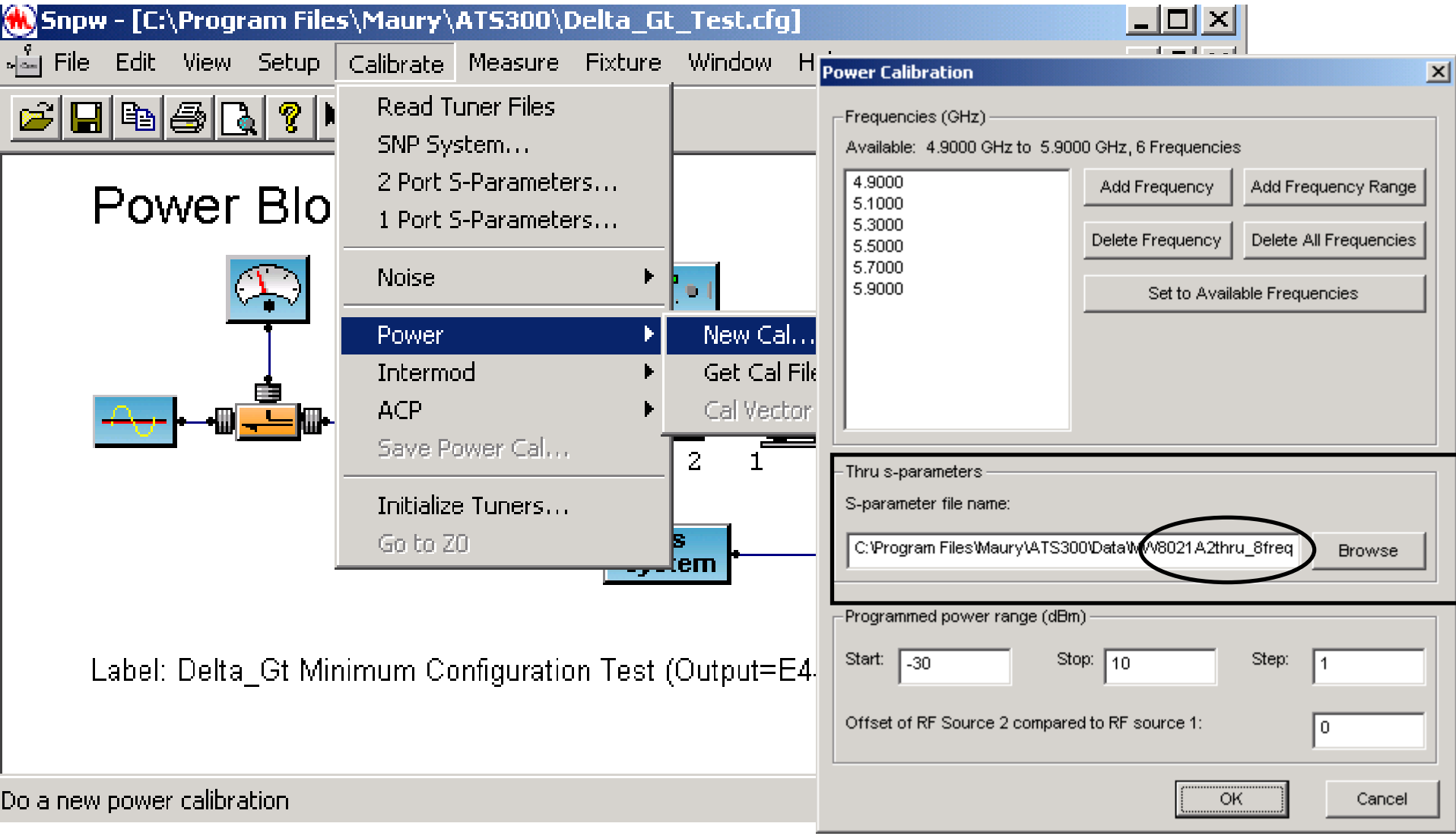
- Delta G_t requires "Use DUT S-parameters in Power Measurement.

Main-Menu→Setup→Options→Use DUT-S



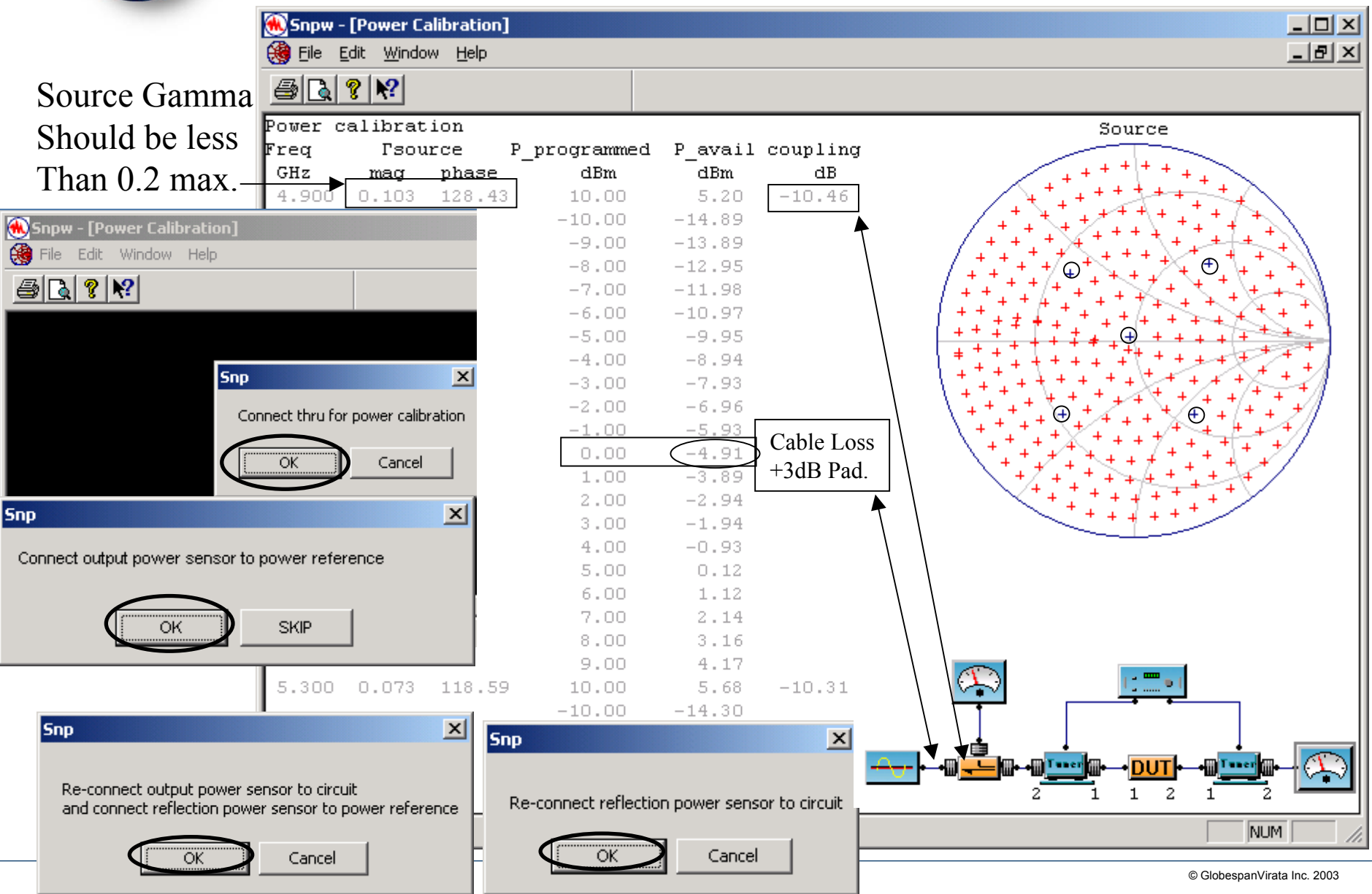


Delta G_t Contours: Power Calibration

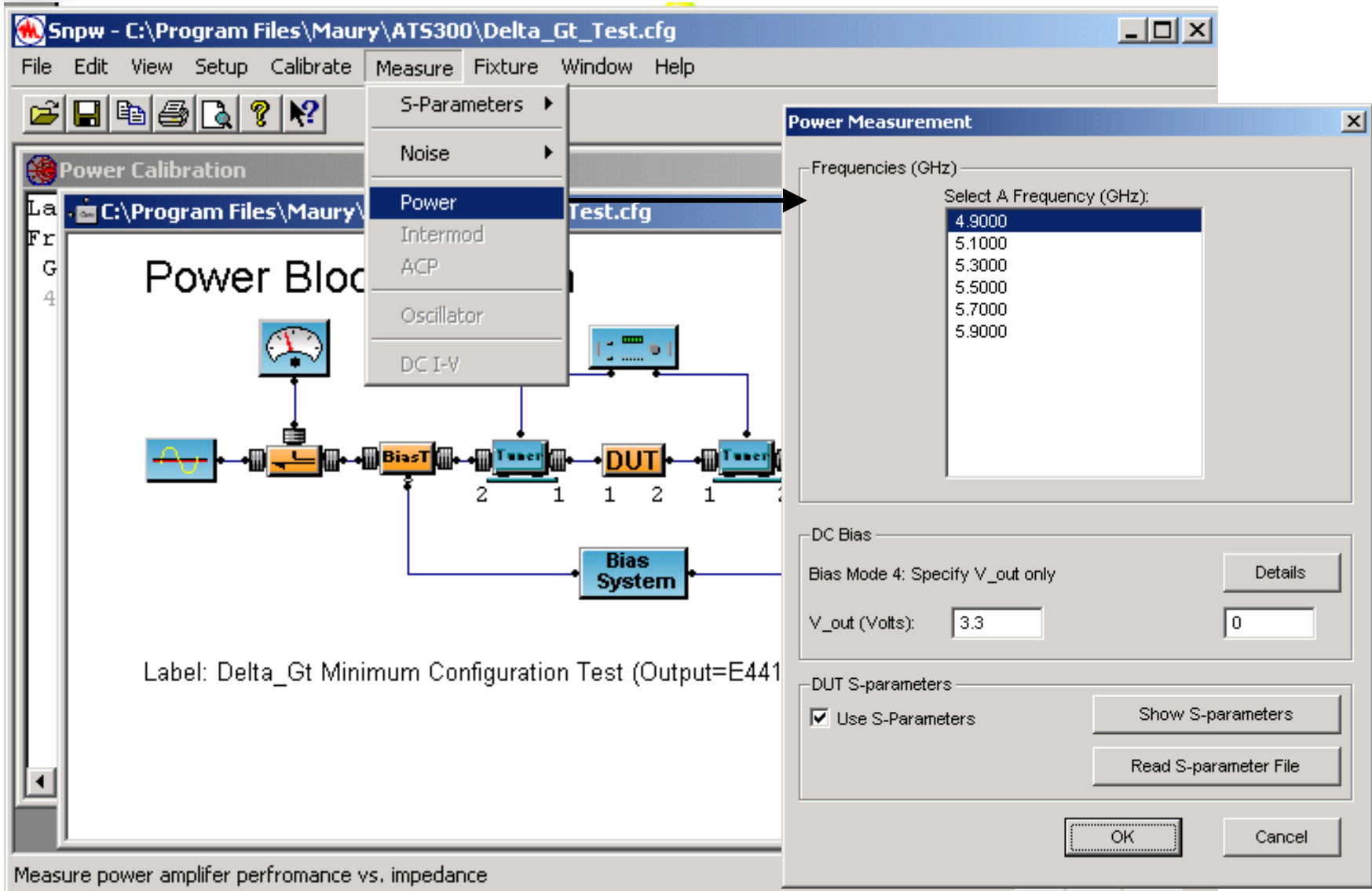


Delta G_t Contours: Source Pull Set-up

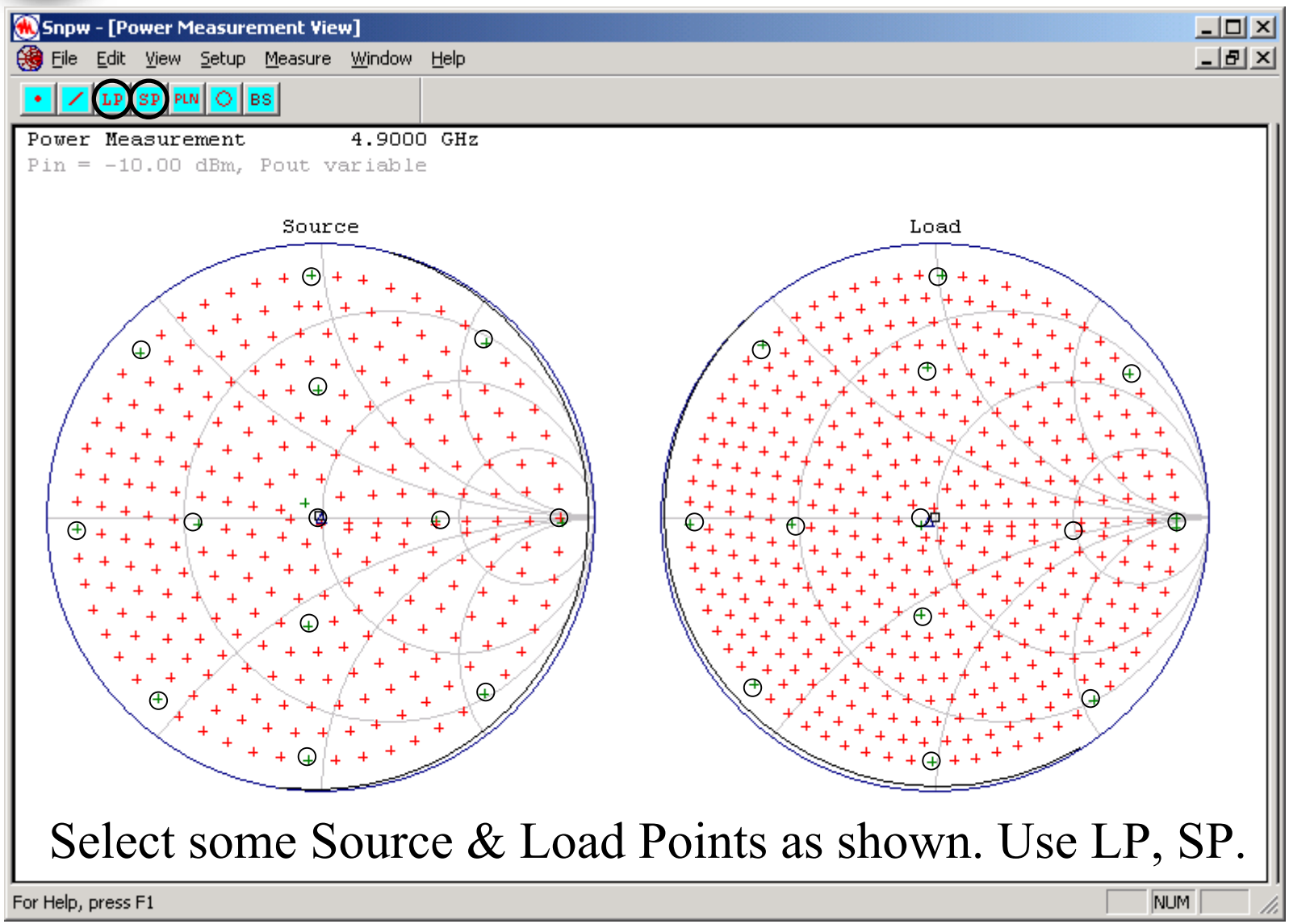
Source Gamma Should be less Than 0.2 max.



Delta G_t Contours: Measure→Power



Delta G_t Contours: Measurement Pre-Checks



Delta G_t Contours: Table

Snpw - [Fixed Pull vs Phase]

File Edit View Window Help

Fixed Pull vs Phase
Source Pull at 4.9000 GHz
Label:
ZLoad (Ohms) = 49.24 + j 1.92

Phase degrees	Gt dB	Gt(s) dB	Delta_Gt dB	Pin_avail dBm	Pin_deliv dBm
-178.85	-6.706	-5.524	-1.182	-10.000	-19.425
-130.55	-7.150	-5.767	-1.384	-10.000	-19.764
-91.01	-7.044	-6.405	-0.638	-10.000	-19.141
-88.01	-1.431	-1.193	-0.238	-10.000	-11.636
-46.42	-6.595	-6.920	0.325	-10.000	-17.743
-32.28	-0.053	-0.031	-0.023	-10.000	-10.137
-1.22	-0.592	-1.089	0.496	-10.000	-10.550
3.57	-5.900	-7.098	1.198	-10.000	-16.866
41.38	-5.705	-6.913	1.208	-10.000	-16.282
84.79	-0.660	-0.993	0.332	-10.000	-10.825
92.30	-5.611	-6.502	0.891	-10.000	-16.719
138.19	-6.300	-6.012	-0.288	-10.000	-18.164
173.15	-1.398	-0.831	-0.568	-10.000	-11.821
181.15	-6.706	-5.524	-1.182	-10.000	-19.425

For Help, press F1 NUM

Delta G_t Contours
Phase Plot for VSWR=15

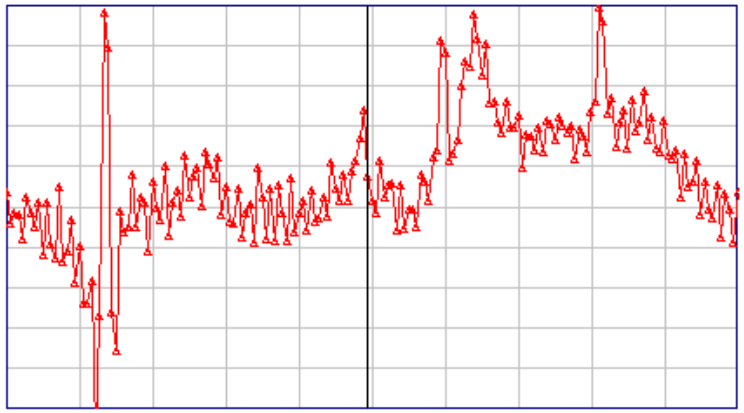
Snpw - [Fixed Pull vs Phase]

File Edit View Window Help

```
Fixed Pull vs Phase
Load Pull at  4.9000 GHz
Δ Delta_Gt:     0.19 dB
  -0.10 to    0.40 dB

Marker: Phase =   0.00 degrees

Label:
Delta_Gt LP Test-VSWR=15:1  SCALE -0.1 to 0.4dB
```




```
Fixed Pull vs Phase
Load Pull at  4.9000 GHz
Label: Delta_Gt LP Test-VSWR=15:1  SCALE -0.1 to 0.4dB
ZSource (Ohms) = 50.00 + j 0.00
   Phase     Delta_Gt
  degrees       dB
 -178.01       0.170
 -176.01       0.132
 -174.01       0.145
 -172.01       0.142
 -170.01       0.112
 -168.01       0.163
 -166.01       0.146
 -164.01       0.128
 -162.01       0.158
 -160.00       0.094
```

For Help, press F1 NUM

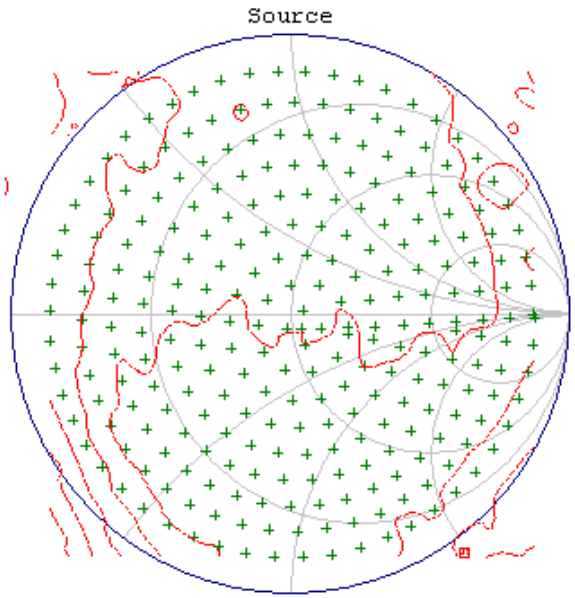
Source Mismatch errors dominate Delta Gt at the outside edges of the Smith Chart. Directivity errors dominate Delta Gt in the center of the Smith Chart.

Delta G_t Contours All Points Plot

- **Source Delta_Gt**
  #contours = 1
  @ 0.25dB/step
  maxDeltaGt=0.9dB
  A reasonable error.

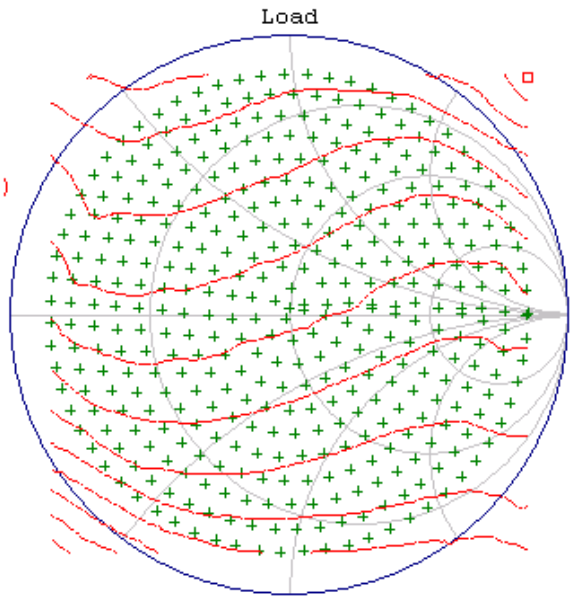
```
Swept Source Pull
Freq = 5.3000 GHz
ZLoad (Ohms): 50.00 + j 0.00

Delta_Gt     max =  0.94 dB
  at -7.03 - j98.47 Ohms
(Pin_avail=-10.00 dBm, 267/267 pts)
124 contours,  0.25 dB step
(-30.00 to 0.75 dB)
Specs: OFF
```




```
Swept Load Pull
Freq = 5.3000 GHz
ZSource (Ohms): 54.49 - j12.68

Delta_Gt     max =  1.49 dB
  at -29.82 + j115.49 Ohms
(Pin_avail=-10.00 dBm, 399/399 pts)
124 contours,  0.25 dB step
(-29.50 to 1.25 dB)
Specs: OFF
```



- **Load Delta_Gt**
  #contours = 8
  @ 0.25dB/step
  maxDeltaGt=1.75dB
  Undesirable Errors.

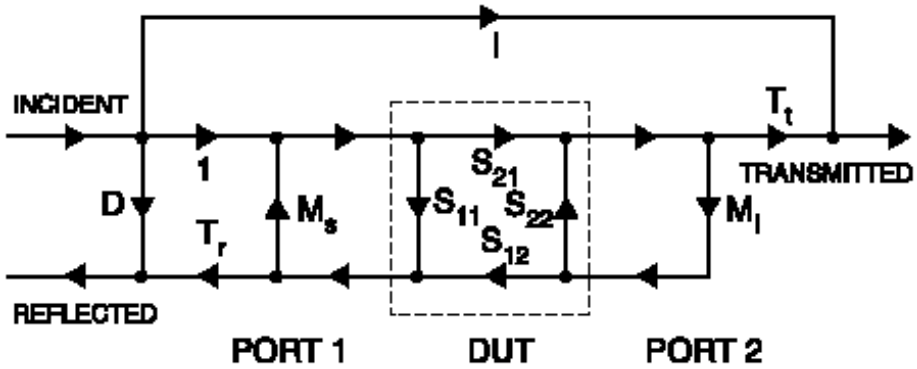
Delta G_t Contours: ANA Accuracy.

- ANA characterization accuracy for S-parameters:

Typical Automatic Network Analyzer Accuarcy Comparision:					
Repeatability of thru calibration after 4~24hours and 2~5C change.					
5~6GHz	**PNA**	**8510**	**8720**	**8753**	
S11	-60	-55	-50	-45	dB
S21	0.001	0.005	0.007	0.01	dB
The optimum frequency range is 1/2 to 2/3 of the maximum.					
Connectors are the major factor in ANA reconnect repeatability.					
Cables are a major factor in ANA accuaracy & stability.					
Temperature coefficient of S21 is about 0.001dB/degree.					
Hint: Cal with IF BW=10Hz, Measure with IF BW=100Hz & Avg=1,On.					

Delta G_t Contours: ANA Errors

- ANA verifications should be performed after calibration:



D = Directivity

T_r = Reflection Frequency Response Tracking

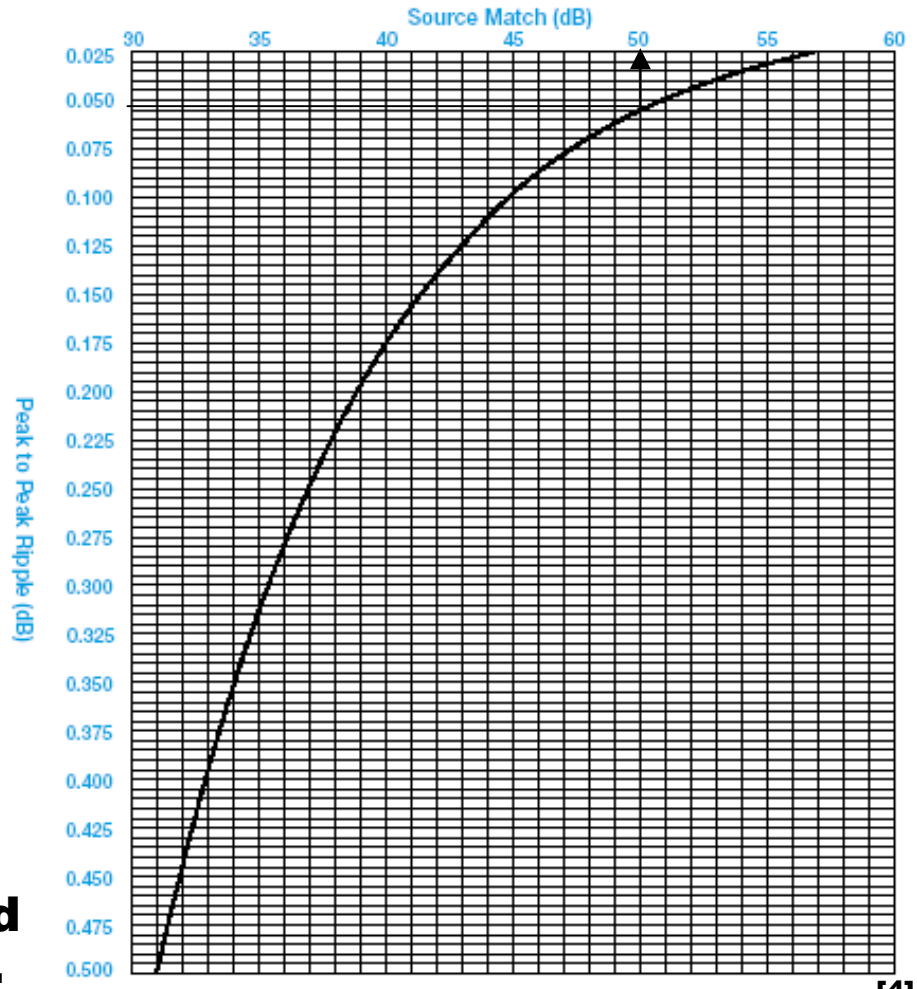
M_s = Source Match

I = Isolation

M_l = Load Match

T_t = Transmission Frequency Response Tracking

Source Match(dB) vs. Peak to Peak Ripple(dB)

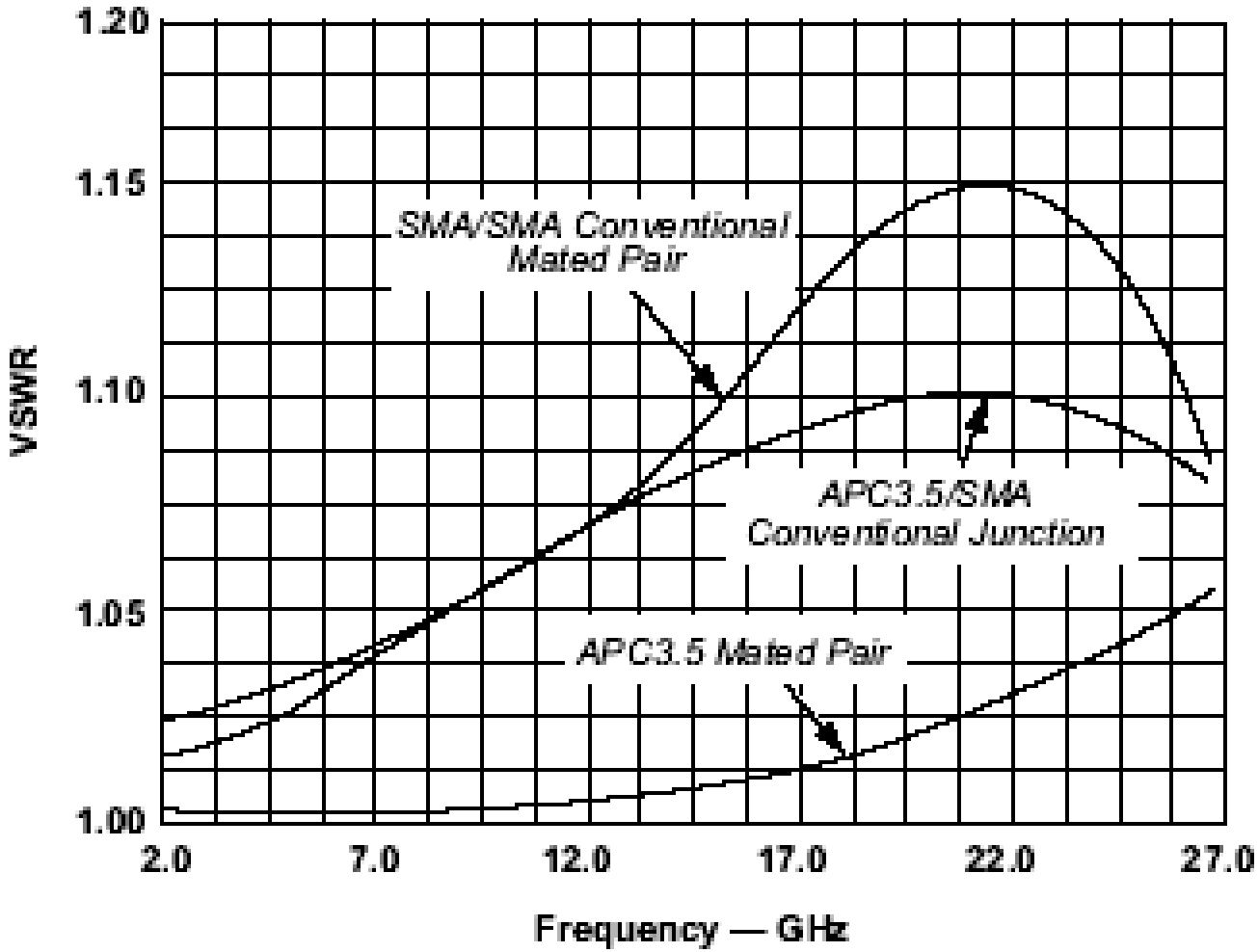


[4]

1) **Use clean calibrated standards.**
2) **Confirm with a verification kit 10cm precision airline terminated with a short. Examine the ripple.**

Delta G_t Contours: SMA vs. 3.5mm

- SMA vs. 3.5mm mated pair VSWR: Use 3.5mm or better connectors!



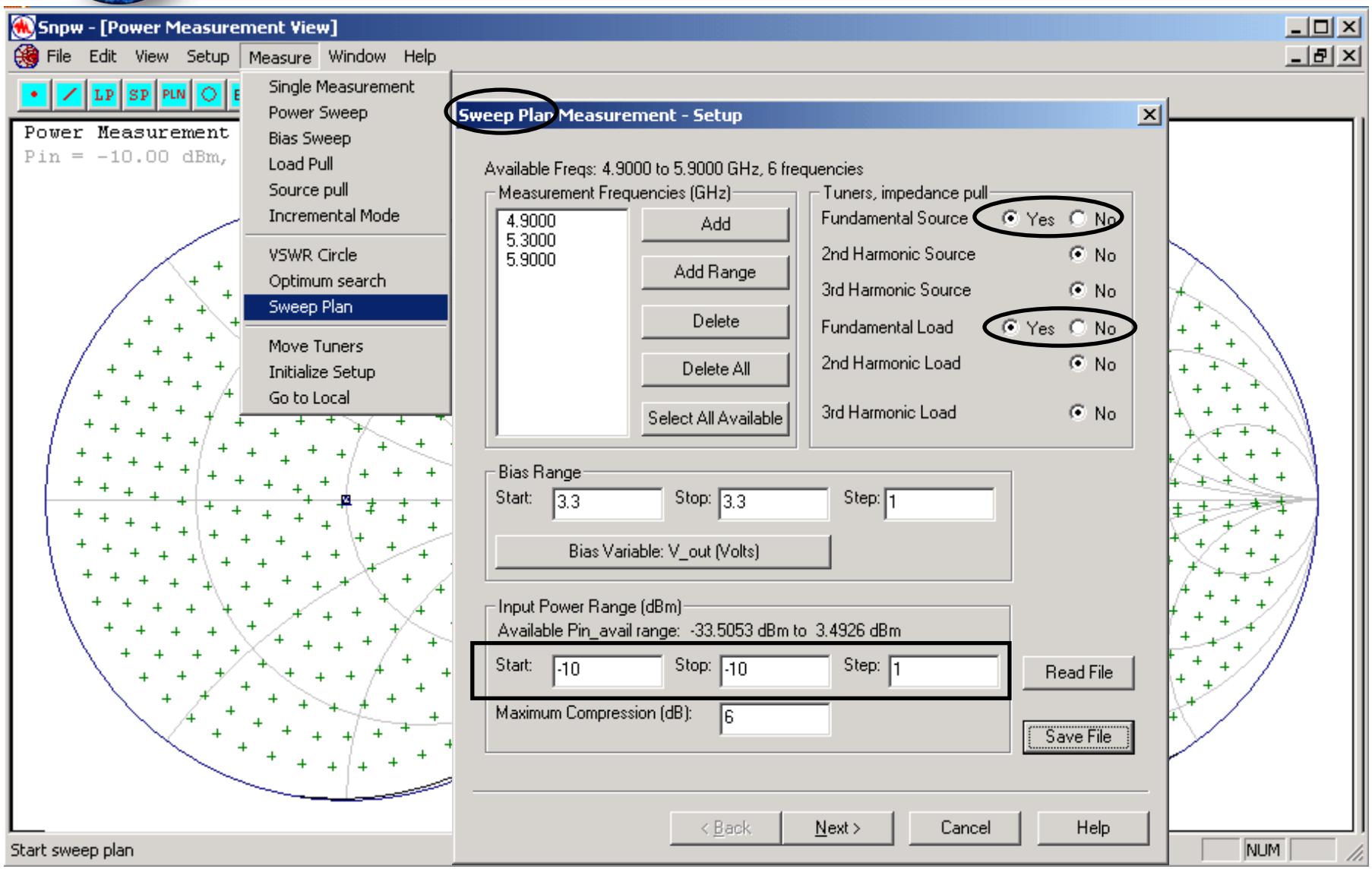
Delta G_t: Connector Repeatability.

- Connectors affect the repeatability of VNA S-Parameters.

Type	Freq.(GHz)	VSWR	Directivity	Zs Match	Torque
Type N	18GHz	1.030+0.003f	42dB	32dB	12 in.lb.
7.00mm	18GHz	1.003+0.002f	52dB	42dB	12 in.lb.
SMA	18GHz	1.050+0.005f	3XdB	2XdB	**5** in.lb.
3.50mm	26.5GHz	1.010+0.004f	44dB	34dB	8 in.lb.
2.92mm	40GHz	1.0X0+0.00Xf	40dB	34dB	8 in.lb.
2.40mm	40GHz	1.0X0+0.00Xf	38dB	33dB	8 in.lb.
1.85mm	60GHz	1.0X0+0.00Xf	36dB	29dB	8 in.lb.
Connector repeatability should be better than 50dB					
If a slotless center connector is used, increase this by 8dB.					
Overtorquing and rotating are major connector wear problems.					
Clean connectors are imperative.					

[6,7]

Delta G_t Contours Sweep Plan Use

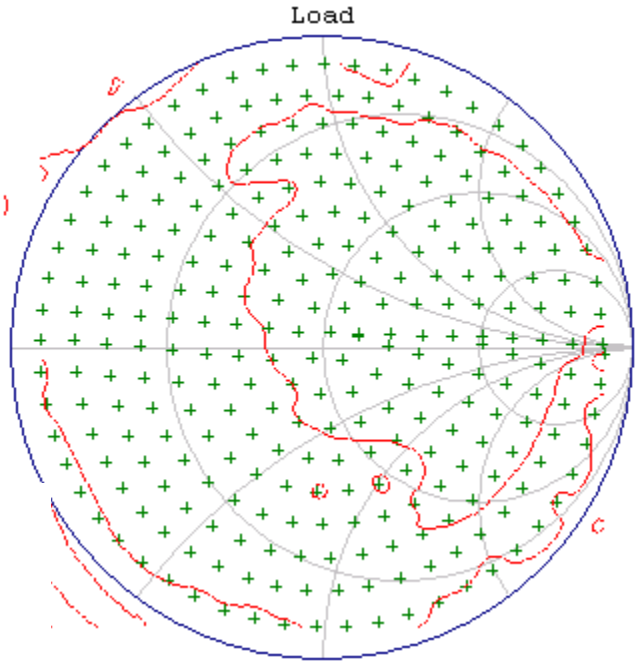


Delta G_t Contours All Points Sweep

- **Load Delta_Gt #contours = 72 @ 0.25dB/step maxDeltaGt=0.8dB**

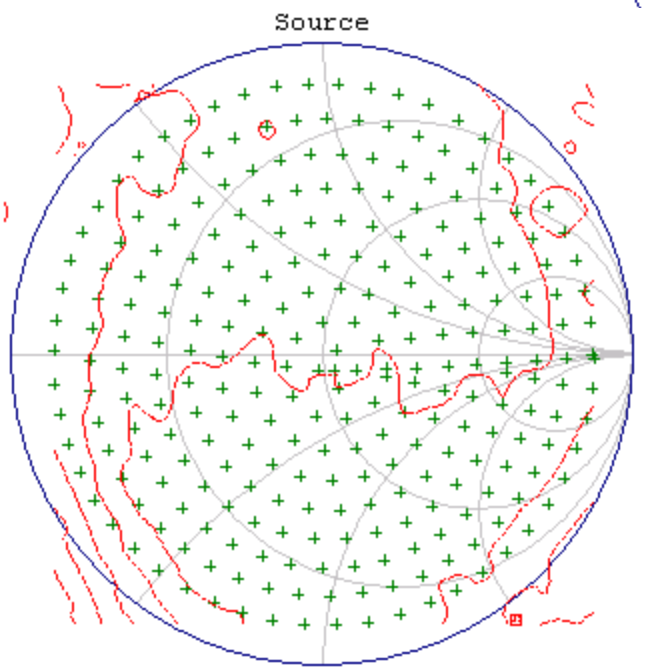
```
Swept Load Pull
Freq = 5.3000 GHz
ZSource (Ohms): 50.32 - j 0.64

Delta_Gt     max =  0.81 dB
  at -6.95 - j20.32 Ohms
(Pin_avail=-10.00 dBm, 287/287 pts)
124 contours,  0.25 dB step
(-30.00 to 0.75 dB)
Specs: OFF
```




```
Swept Source Pull
Freq = 5.3000 GHz
ZLoad (Ohms): 50.00 + j 0.00

Delta_Gt     max =  0.94 dB
  at -7.03 - j98.47 Ohms
(Pin_avail=-10.00 dBm, 267/267 pts)
124 contours,  0.25 dB step
(-30.00 to 0.75 dB)
Specs: OFF
```



- **Source Delta_Gt #contours = 3 @ 0.25dB/step maxDeltaGt=0.9dB**

Summary & Conclusions

- Delta G_t verification tests should be run prior to any Load Pull.
- G_t is the most appropriate gain parameter since it contains both source and load matching terms.
- S-Parameter characterizations are a major source of uncertainty in the Delta G_t Load Pull system test.
  - Calibrations, connectors, and cables are very important.
  - Upgrading to new cables and connectors may be required.
- Contours are an easy way to view Delta G_t data.
  - Increase the number of contours to the 128 maximum
  - Select the Max or Min value to best display results.
  - Count the number of contours to get an estimate.
  - Select points at min & max area's to determine values.
- Re-calibrate & Re-characterize to reduce errors <0.5dB.

Delta G_t Contours

- References:

1. Guillermo Gonzalez, *"Microwave Transistor Amplifiers: Analysis and Design"*, pp183 Prentice Hall 1997
2. "Measurement of Large Signal Device Input Impedance During Load Pull Applications", Maury Microwave Application Note 5C-029 [www.MauryMW.com]
3. Joel Dunsmore & Dennis Poulin, Personal Communications, Aug.~Sept. 2003.
4. "Verifying the Performance of Vector Network Analyzers", Maury Microwave Application Note 5C-026 [www.MauryMW.com]
5. "Improving SMA Tests with APC3.5 Hardware", Maury Microwave Application Note 5A-011 [www.MauryMW.com]
6. "Microwave Coaxial Connector Technology: A Continuing Evolution", Mario Maury Microwave Journal, 1990 State of the Art Reference pg. 39~59
7. Connectors: www.amphenolrf.com, www.agilent.com, www.us.anritsu.com