Product Note 50

Long and Short Term Tuner Accuracy and Calibration Repeatability

This Note includes the following topics, necessary to understand the design, operation and performance of the Programmable Microwave Tuners, CCMT, of Focus Microwaves.

- Tuner Description
- Tuner Accuracy and Reproducibility
- System Accuracy and Reproducibility
- Tuner Calibration Accuracy
- Real Tuning Accuracy

• Tuner Description

slotted transmission line, in order to generate repeatable complex microwave reflection factors.

MHz to

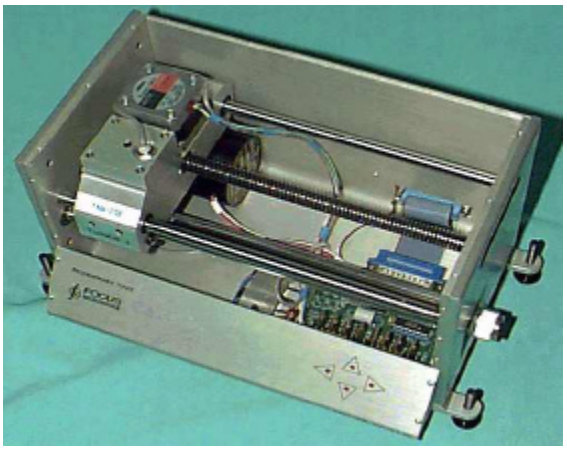
50 GHz in different multioctave bands.

cover standard WR bands from 28 to 110

CCMT-1808 (0.8-18 GHz) tuner ===

The positioning of the probe is obtained using computer controlled stepper motors and a vertical and a horizontal screw translation mechanism driven by timing belts. All CCMT tuners use the same vertical antibacklash mechanism with a resolution of 1.5 micrometer per motor step (closest distinguishable positions). Horizontally the step size varies between 3 and 25 micrometers depending on the frequency of operation (3 microns for

obtain an optimum "tuning speed/resolution" ratio. The use of timing belts to control axis positioning reduces the vibrations translated from the stepping motors to the axis and thus to the



- Both axis use spring loaded antibacklash drives. In addition the software may be directed to

direction in older tuner models. The initialization position of the tuners is detected using mechanical

specified to accuracies of +/-1 um and are tested individually and automatically before being

switch is widely used in numeric milling machines around the world, where dependency of the switch

axis movement and cutting tools is considered. After assembly and alignment each tuner is being tested for 24 hours nonstop over the maximum

released. This corresponds to average load pull testing of about 150 days (at an average of 30 full tests per day). The tuners are delivered fully calibrated and with the calibration data on a diskette

central computer and are available on request.

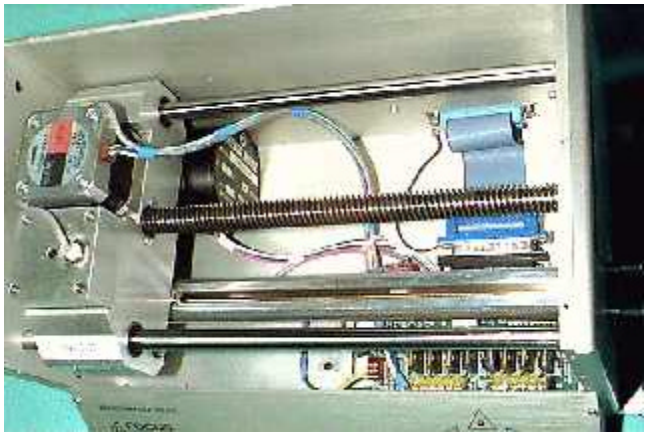
Due to the antibacklash and spring loaded driving mechanism the carriage of the vertical axis has

- The microwave probes are slotted and make light spring loaded contact with the walls of the airline for perfect RF grounding. They are made out of Bronze or Beryllium Copper. This choice

walls of the transmission line, which are made of special hard aluminum ("yellow on white metal" selflubrication). Observations of such structures over the last 15 years do not indicate a

order to insure insensitivity to mechanical vibrations and by consequence RF impedance jitter (microphonics).

- ## Maintenance



The tuners do not really need maintenance. If not used for longer time then after some use the possible residuals are carried away by the movement and they recover their original behaviour. The tuners are very rugged. They can be opened and closed without any effect on their performance. They in general survive without alterations of the calibration data a fall from the laboratory table on a hard floor, except if there is damage to the connectors.

The tuners include all their driver electronics. Control from the PC is through TTL pulses whereas the average motor bias is roughly constant. This insures a minimum of interference with other instruments in the setup and allows control with long cables (standard up to 12 feet, longer cables are also possible) for an easier setup.

- ## Handling and Calibration

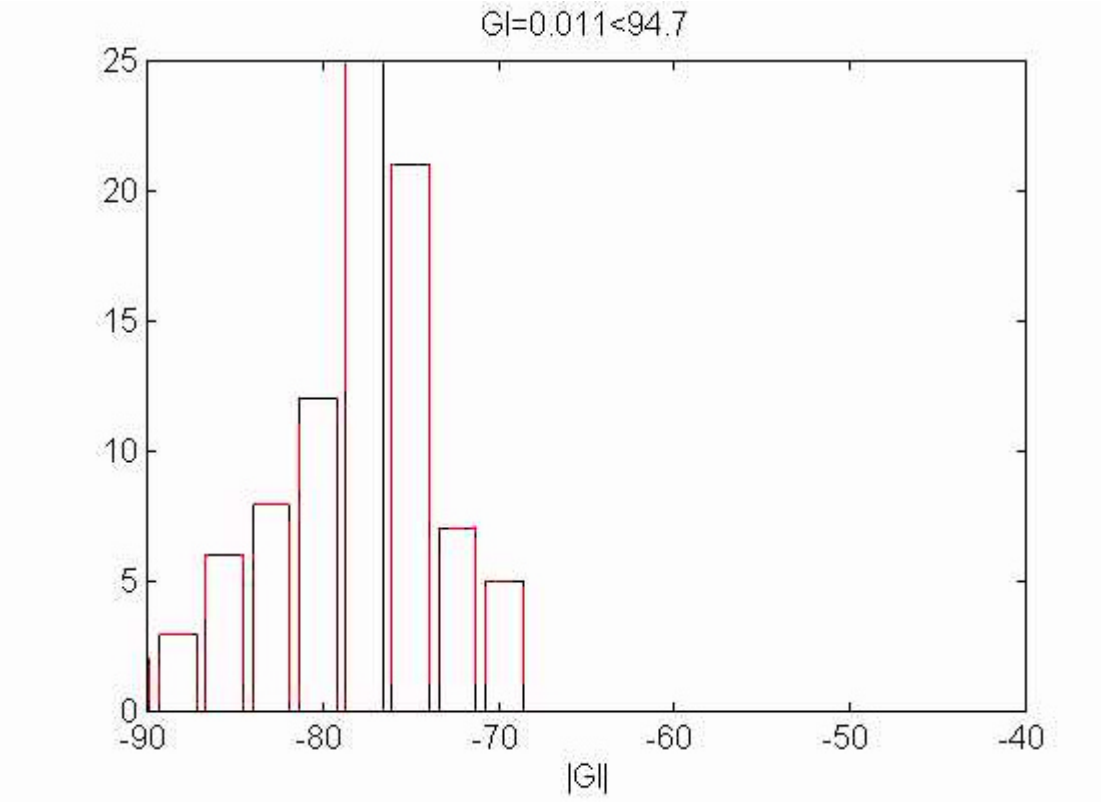
The tuners should be handled properly. Especially overtorquing the connectors is very detrimental to their accuracy and longevity. If well maintained the tuners do not need to be recalibrated more than once every few months, for intense use. There is no reasonable way to guarantee the RF performance of a moving mechanical device in changing laboratory conditions like temperature, humidity, transportation, unrecorded vibrations etc. except by recalibrating it and verifying its performance. If left unused for a longer period of time the tuners should be run a couple of hours first and then recalibrated together with all the other components of the setup.

Dual Axis Instantaneously Wideband Tuners; models -2C ===

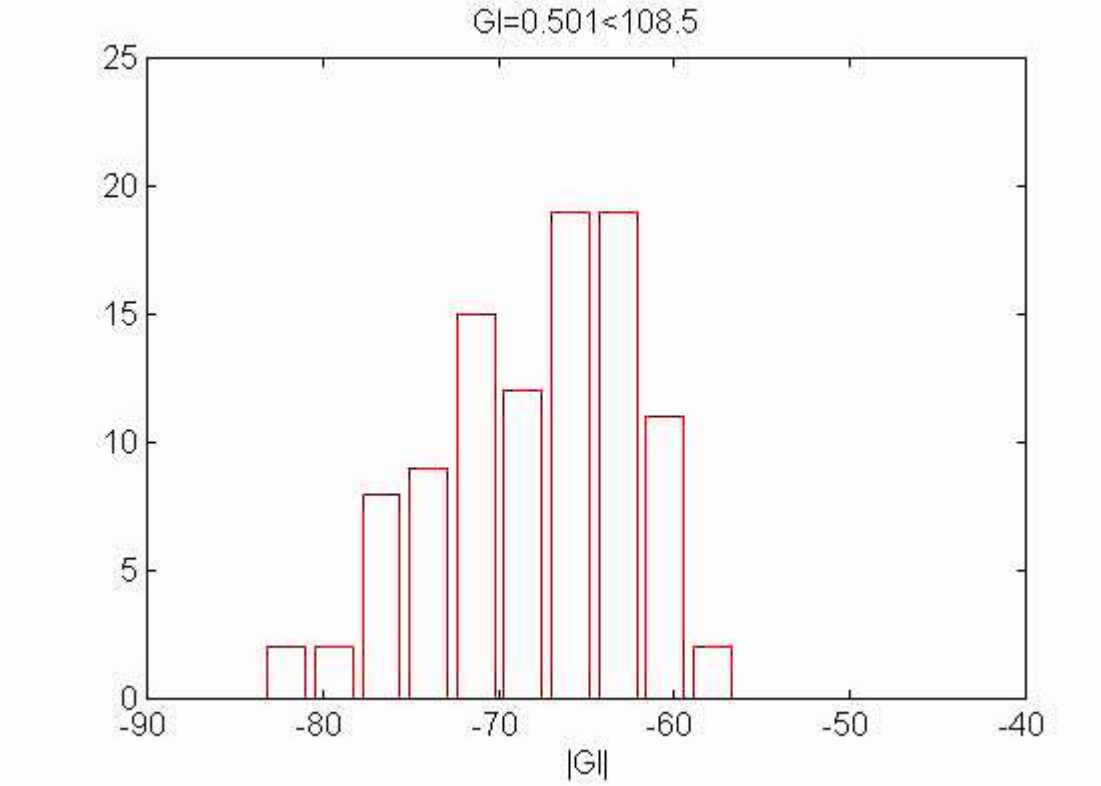
In that context special attention has to be paid to the calibration of the network analyzer in order to avoid strange phenomena like *tuners with gain* or *points outside the Smith Chart*, ***all due to insufficient quality of VNA calibrations***. Focus Microwaves considers the use of **TRL** calibration techniques throughout the frequency range from 400 MHz to 110 GHz **imperative** for good test results.

- **<u>Tuner</u> Accuracy and Reproducibility**

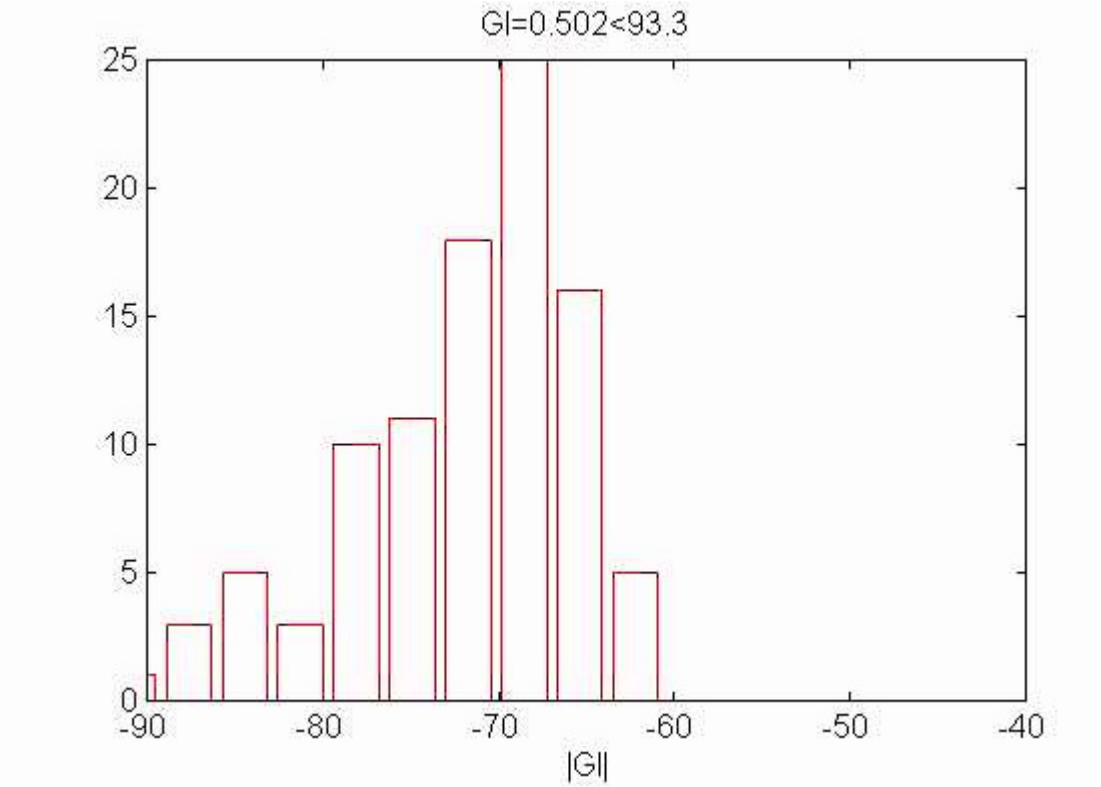
CCMT tuners are very accurate. Their accuracy exceeds the requirements for repeatable Load Pull and Noise measurements for short and for long term (over several months). We tested the RF reflection factor repeatability of a demonstration tuner in the lab (SN/294). Both amplitude and phase repeatability depend on tuner type, frequency and actually realized reflection factor. The following histogramms show typical repeatability errors of 1808 tuners in the Cellular/PCS frequency range (1 - 3 GHz). If plotted against an average value, these numbers, defined as 20*log10(|S11 - S11.av|), correspond to **worst case errors** between -65 and -55 dB at VSWR=6:1 to 10:1. The **data include the short term drift of the network analyzer** itself, which was tested by measuring using the same routine but without moving the tuners. Typical VNA measuring error also depends on the actual Gamma and is between -75 and -70 dB. The following plots show a number of measured histogramms at 3 GHz. However, it is very important to be able to verify and re-calibrate the tuners within reasonable time. FOCUS tuners can be recalibrated within minutes. Depending on the network analyzer used it takes between 2 and 8 minutes to calibrate a CCMT tuners at one frequency. The fastest calibrations are made using HP-8753E (1:58 minutes/frequency) and Wiltron 360 (2:30 minutes/frequency). This has to be compared to calibration times taking hours if not entire days of other electromechanical systems on the market.



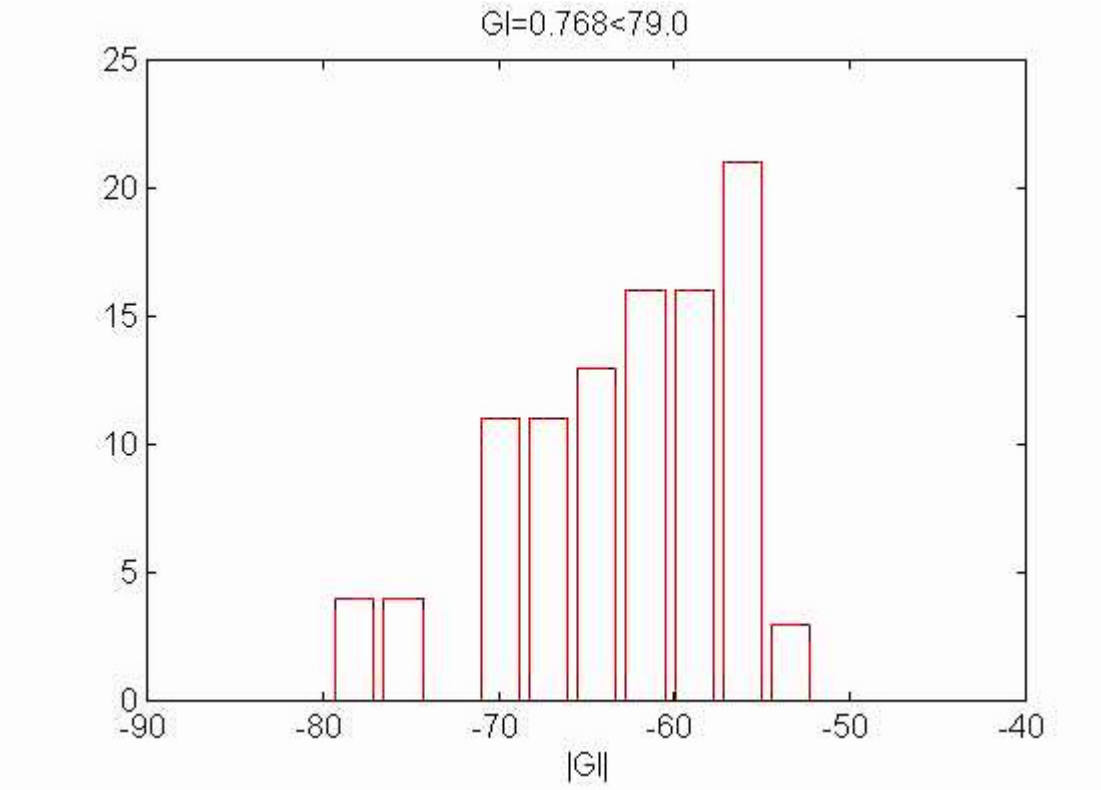
Resetability measurement of CCMT tuner at Zero Position (this plot shows the repeatability of the HP-8753D in our lab).



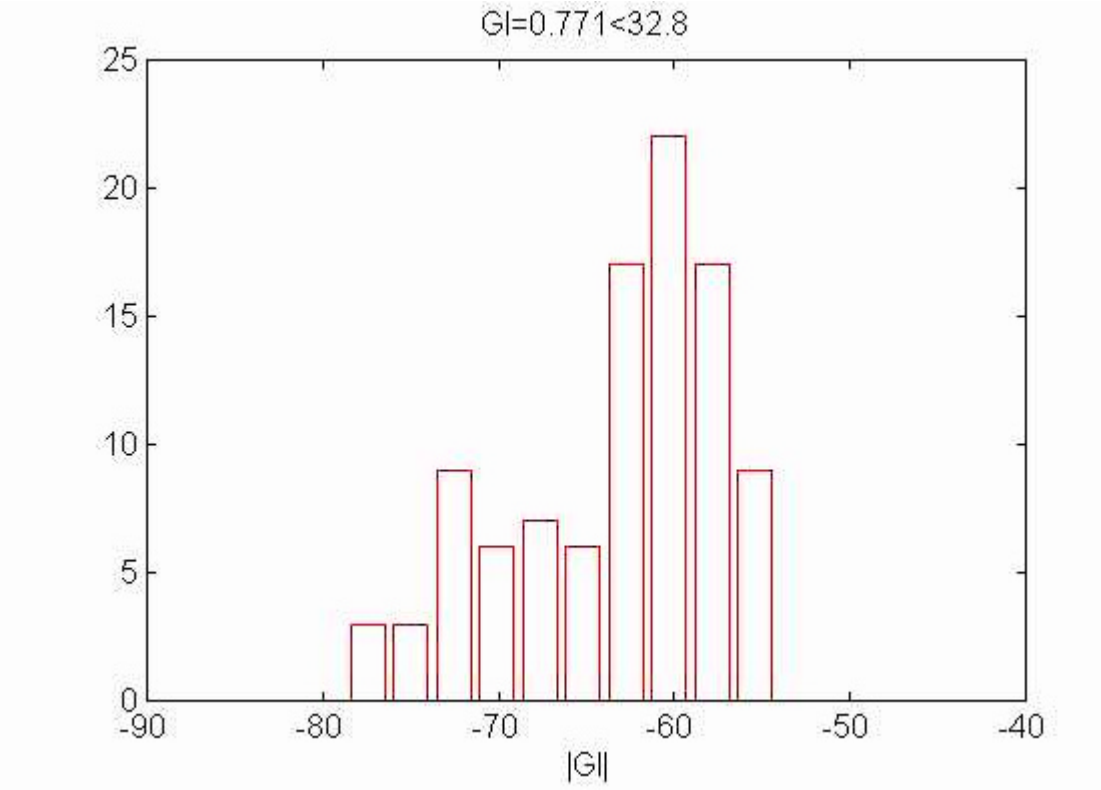
Repeatability of S11 of CCMT tuners at 3 GHz (20*log10(|S11-S11.average|) at medium S11



Repeatability of S11 of CCMT tuners at 3 GHz (20*log10(|S11-S11.average|) at medium S11



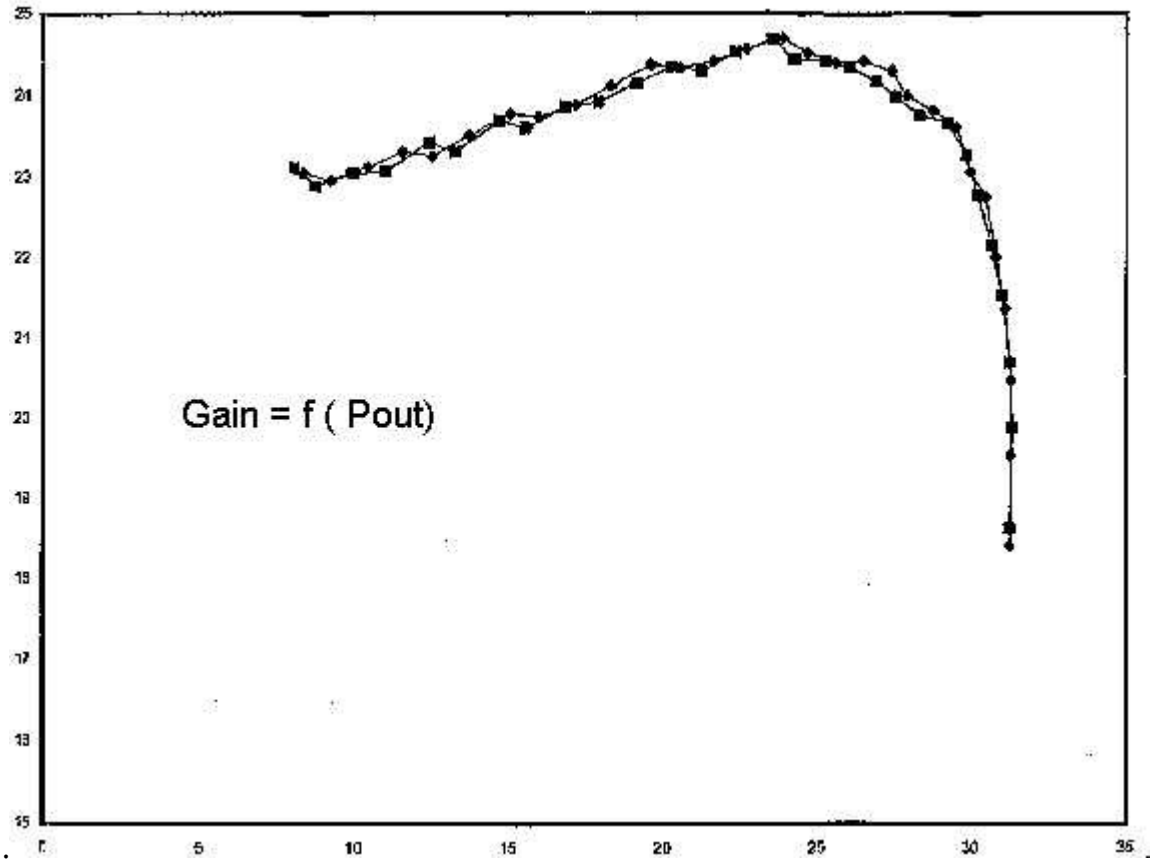
Repeatability of S11 of CCMT tuners at 3 GHz (20*log10(|S11-S11.average|) at high S11



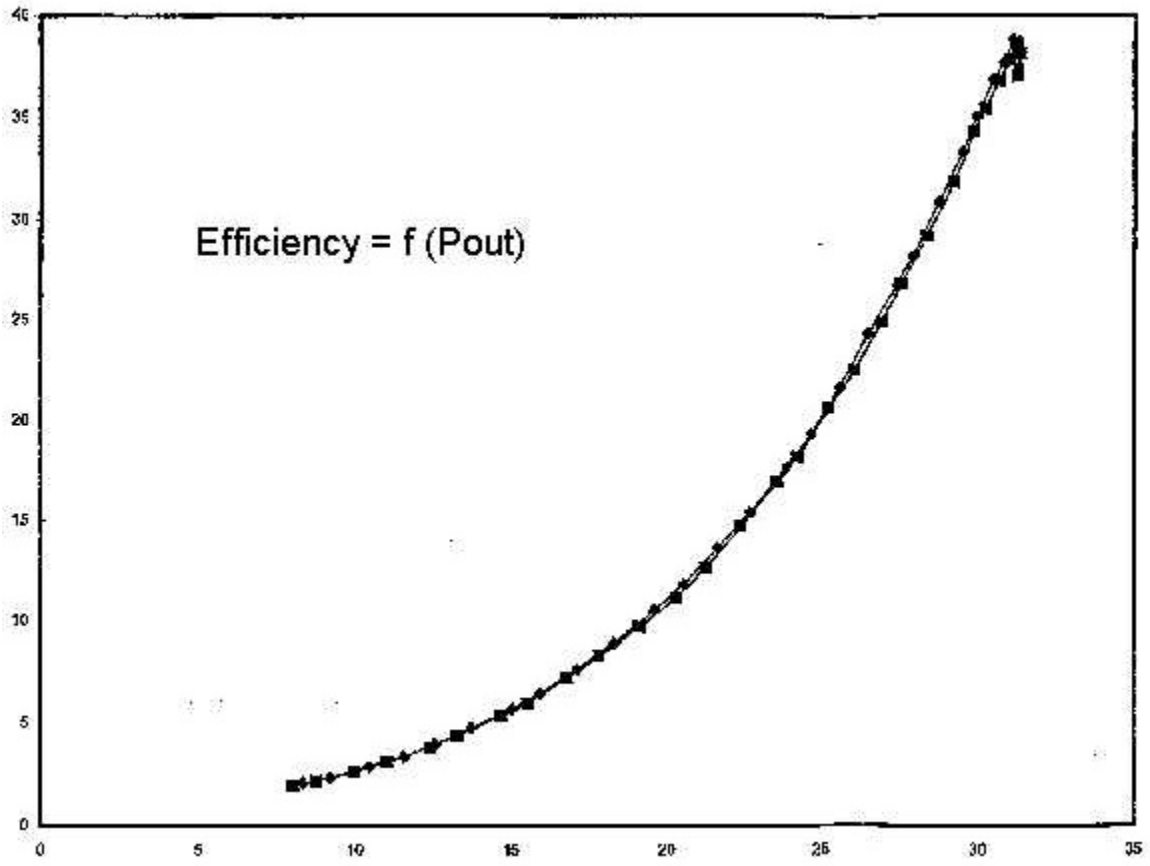
Repeatability of S11 of CCMT tuners at 3 GHz (20*log10(|S11-S11.average|) at high S11

- **System Accuracy and Reproducibility**

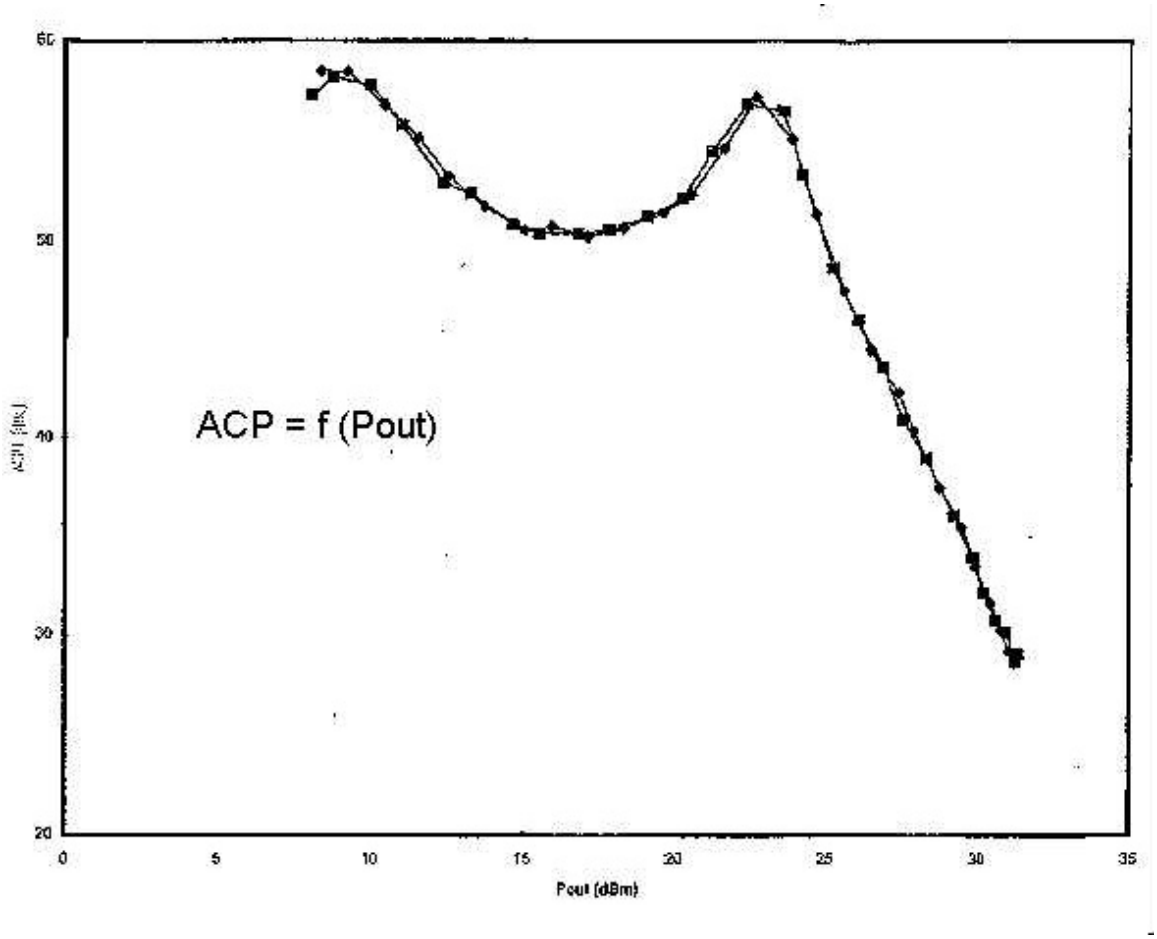
Much more important, from the **User point of view,** is **Overall System Performance**, **Reproducibility, Consistency of the Results and Reliability**. The CCMT system generates reliable and consistent data over long periods of time with or without re-calibration. The following graphs show two overlapping sets of data. The two sets correspond to measurements taken using a CCMT load pull system before and after two months continuous operation. The data has not been generated by Focus but has been supplied by some of our customers.



Overall System Repeatability: Deviation of Gain Measurement on the same device after two months of continuous operation of the Load Pull system.



Overall System Repeatability: Deviation of Efficiency Measurement on the same device after two months of continuous operation of the Load Pull system.



Overall System Repeatability: Deviation of Adjacent Channel Power Ratio (ACPR) Measurement on the same device after two months of continuous operation of the Load Pull system.

- **Tuner Calibration Accuracy**

The following test shows **how a typical CCMT tuner out of a production run reproduces the 181 points of the calibration data**. The measurements were taken at 5 GHz using a HP-8753D network analyzer with 6 GHz option, calibrated using TRL. The calibration points cover from Gamma<0.05 to Gamma 0.88. On each Gamma level the points cover 360 degrees.

Data File : 297_1.ACC @ 5.000 GHz Calibration: #297 unit 1/F, Fri Jun 27 15:08:29 1997 ----------
----

Cal Point --- dS11 dS12 dS21 dS22 [dB] : Vector Difference = 20*log10(delta) ----------
----

Center of Smith Chart

1: -48.223 -57.399 -70.424 -54.961 "this line shows the repeatability of the 8753D"

Gamma=0.1

2: -58.342 -62.271 -52.878 -51.315

3: -78.002 -59.333 -54.495 -56.911

4: -74.934 -57.823 -61.604 -66.418

5: -55.074 -56.289 -65.496 -69.735 Reproduction of Tuner Cal Data

Gamma=0.2 all numbers: (20*log10(delta Sij))

6: -58.344 -60.626 -56.802 -55.937

7: -61.023 -55.798 -53.913 -65.225

8: -58.805 -56.546 -61.671 -74.226

9: -57.099 -59.549 -61.674 -71.905

10: -62.404 -56.133 -58.307 -60.443

11: -54.427 -53.565 -54.196 -72.716

12: -63.998 -62.126 -57.263 -53.450

13: -56.307 -58.067 -56.263 -56.647

Gamma=0.3

14: -52.982 -61.656 -59.160 -61.434

15: -77.870 -63.597 -56.597 -54.988

16: -53.237 -65.908 -51.320 -56.519

17: -63.672 -54.623 -65.013 -51.684

18: -63.114 -73.263 -57.068 -55.253

19: -55.730 -58.961 -56.961 -54.329

20: -60.498 -69.763 -52.066 -52.947

21: -52.095 -54.996 -57.004 -54.560

22: -55.588 -68.552 -67.890 -63.834

23: -67.093 -55.647 -53.902 -57.603

24: -55.103 -51.104 -56.385 -52.770

25: -56.787 -56.725 -58.818 -56.436

Gamma=0.4

26: -53.967 -59.607 -69.972 -52.642

27: -50.427 -54.825 -51.850 -54.899

28: -53.418 -63.324 -57.578 -48.706

29: -69.440 -56.952 -67.208 -58.318

30: -63.466 -56.244 -55.782 -56.756

31: -57.146 -65.937 -58.693 -63.019

32: -50.273 -52.526 -62.029 -63.379

33: -54.624 -61.172 -60.100 -56.566

34: -53.847 -55.165 -59.473 -58.812

35: -51.843 -49.319 -57.478 -52.467

36: -50.202 -76.415 -52.282 -52.006

37: -48.942 -61.183 -61.999 -56.940 Reproduction of Tuner Cal Data

38: -51.205 -60.527 -57.624 -53.593 all numbers: (20*log10(delta Sij))

39: -52.532 -52.317 -68.096 -53.456

40: -51.270 -52.931 -55.678 -51.516

41: -50.788 -58.671 -54.029 -51.885

Gamma=0.5

42: -49.402 -56.041 -58.139 -56.839

43: -65.869 -60.593 -56.286 -52.200

44: -66.881 -51.439 -62.994 -52.238

45: -69.100 -65.140 -55.385 -55.057

46: -57.223 -55.215 -63.413 -58.452

47: -57.813 -59.839 -62.748 -53.990

48: -52.138 -58.421 -61.212 -59.872

49: -56.568 -51.762 -56.141 -60.444

50: -66.608 -54.547 -54.596 -52.778

51: -57.447 -58.391 -51.899 -51.193

52: -56.260 -62.244 -63.109 -52.874

53: -53.272 -61.744 -56.905 -66.507

54: -46.883 -48.415 -52.704 -52.808

55: -51.065 -61.319 -51.467 -51.137

56: -56.608 -61.997 -61.287 -60.233

57: -51.925 -55.251 -56.070 -53.440

58: -56.745 -63.711 -55.959 -54.172

59: -55.376 -53.561 -52.608 -57.674

60: -59.543 -53.071 -58.425 -51.794

61: -65.849 -54.712 -71.272 -50.493

Gamma=0.6

62: -58.218 -63.775 -52.022 -50.153

63: -56.152 -53.755 -58.872 -54.918

64: -61.488 -61.382 -58.877 -55.573

65: -60.169 -53.197 -52.956 -51.549

66: -62.479 -55.772 -53.832 -51.922

67: -50.778 -52.122 -52.071 -52.763

68: -52.921 -53.853 -55.216 -52.409

69: -57.453 -54.630 -45.257 -50.808 Reproduction of Tuner Cal Data

70: -61.478 -54.908 -51.842 -56.127 all numbers: (20*log10(delta Sij))

71: -52.223 -56.451 -52.014 -51.164

72: -54.274 -52.818 -54.977 -59.688

73: -53.722 -68.263 -57.079 -51.101

74: -52.247 -60.625 -53.431 -69.787

75: -50.806 -56.877 -55.635 -50.617

76: -57.982 -64.122 -61.703 -56.085

77: -51.592 -53.258 -52.230 -55.518

78: -53.420 -55.105 -60.447 -64.580

79: -58.392 -59.267 -63.180 -54.223

80: -48.584 -53.421 -53.608 -48.986

81: -52.479 -51.622 -49.693 -53.180

82: -51.448 -55.756 -54.712 -54.660

83: -57.289 -59.301 -56.306 -64.303

84: -53.026 -57.714 -55.630 -52.968

85: -64.714 -54.606 -56.321 -52.890

Gamma=0.7 (VSWR = 5.7:1)

86: -46.682 -55.340 -59.091 -55.363

87: -61.491 -58.642 -67.662 -50.197

88: -67.128 -51.674 -51.100 -57.105

89: -60.998 -48.145 -48.734 -46.846

90: -70.456 -51.986 -51.785 -50.623

91: -58.810 -49.708 -59.036 -53.211

92: -51.715 -57.042 -53.007 -51.768

93: -61.562 -53.435 -59.352 -53.894

94: -61.421 -54.437 -48.891 -50.039

95: -55.518 -51.513 -48.820 -52.290

96: -55.006 -53.765 -59.701 -47.584

97: -55.052 -55.118 -50.010 -54.068

98: -55.469 -53.429 -49.560 -47.247

99: -54.860 -58.686 -55.757 -55.522

100: -57.741 -51.513 -54.547 -56.717

101: -51.816 -56.418 -54.267 -54.169

102: -57.107 -56.941 -50.092 -55.709

103: -52.560 -52.398 -58.480 -49.218

104: -50.961 -62.038 -57.255 -53.441

105: -47.042 -52.437 -47.825 -53.556

106: -50.115 -54.223 -49.525 -48.688

107: -55.317 -56.550 -55.442 -53.646

108: -55.305 -47.401 -52.198 -49.567

109: -54.871 -48.599 -54.410 -54.924

110: -55.592 -53.331 -63.265 -55.226

111: -57.476 -49.575 -46.579 -45.645

112: -52.755 -57.664 -53.778 -50.026

113: -56.491 -53.106 -64.041 -48.684

Gamma=0.78 (VSWR = 8:1) Reproduction of Tuner Cal Data

114: -53.940 -63.988 -55.937 -54.048 all numbers: (20*log10(delta Sij))

115: -60.309 -52.140 -58.566 -51.067

116: -51.699 -54.177 -51.464 -49.133

117: -61.952 -55.811 -58.220 -52.520

118: -48.731 -59.187 -66.577 -54.973

119: -56.596 -61.115 -59.287 -54.675

120: -49.162 -48.860 -53.679 -54.468

121: -50.477 -57.488 -50.603 -60.558

122: -53.007 -51.971 -51.419 -51.335

123: -49.788 -53.233 -49.937 -52.365

124: -47.562 -53.323 -51.426 -48.683

125: -49.265 -54.423 -57.469 -51.900

126: -48.863 -50.391 -52.043 -52.215

127: -46.990 -50.764 -50.980 -46.721

128: -48.030 -53.088 -52.341 -50.699

129: -44.303 -49.526 -59.561 -57.657

130: -49.099 -49.197 -57.505 -47.323

131: -46.554 -54.629 -50.291 -51.719

132: -50.256 -50.270 -48.984 -48.674

133: -46.018 -49.979 -50.555 -48.900

134: -45.567 -48.268 -54.042 -49.353

135: -45.986 -52.336 -56.447 -47.604

136: -49.075 -47.480 -51.632 -47.047

137: -46.707 -48.509 -49.947 -45.442

138: -45.914 -50.481 -51.796 -43.933

139: -48.733 -48.410 -47.499 -47.172

140: -49.563 -52.280 -51.689 -48.197

141: -56.499 -49.653 -47.568 -46.778

142: -47.139 -48.627 -50.507 -48.405

143: -45.310 -47.640 -46.742 -46.278

144: -48.014 -49.238 -48.346 -45.975

145: -51.327 -49.387 -46.989 -44.265

Gamma=0.87 (VSWR = 15:1) Reproduction of Tuner Cal Data

146: -43.293 -53.421 -53.721 -55.084 all numbers: (20*log10(delta Sij))

147: -66.217 -52.698 -49.322 -47.830

148: -51.647 -51.639 -48.900 -45.017

149: -51.605 -52.603 -48.878 -45.066

150: -51.150 -46.755 -44.003 -45.707

151: -48.615 -49.058 -50.268 -46.902

152: -54.796 -51.225 -48.831 -45.282

153: -49.998 -49.703 -50.335 -46.635

154: -46.029 -47.449 -45.686 -47.998

155: -46.718 -49.522 -48.672 -46.256

156: -48.677 -47.026 -56.391 -47.987

157: -46.488 -46.154 -47.794 -44.831

158: -46.492 -47.102 -47.031 -51.786

159: -44.966 -46.296 -47.766 -47.802

160: -52.452 -50.383 -51.061 -52.777

161: -44.041 -48.723 -51.060 -51.148

162: -47.599 -47.722 -47.706 -46.542

163: -53.355 -49.166 -50.704 -50.678

164: -46.794 -47.602 -48.711 -44.463

165: -44.044 -45.318 -46.295 -45.000

166: -46.040 -47.688 -49.667 -46.504

167: -44.363 -47.503 -49.047 -47.278

168: -47.951 -48.381 -46.642 -45.975

169: -46.431 -44.207 -45.851 -44.176

170: -51.993 -50.832 -52.651 -53.710

171: -55.283 -55.390 -52.682 -44.118

172: -59.453 -55.373 -53.573 -45.208

173: -57.079 -46.461 -45.610 -47.066

174: -62.938 -53.257 -53.353 -48.713

175: -48.897 -47.774 -45.494 -46.548

176: -52.752 -46.097 -49.342 -47.942

177: -45.985 -49.112 -65.252 -48.712

178: -58.307 -50.471 -52.066 -45.499

179: -65.084 -47.625 -47.214 -45.310

180: -50.437 -47.880 -48.321 -45.128

181: -63.502 -56.664 -55.149 -46.853

- ## **Real Tuning** Accuracy

The CCMT system has an important basic capability that is not available from the other tuner systems on the market: The CCMT software provides almost **continuous tuning over the entire Smith Chart** taking full advantage of the CCMT tuner's high resolution capability (10,000,000 impedance states at 1 GHz); instead of some impedance switching to precalibrated points, of the other systems. To be able to do this the CCMT software incorporates *patented calibration routines and interpolation algorithms* which describe best the tuner's physical behaviour. Only the Tuner System of Sarnoff-Labs (not available any more) had this real tuning capability, but lacked accuracy and bandwidth. We present here some typical Verification Test Results, as measured on a typical production unit (tuner S/N 207). The test is applied systematically to all tuners before shipment; the test consists of sending the tuner to 25 IMPEDANCES (not physical positions !) on the Smith Chart at Gamma=0.65, equally spaced in phase, and compare the reading of the Network Analyzer to the tuned impedance. The tuned points are **interpolated points,** so the **error shown includes both tuner repeatability and interpolation accuracy**. This test is performed several times and the error registered is the absolute value of the vector difference between measured and synthesized reflection factor (expressed in dB).

PERFORMANCE VERIFICATION
Date of Test = Fri Aug 25 17:05:08 1995
File name = C:\CCMT\DATA\207_4.PRF
CAL comment = s/n 207-1816-hr/4, Fri Aug 25 15:15:16 1995
Calibrated at 181 points
Cycle - **Tuning Error [dB]** (25 points / freq)

GHz	1	2	3	4	5	Average
4.0	-57.8	-43.8	-57.2	-51.3	-48.6	-51.7
5.0	-51.3	-47.6	-48.8	-44.5	-51.1	-48.7
6.0	-54.2	-47.3	-54.1	-46.6	-51.7	-50.8
7.0	-57.3	-45.1	-54.5	-50.9	-48.5	-51.3
8.0	-40.9	-48.3	-41.7	-47.1	-45.8	-44.8
9.0	-52.5	-45.2	-51.9	-45.9	-45.6	-48.2
10.0	-54.4	-41.3	-49.8	-39.4	-44.4	-45.9
11.0	-56.1	-43.9	-50.8	-45.6	-45.2	-48.3
12.0	-45.1	-48.5	-42.8	-46.3	-40.3	-44.6
13.0	-43.0	-52.2	-45.7	-44.9	-54.8	-48.1
14.0	-41.6	-51.5	-40.0	-46.6	-37.9	-43.5

```
15.0  -53.2 -39.4 -49.0 -36.9 -44.6 -44.6
16.0  -55.8 -38.4 -47.6 -36.5 -43.9 -44.5
17.0  -42.9 -46.5 -41.1 -50.7 -40.0 -44.2
18.0  -38.0 -51.8 -38.9 -48.8 -41.0 -43.7
```

For more information about the CCMT System's Measurement capability click here.