MICROWAVE POWER SENSOR LIMITATIONS

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Scope of Talk

- RF power sensor uncertainties

- Test equipment and measurement methods

Background

- Interest in metrology and the accuracy limits of RF power
- Considerable experience with power meters
- The arrival of a Boonton generator pushed me to explore the accuracy of sensors and their linearity.
- I was only able to resolve four digits accurately with the calorimeter.
- It turns out that is good enough.

Definitions

- **Bolometer/thermistor**- Resistance changes with exposure to RF
- **Thermocouple**- Voltage is generated from two dissimilar metals exposed to the heat of a load.
- **Thermopile**- a series of thermocouples exposed to the heat of a load resistor.
- **Diode Sensor-** generates a DC voltage through diode rectification.

Traceability tools

- **At Boonton**
- NIST Micro Calorimeter for DC substitution
- Wandel and Goltermann EPM 1 –
- Trombone attenuator at 30MHz
- Boonton 2520 .05db accuracy

- **At HP**
- 0dbm thermistor reference sensor. (HP 478 h75)

Micro calorimeter at NIST

Calibration is done at 30-50Mhz

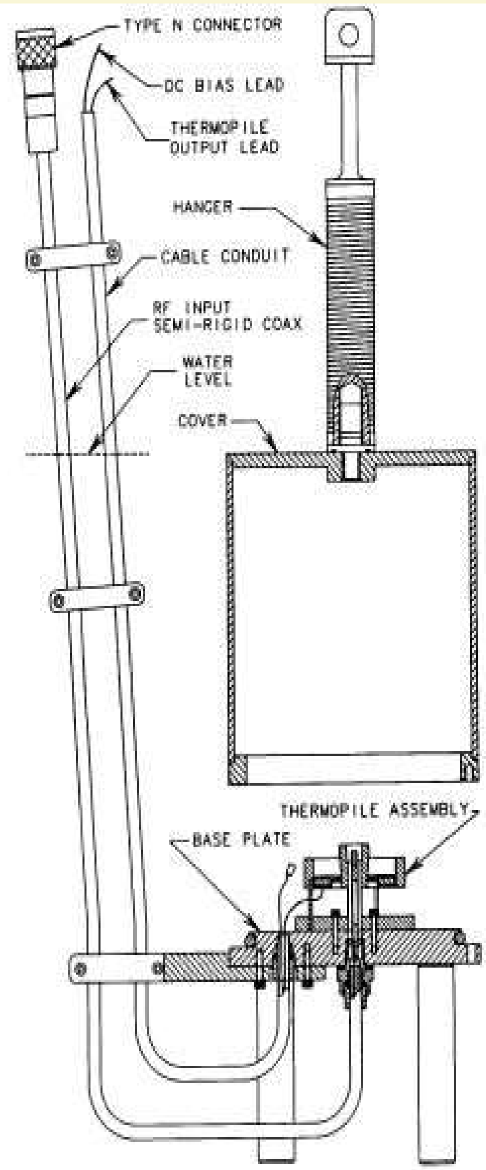


Figure 2-7. Schematic cross-section of the NIST coaxial microcalorimeter at Boulder, CO. The entire sensor configuration is maintained under a water bath with a highly-stable temperature so that RF to DC substitutions may be made precisely.

Wandel and Goltermann
EPM-1
1mw power meter

Boonton 2520- 30MHz, -70 to +20 DBm.
Accuracy is .05db

2520 Meter Calibrator Output

- Cal output is .7% to 1.2% accuracy
- Based on Standards lab equipment at Boonton
  - Thermopile DC substitution
  - Calibrated trombone attenuator at 30MHz
  - In Cal if .988mw to 1.012mw- 1.2%
- Far exceeds the measurement accuracy.

Lab standard at HP

Selected for low SWR. 10MHz to 500MHz

Used price $1,400 HP478-H75

Agilent- N432A

New Life for the HP 478 power sensors- at $8800

- Internal rather than External DVM
- Still have inherent inaccuracies of the sensor.
  - SWR
  - Sensor Linearity

AIL Type 32
Trombone Attenuator

My Lab Traceability

- **DC source calibration- HP34401A** DVM Calibrated to .0002%
- **DC Power source- Valhalla 2700b**
- **Transfer standard- PRD 685** Calorimetric Thermopile (1mw= 100uv)

Power meter - HP 8482B sensor on an HP **E4418b**. In Cal

RF Power source- Boonton 2520 RF power calibrator. 30MHz +20to -70DBM

- Accuracy .05DB or 1.2%

PRD 670 Thermopile Calorimeter
.2236v (1mw) input =
.1160v output

What are We Up against?

- The lab uncertainties are about 0.7% accuracy.
- The practical sources of uncertainty can push us above 10%.
- What is the list of uncertainties in measurement with a microwave power sensor?
- What factors contribute the most to inaccuracy?

Sum of Uncertainties- Worst Case

The real problem -

Series	Distribution	MA24002A	MA2442D	MA2472D
Instrumentation Accuracy	Rectangular	0.50%	0.50%	0.50%
Sensor Linearity	Rectangular	1.80%	1.80%	1.80%
Noise, 256 Average	Normal at 2σ	0.01%	0.01%	0.00%
Zero Set and Drift	Rectangular	0.06%	0.04%	0.01%
Mismatch Uncertainty	Rectangular	3.67%	3.84%	4.49%
Sensor Cal Factor Uncertainty	Normal at 2σ	1.60%	0.79%	0.83%
Reference Power Uncertainty	Rectangular	1.20%	1.20%	1.20%
Reference to Sensor Mismatch Uncertainty	Rectangular	0.36%	0.36%	0.44%
Temperature Linearity, ±20 °C	Rectangular	1.00%	1.00%	1.00%
RSS, Room Temperature	–	4.59%	4.52%	5.10%
Sum of Uncertainties, Room Temperature	–	9.19%	8.55%	9.27%
RSS ±20 °C	–	4.70%	4.63%	5.20%
Sum of Uncertainties ±20 °C	–	10.19%	9.55%	10.27%

3.8% mismatch?

Power Range Vs. Uncertainty

HP 432 and 8478

HP 8481A
HP 8481D

E4412A EPROM Sensor

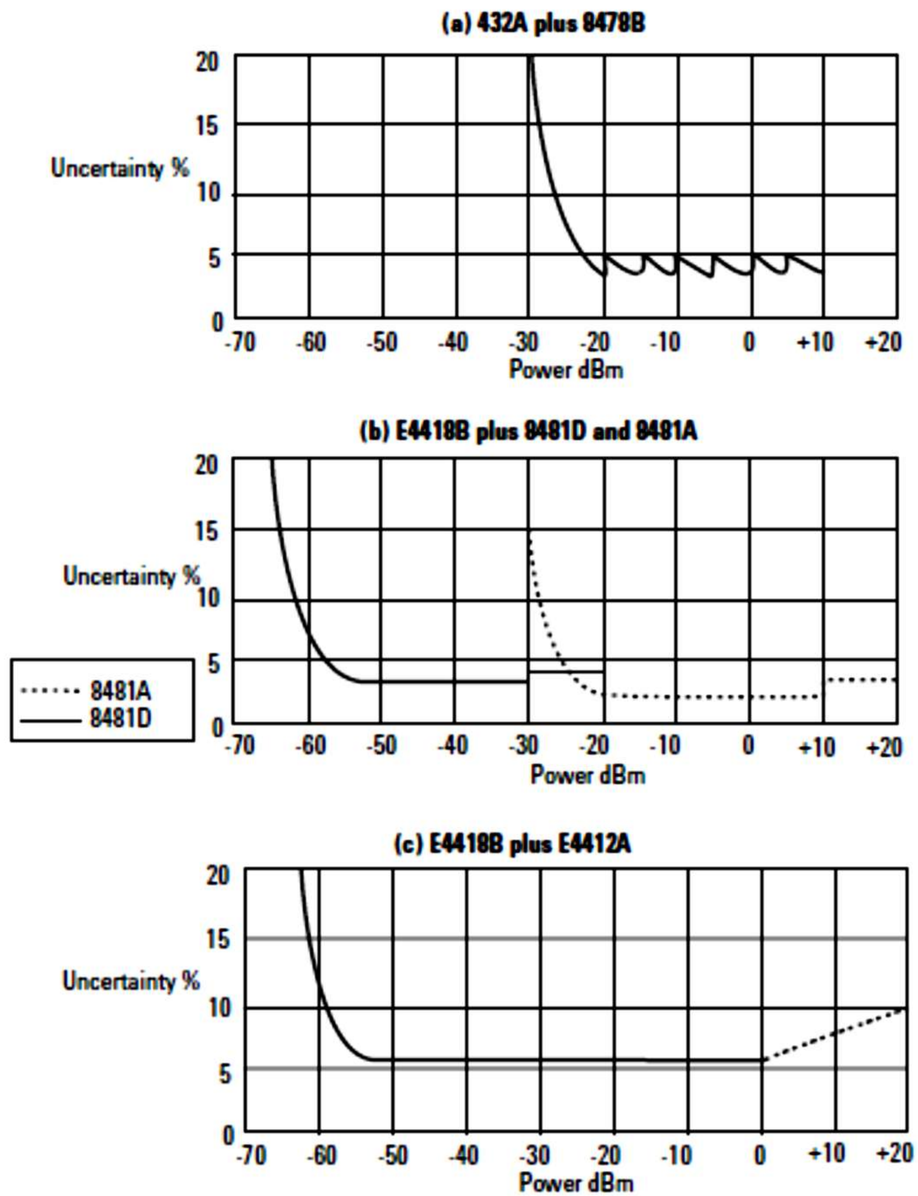
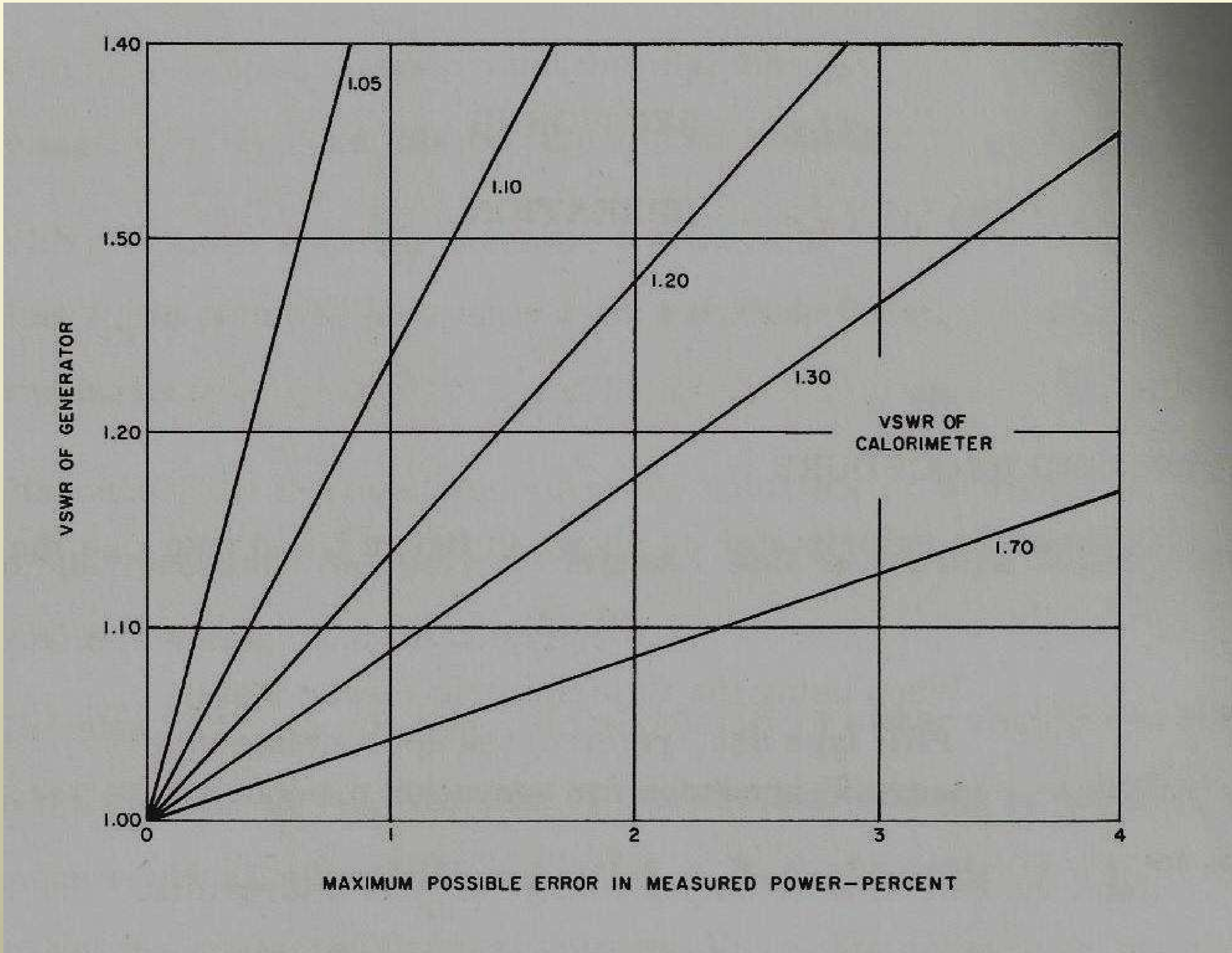


Figure 8-1. RSS uncertainty vs. dynamic power range from data sheet specs for source SWR = 1.15 (ρs =0.07) and f = 2 GHz: (a) Analog thermistor mount system. (b) E4418B digital power meter system using 8481D diode and 8481A thermocouple sensors. (c) E4418B digital power meter and E4412A PDB extended-range sensor. RSS-combining method is the same as used in Chapter VII.

Mismatch and Accuracy

- The SWR of both the source and sensor have to be
- Below 1.10:1 in order to add no more than .5% error to the reading. (20DB RL)
- At 1.2 SWR the Inaccuracy is 1.5% (9DB RL)
- Anything higher at either end due to any factor, and the inaccuracy skyrockets.
- Sensor SWR and generator SWR are key to the accuracy problem.


1.40
1.50
1.20
1.10
1.00
VSWR OF GENERATOR
1.05
1.10
1.20
1.30
1.70
VSWR OF
CALORIMETER
0
1
2
3
4
MAXIMUM POSSIBLE ERROR IN MEASURED POWER—PERCENT

Sensor SWR

Input coupling
Capacitor affects
Low freq. response

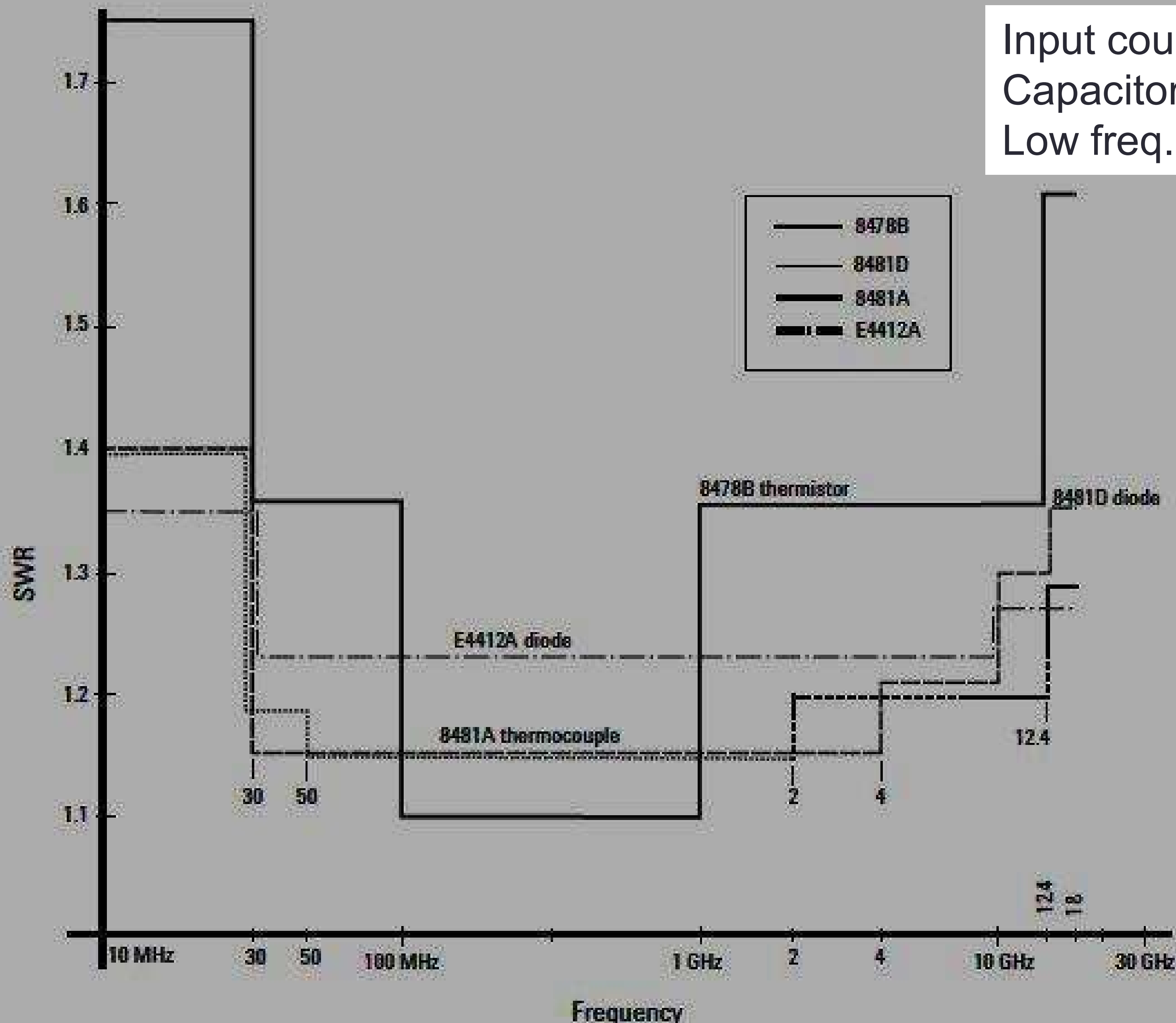
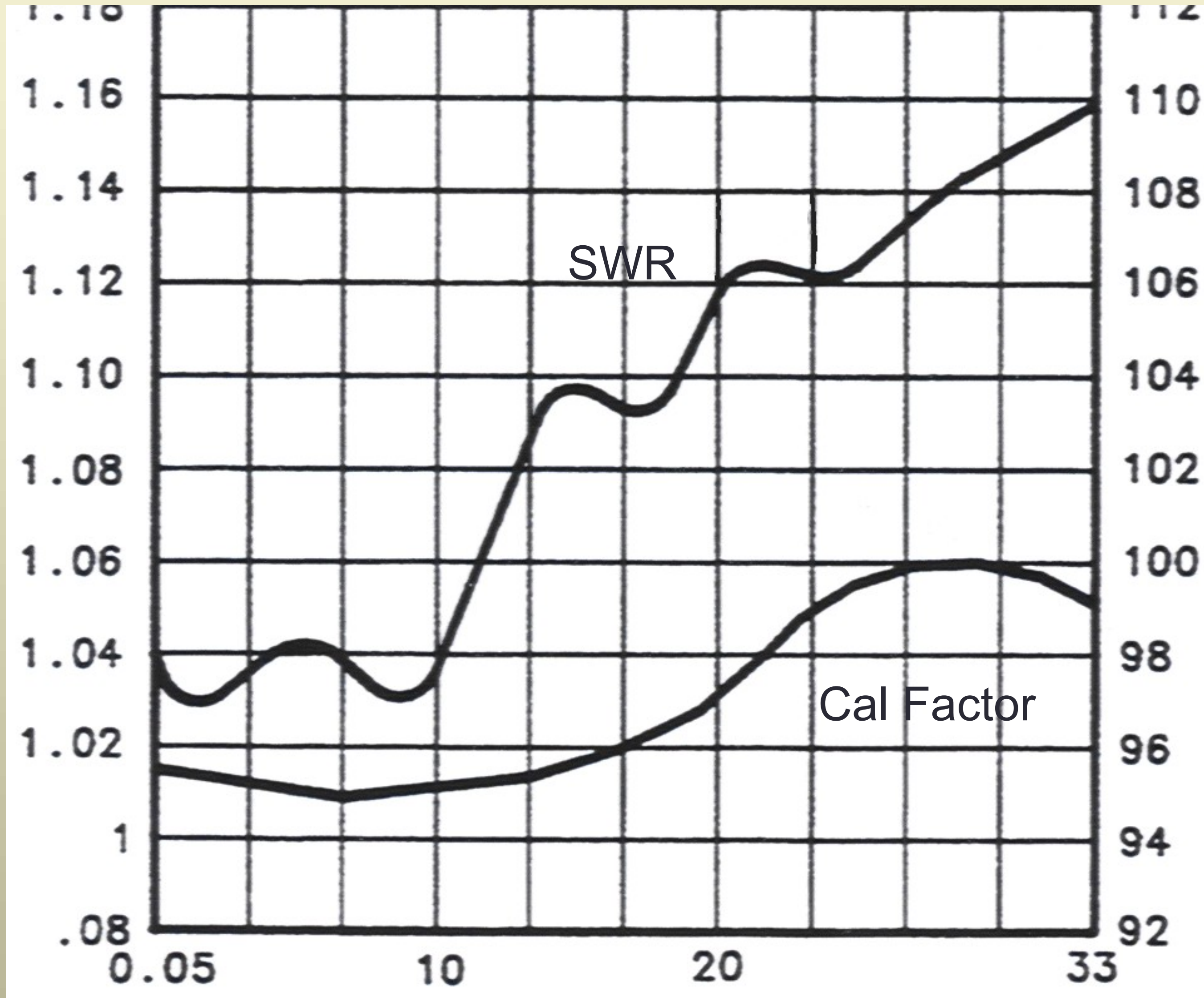


Figure 8-2. A comparison of specified SWR limits for the 8478B thermistor mount, 8481A thermocouple power sensor, 8481D PDB power sensor, and E4412A PDB sensor.

Cal Factor/SWR
vs Frequency for HP 18 GHz Sensor

SWR



Cal Factor

Accuracy Losses

- 0.5% **Meter**- fixed
- 4.5% **Temperature**- variable 1%?
- 1.8% **Sensor** Linearity- fixed
- 3.8% **Mismatch** loss- 1-2%
- <u>1.2% **Calibrator** calibration- .7% more likely</u>
- 11.8% **total uncertainty** of reading worst case.
- With some attention to detail, **6% is more like it.**

Perspective

- Modern meters like the E4418b/E4412a & Anritsu ML3437a
  - Use averaging through DSP
  - Have stored factors in the sensor
  - Compensate for temperature
  - Use computers to characterize both the meter and sensor.
- The N432A is in a class by itself.
- Modern meters may constrain the errors to 5%.
- Meters like the HP 436 may do a pretty good job if you have a calibrated sensor, esp. with an external DVM

- Note- **dropping the sensor or applying too much power**, even for a second, can completely change the sensor linearity and accuracy

Conclusion

- SWR of the load and sensor are key factors
- Sensor Linearity is largely unknown
- **An old meter(HP436) with a great sensor is better than a great meter with a cheap sensor.**

Resources

- HP Application Note on RF Power Measurement
- 64-1C
- PRD Calorimeter Manuals 680 series.
- Anritsu manual on 2400 power sensors
  - https://www.atecorp.com/ATECorp/media/pdfs/data-sheets/Anritsu-MA2400-Series_Manual.pdf
  - Modern Microcalorimeters and their status
  - *https://pdfs.semanticscholar.org/4543/4397d49049c5aff02605cf46c20e*
  - *https://pdfs.semanticscholar.org/4543/4397d49049c5aff02605cf46c20ee1f70db9.pde1f70db9.pdf*
  - *Download the talk at- http://www.nitehawk.com/k6jey/k6jey_dwnload.html*

Questions?

Thanks very much!

Sensor Linearity Record

.05db/1.2%

Table 5-3a. Calibrator Linearity - High Power Range

Cal Level (dBm)	Minimum (dBm)	Measured (dBm)	Maximum (dBm)
20.0	19.84	________	20.16
15.0	14.84	________	15.16
10.0	9.84	________	10.16

Table 5-3b. Calibrator Linearity - Low Power Range

Cal Level (dBm)	Minimum (dBm)	Measured (dBm)	Maximum (dBm)
5.0	4.9	________	5.1
-5.0	-5.1	________	-4.9
-10.0	-10.16	________	-9.84
-15.0	-15.16	________	-14.84
-20.0	-20.25	________	-19.75
-25.0	-25.25	________	-24.75
-30.0	-30.25	________	-29.75