Corso di Misure a Microonde

Misure di potenza

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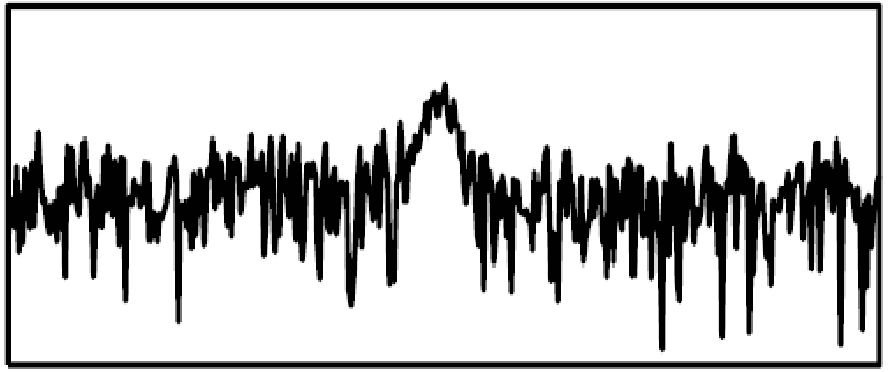
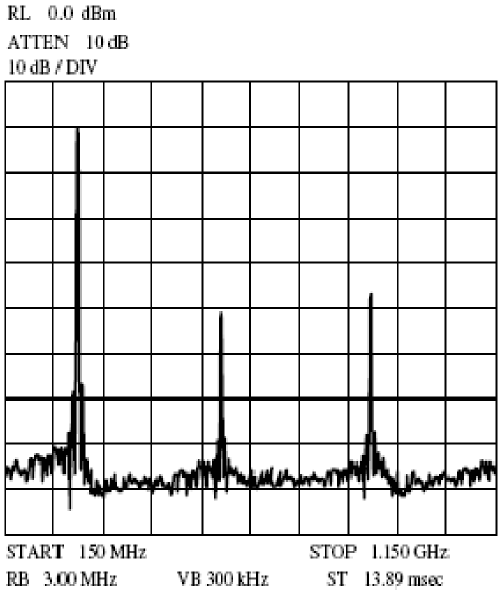
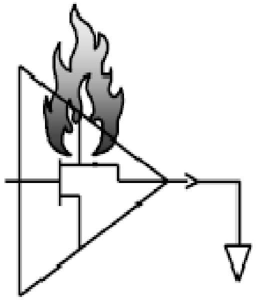
Importance of Proper Signal Levels

- Too low
  - Signal buried in noise





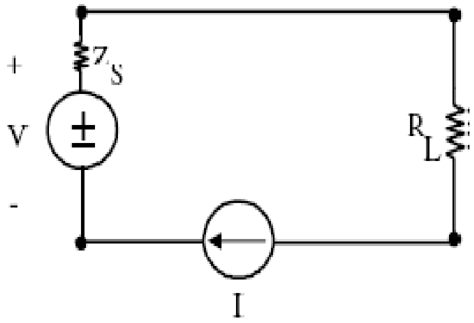
- Too high
  - Nonlinear distortion can occur



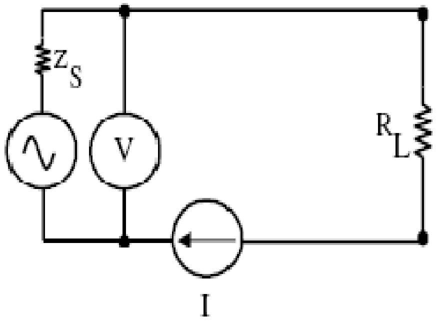
- Or even worse!

Why Not Measure Voltage?

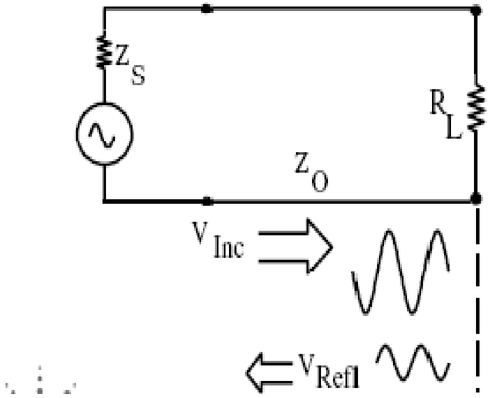
- DC



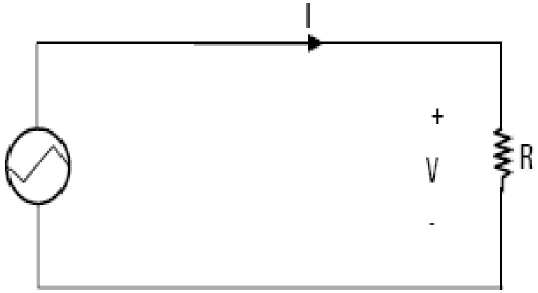
- Low Frequency

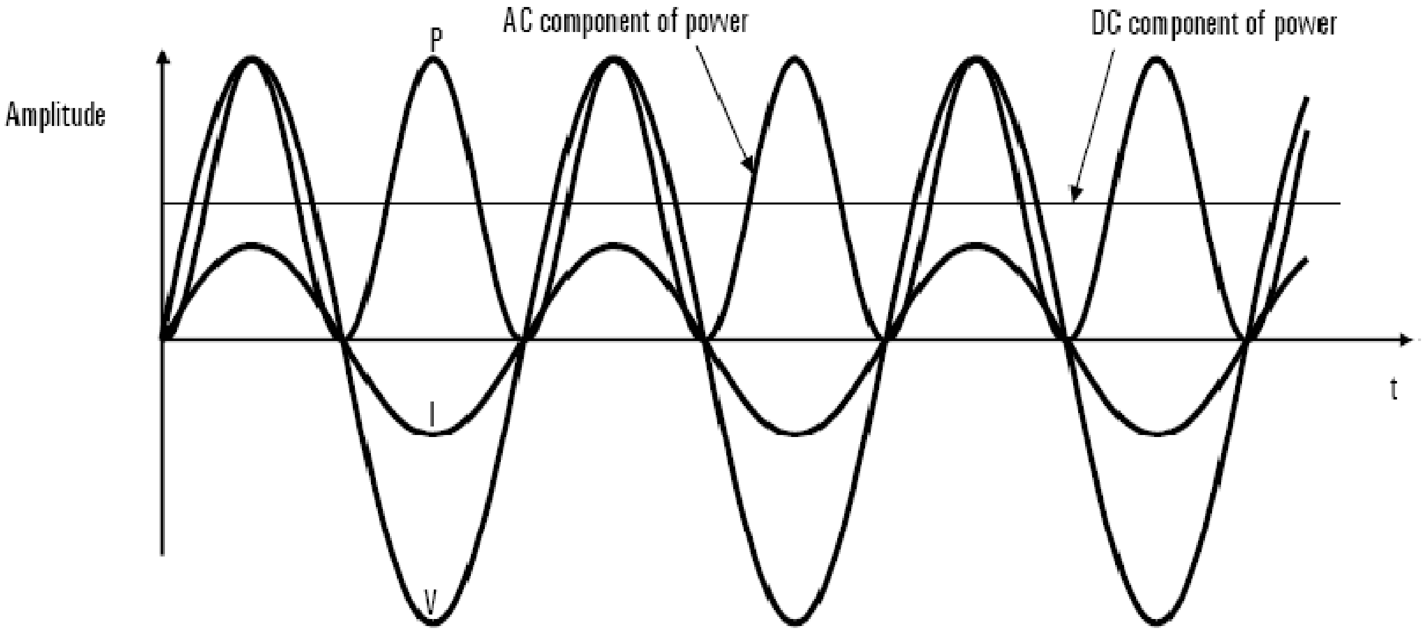


- High Frequency



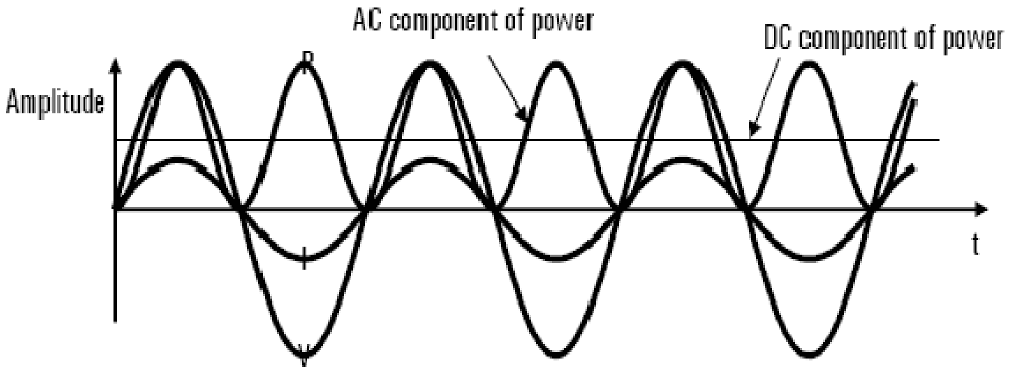
Power: P = V I


I
+
V
-
R


AC component of power
DC component of power
P
Amplitude
t
I
V

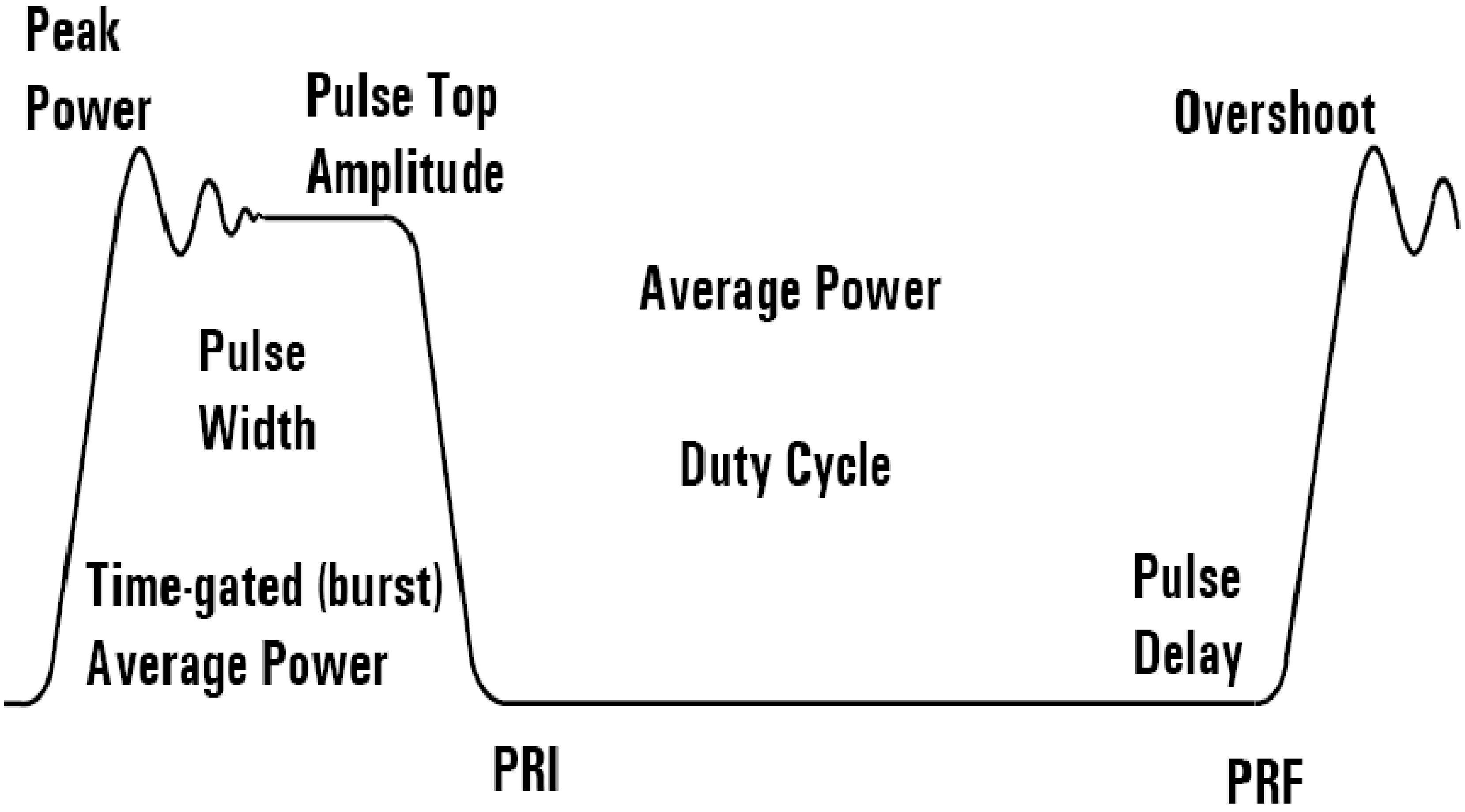
Units and Definitions

Power: P = (I)(V)



- Unit of power is the watt (W): 1W = 1 joule/sec
- Some electrical units are derived from the watt:
  1 volt = 1 watt/ampere
- Relative power measurements are expressed in dB:
  P(dB) = 10 log(P/Pref)
- Absolute power measurements are expressed in dBm:
  P(dBm) = 10 log(P/1 mW)

Types of Power Measurements



Peak Power

Pulse Top Amplitude

Overshoot

Average Power

Pulse Width

Duty Cycle

Time-gated (burst) Average Power

Pulse Delay

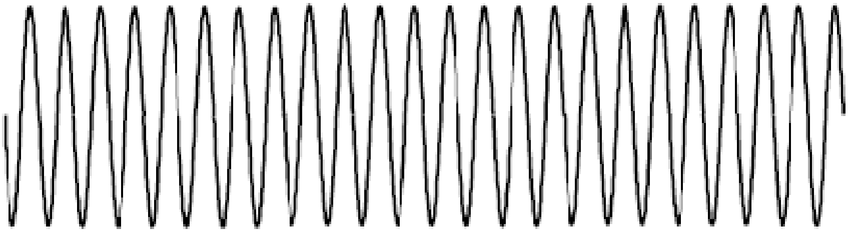
PRI

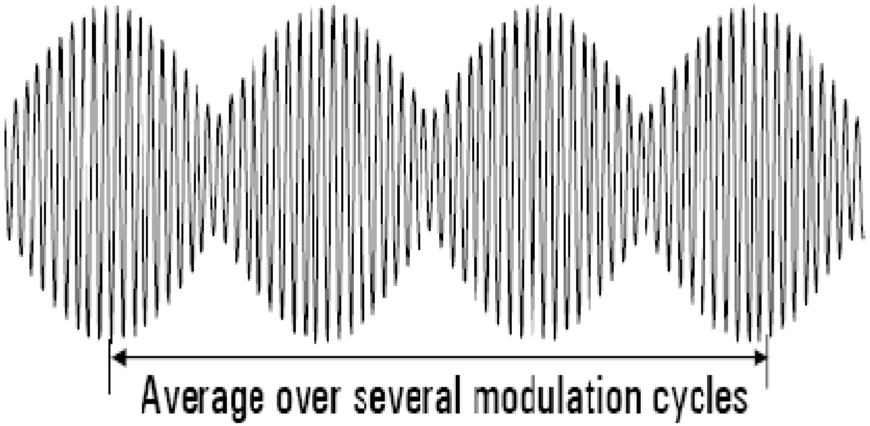
PRF

Instruments to measure microwave power

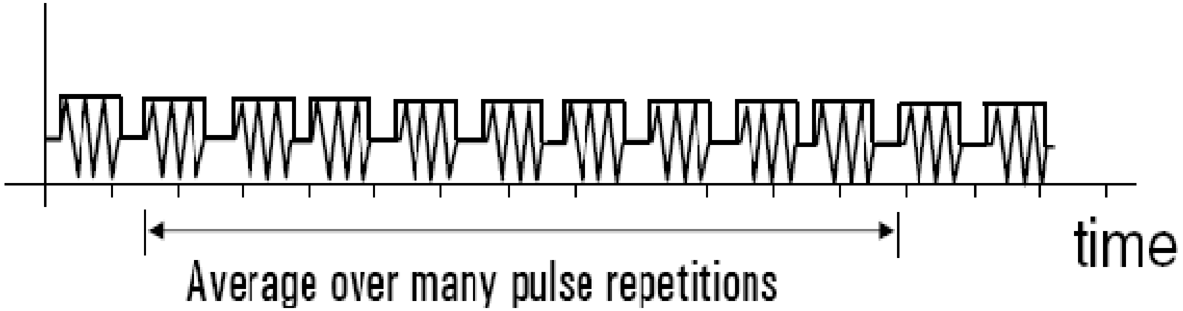
- Vector Signal Analyzer
- Spectrum Analyzer
- Network Analyzer
- Power Meter and Sensor

Average Power



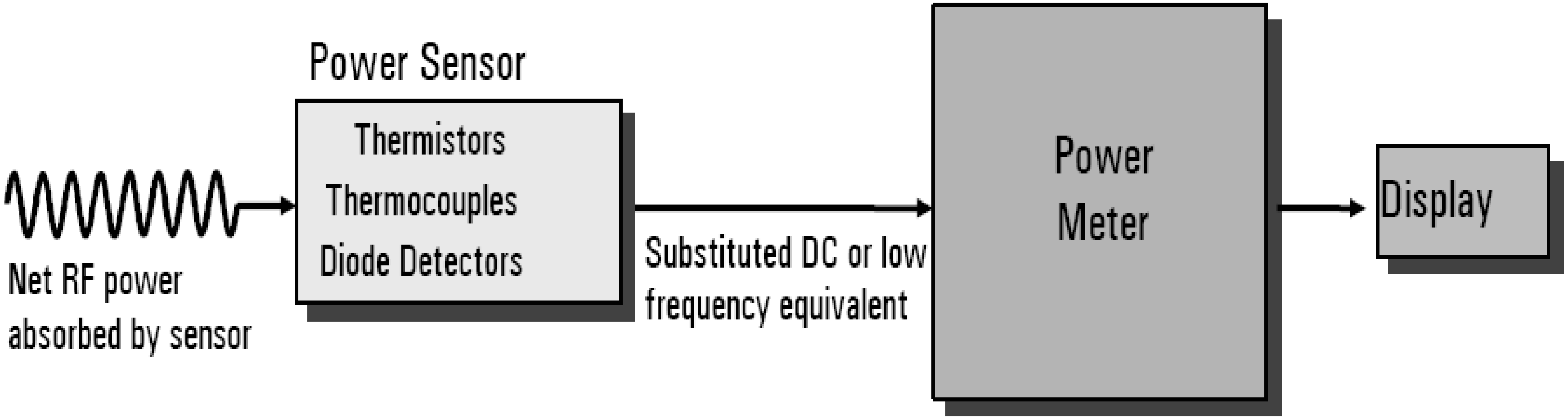


$$P_{peak} = \frac{P_{avg}}{DutyCycle}$$



Basic Measurement Method

Using a Power Meter



Power Sensor

Thermistors

Thermocouples

Diode Detectors

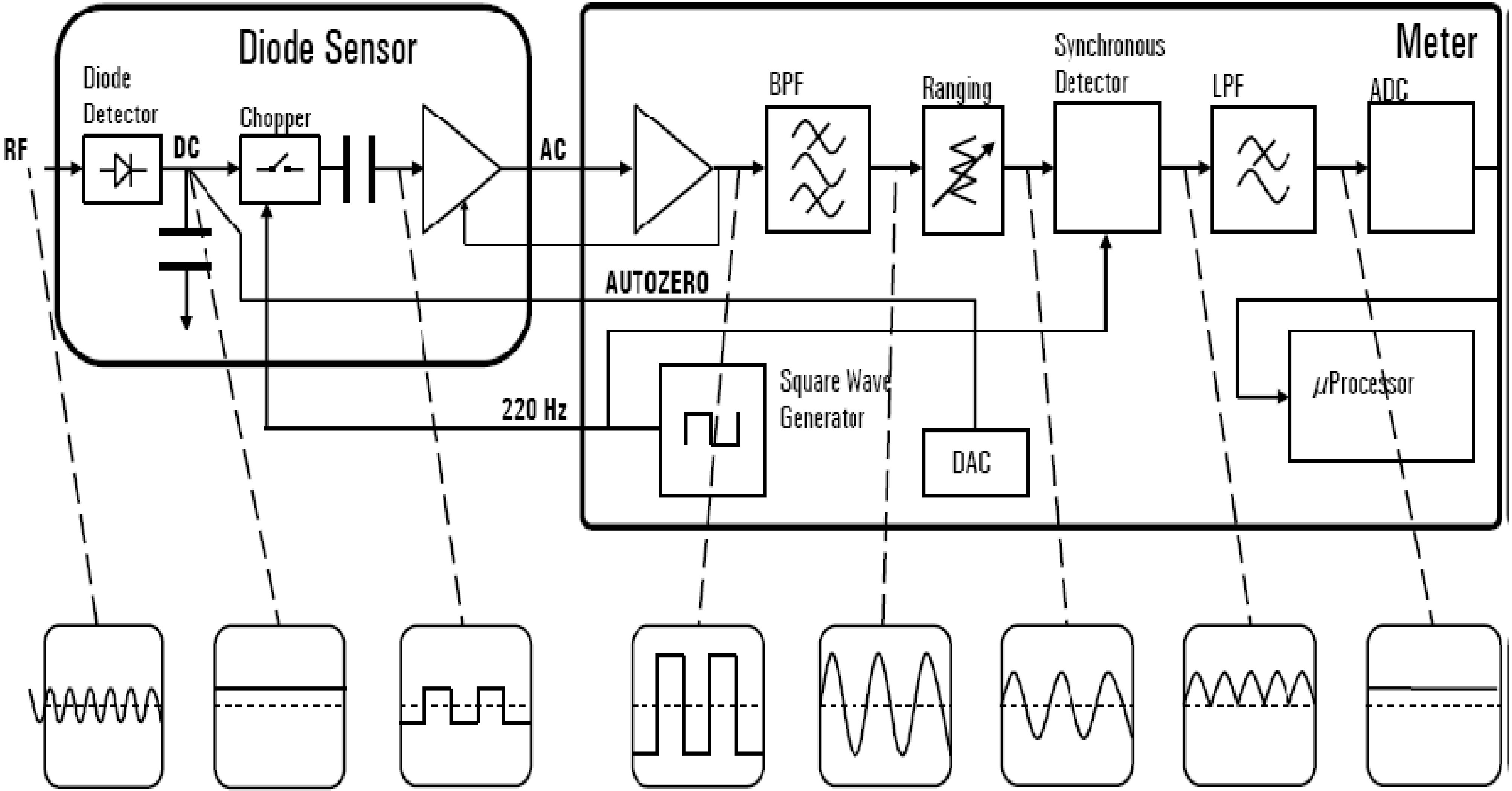
Net RF power absorbed by sensor

Substituted DC or low frequency equivalent

Power Meter

Display

Basic Measurement Method Explained



Thermocouples

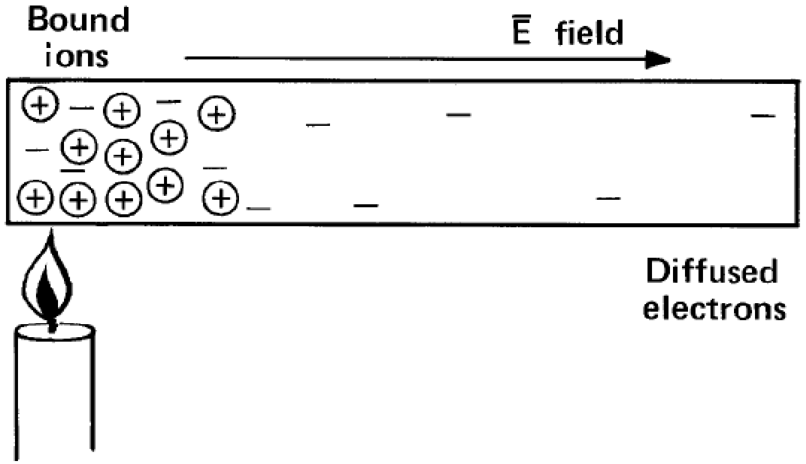


Figure 3-1. Heat at one end of a metal rod gives rise to an electric field.

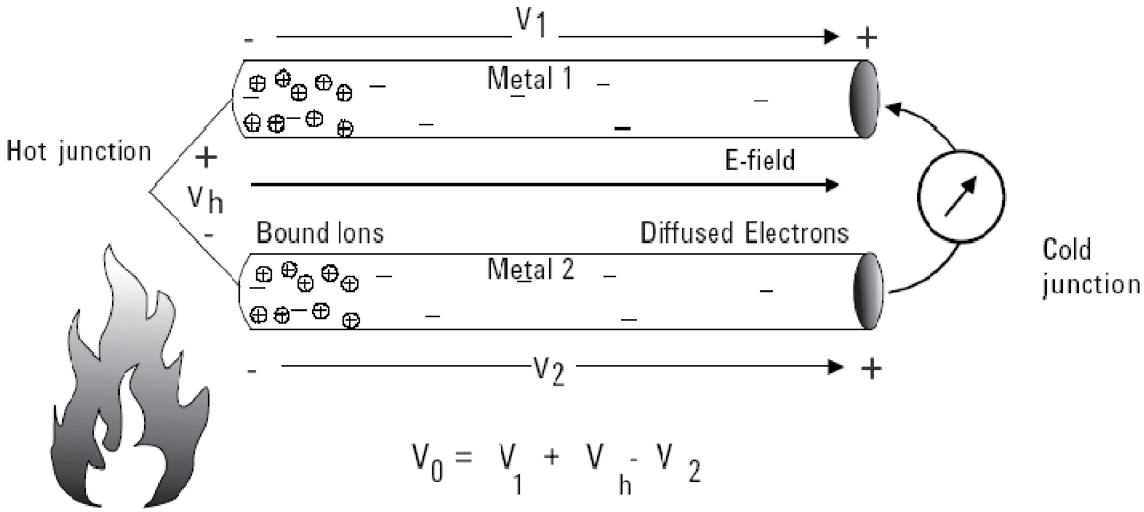


Figure 3-2. Total thermocouple output is the resultant of several thermoelectrical voltages generated along the two-metal circuit.

Thermocouples

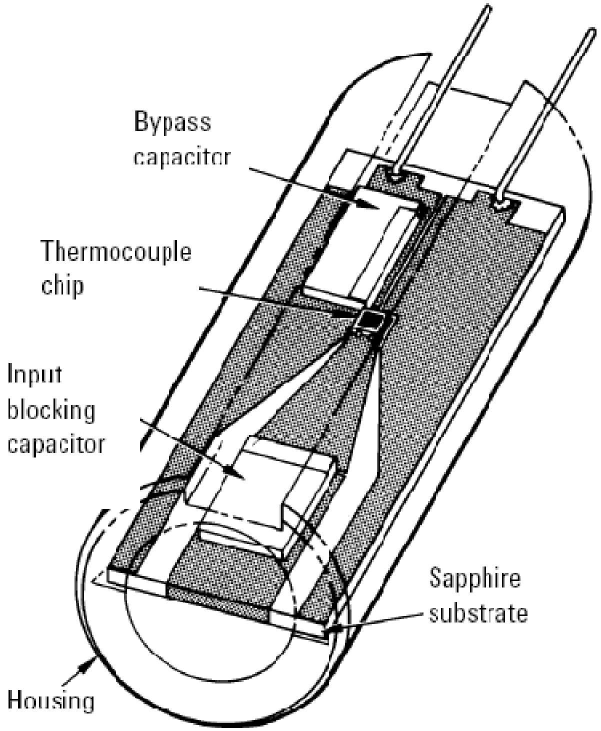


Figure 3-6. Sketch of the thermocouple assembly for the 8481A.

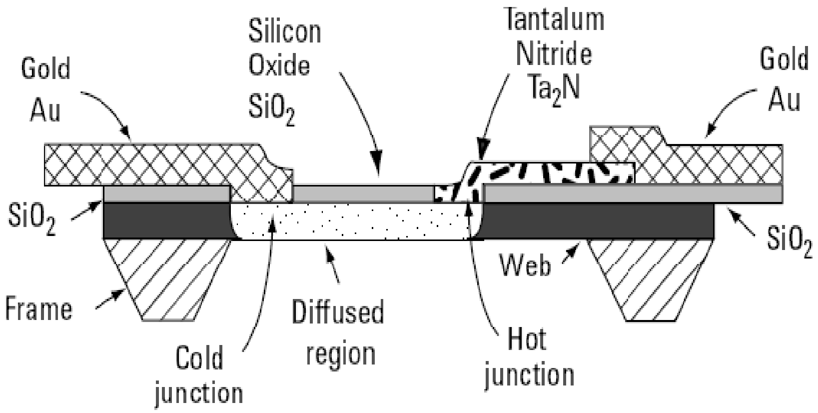


Figure 3-4. Cross section of one thermocouple. Power dissipated in the tantalum-nitride resistor heats the hot junction.

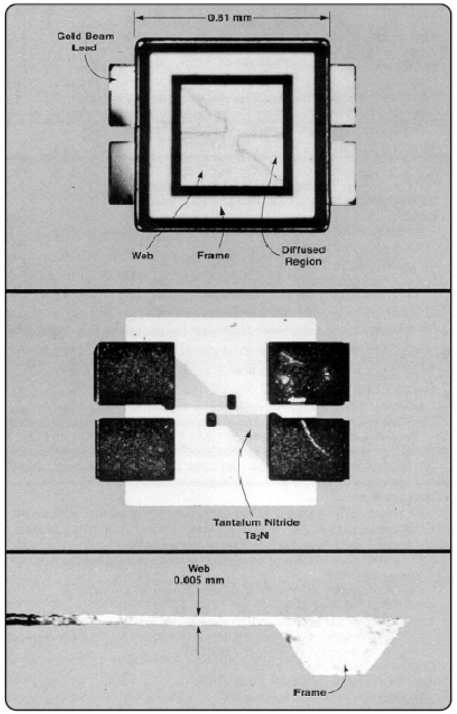
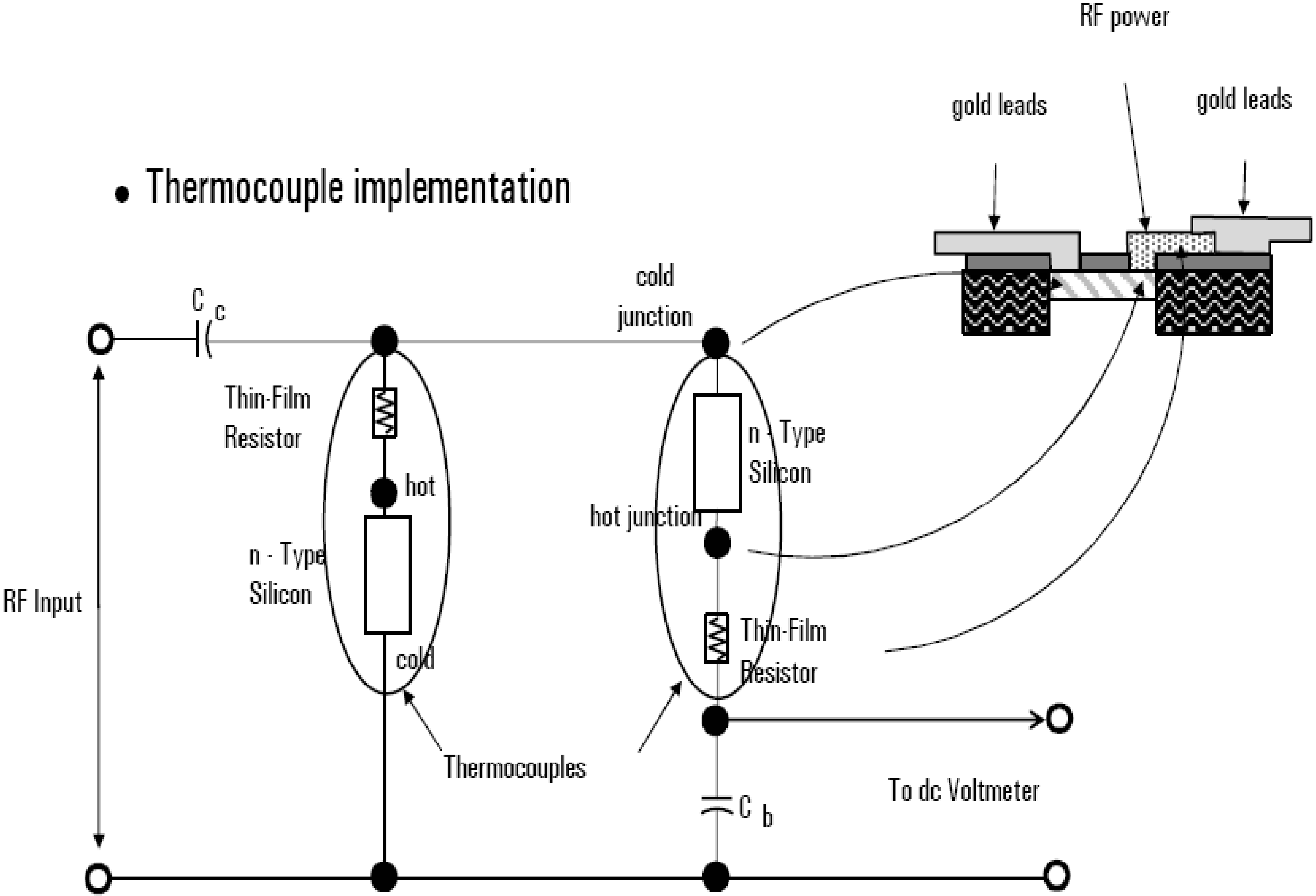


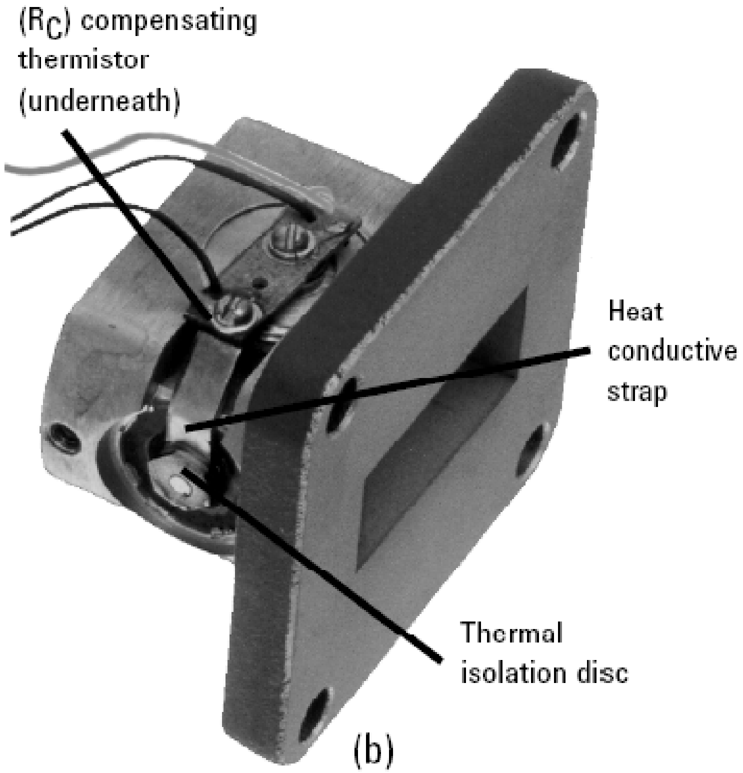
Figure 3-3. Photo-micrograph of the structure of the 8481A thermocouple chip on a thin silicon web.

Thermocouples

- Thermocouple implementation



Thermistors



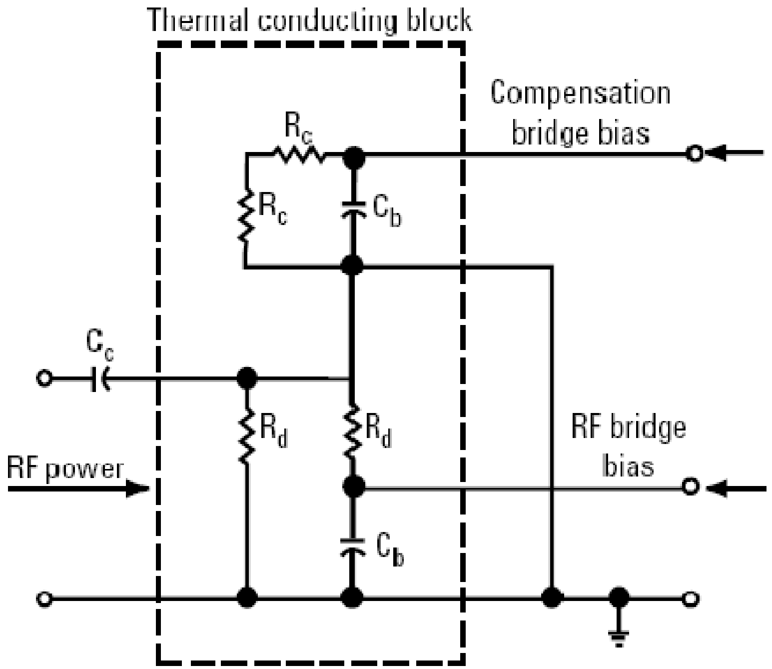
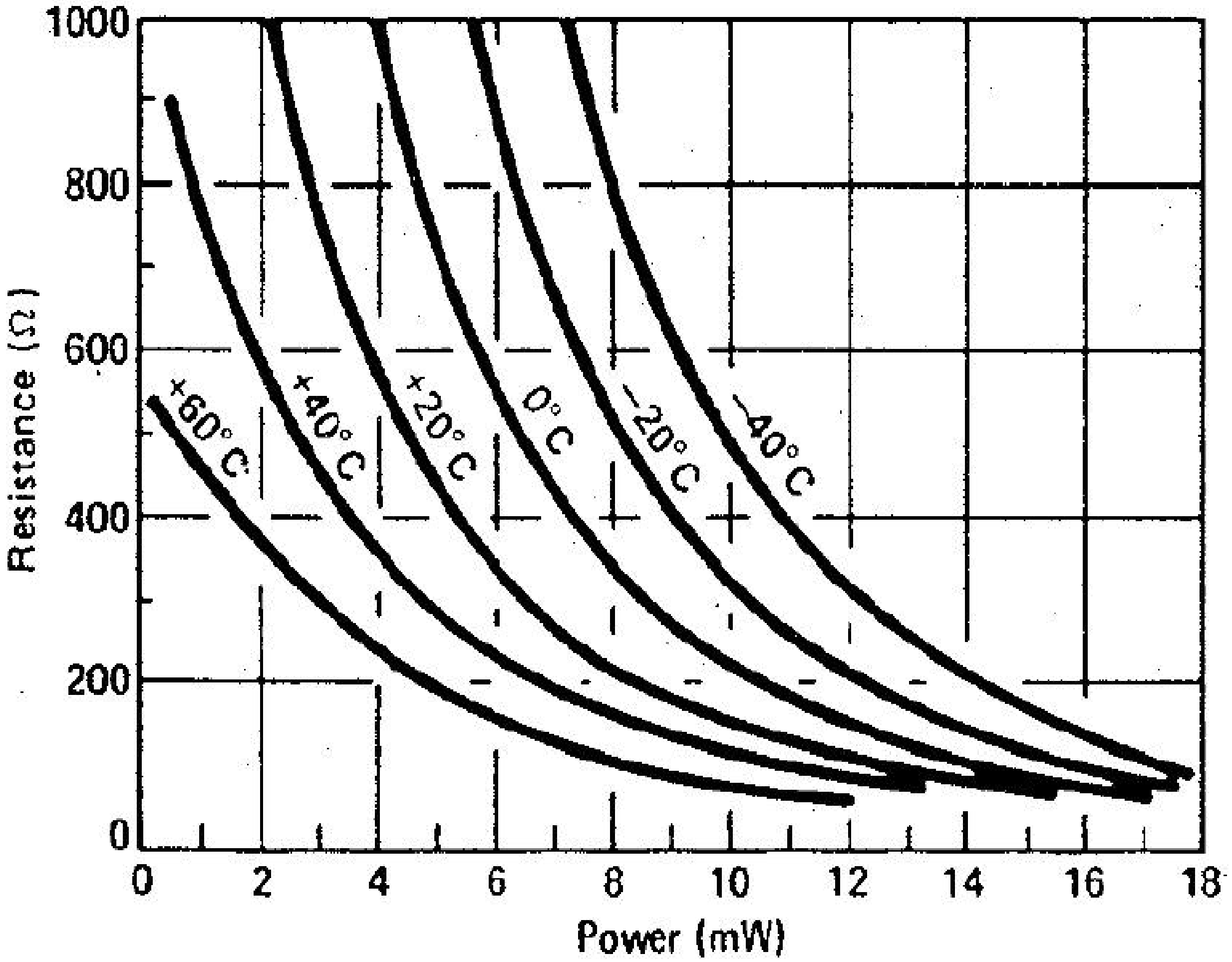


Figure 2-1. 478A coaxial sensor simplified diagram

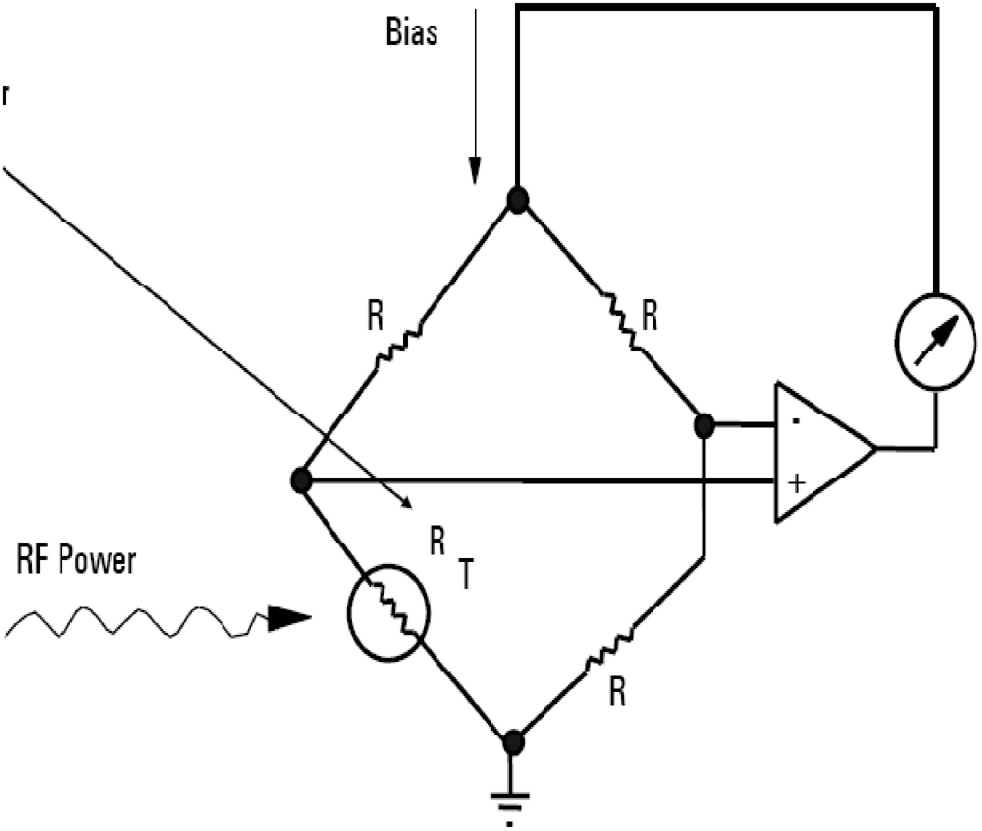
Thermistors

Characteristic curves of a typical thermistor element



Thermistors

A self-balancing bridge containing a thermistor



Thermistors

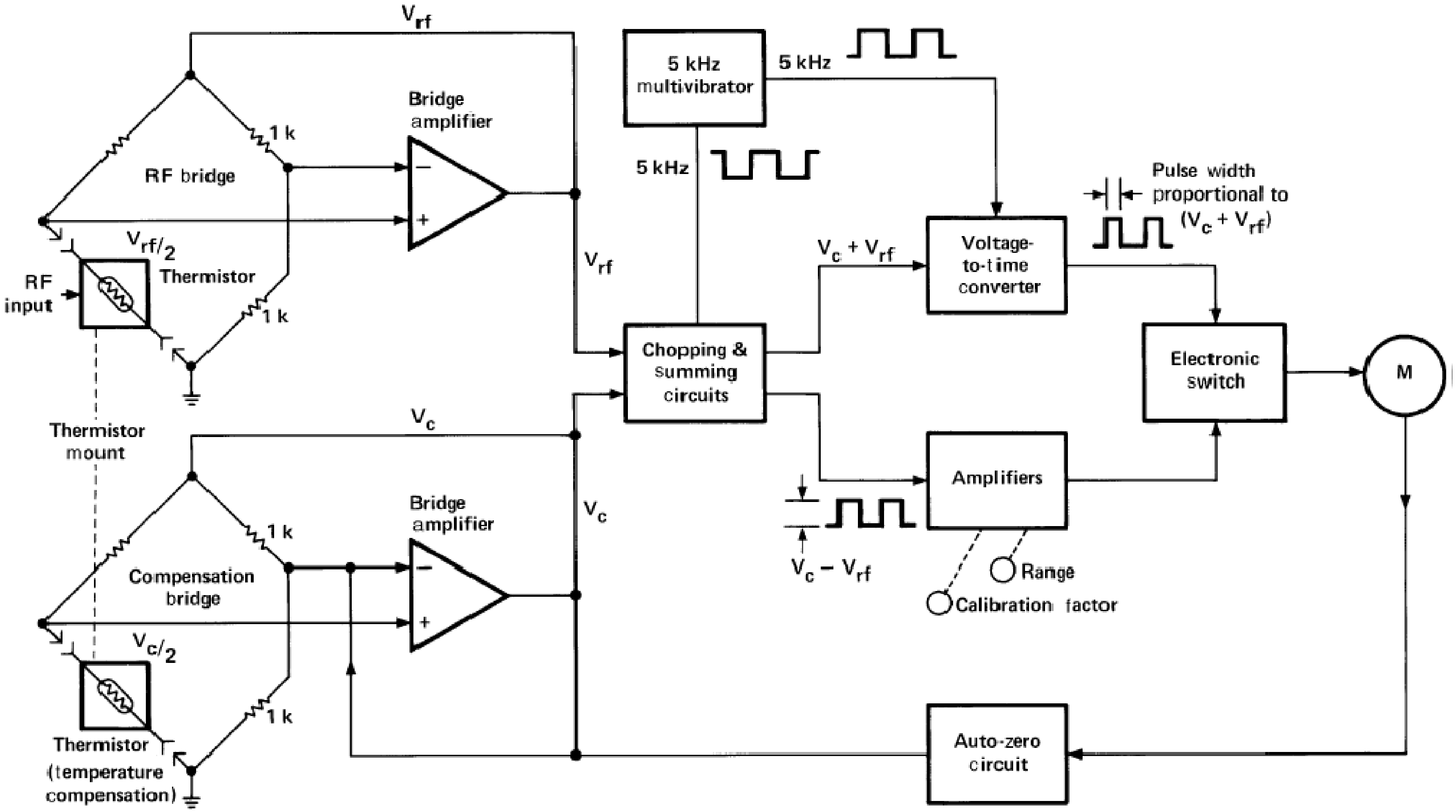
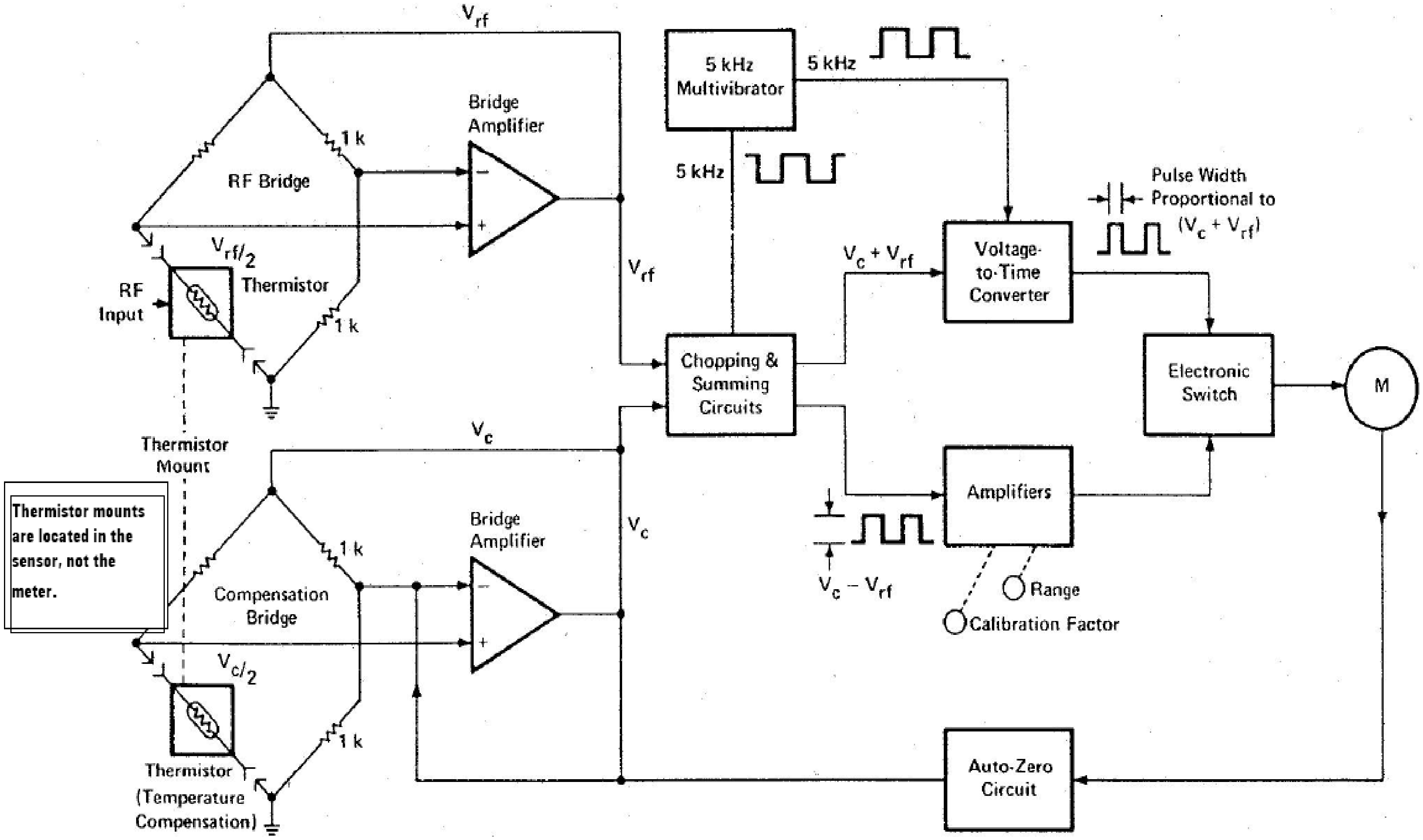


Figure 2-2. Simplified diagram of the 432A power meter.

Power Meters for Thermistor Mounts

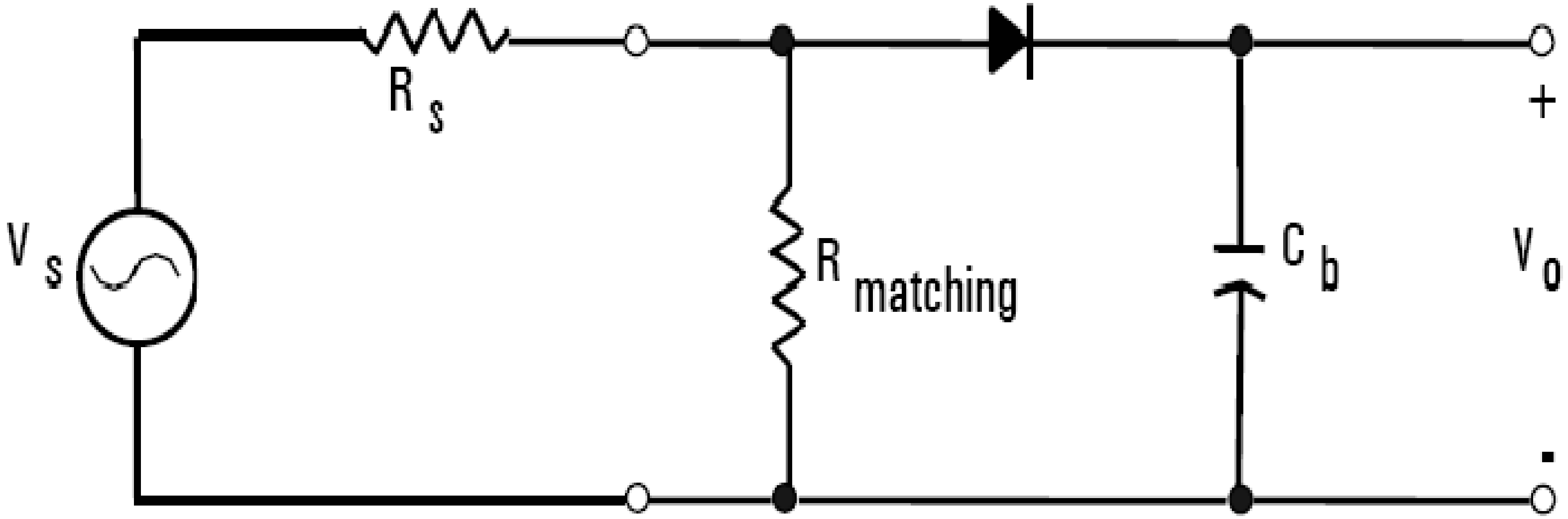
- 432A Power Meter



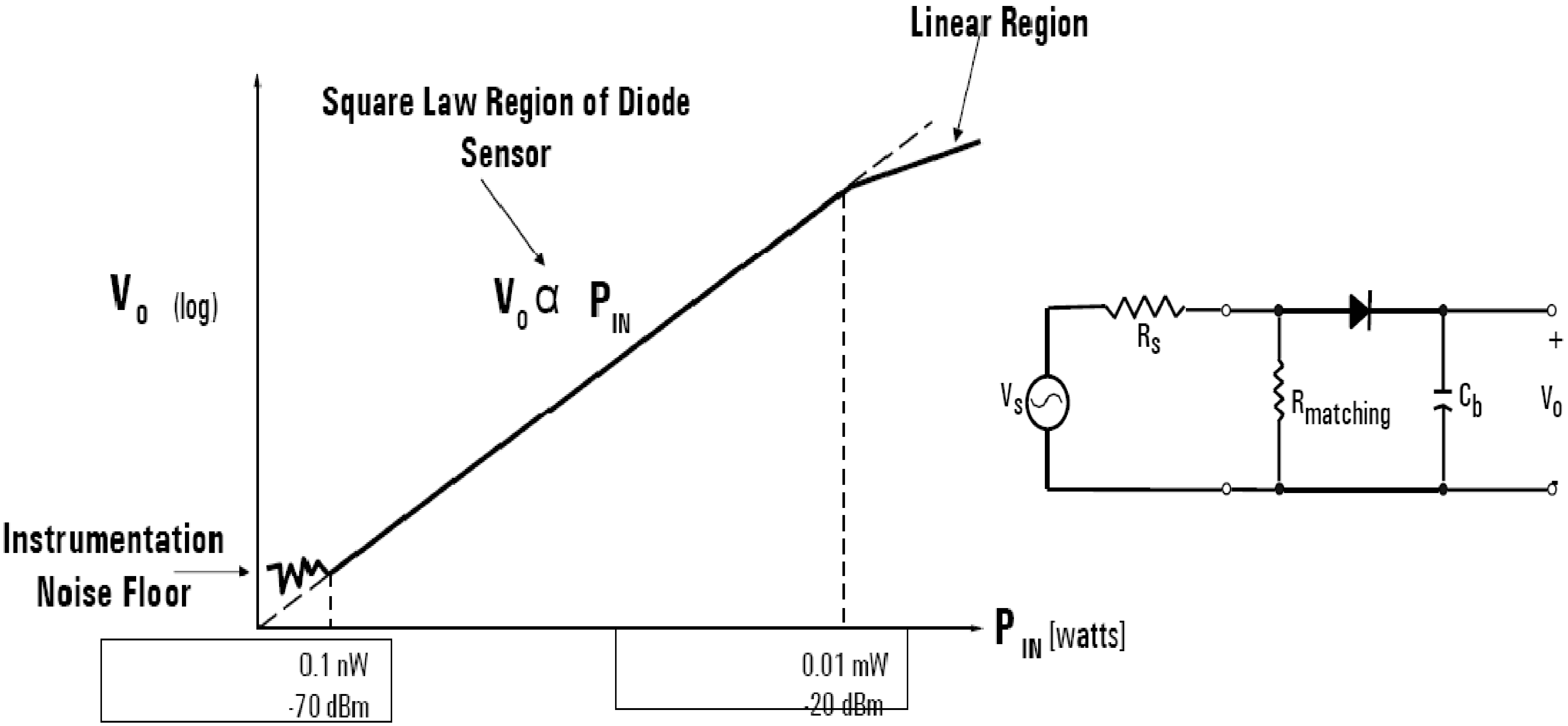
Thermistor mounts are located in the sensor, not the meter.

Diode Detectors

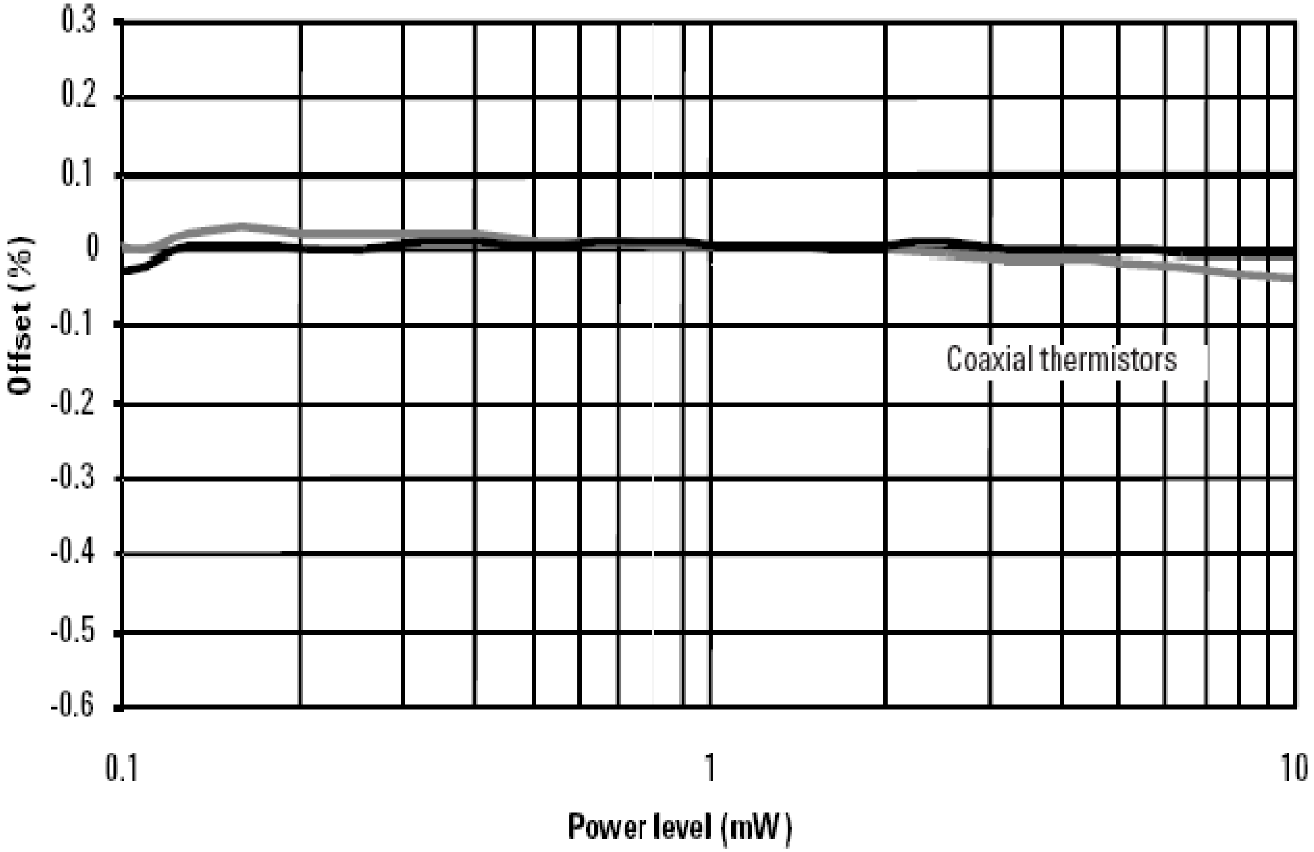
- How does a diode detector work?



Diode Detectors



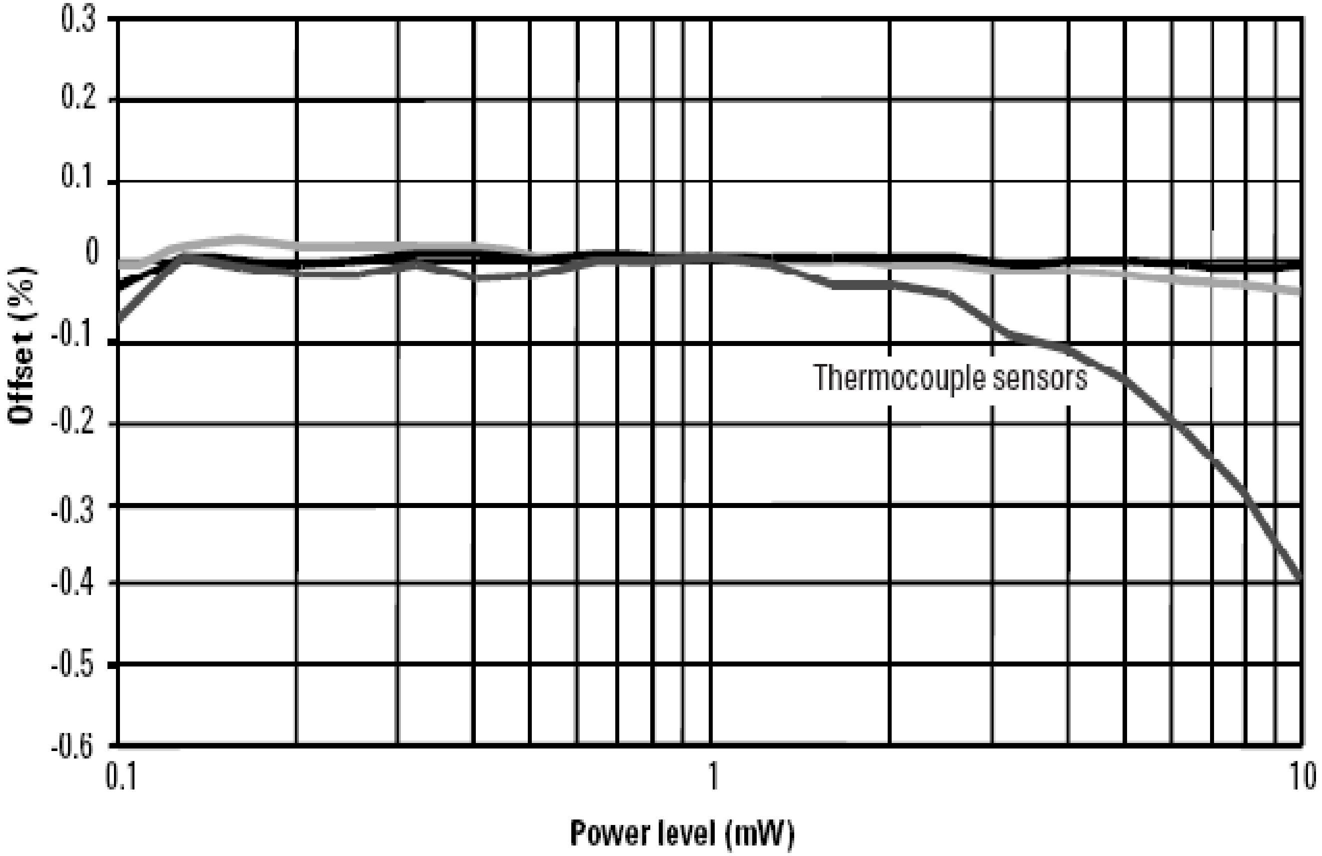
Sensors linearity



Data courtesy of NPL, Teddington, UK.

Figure 3-9. Mean linearity of seven units of model 8478A coaxial thermistor sensors from 0.1 to 10 mW. (8478A is an older model, the current model is 8478B.)

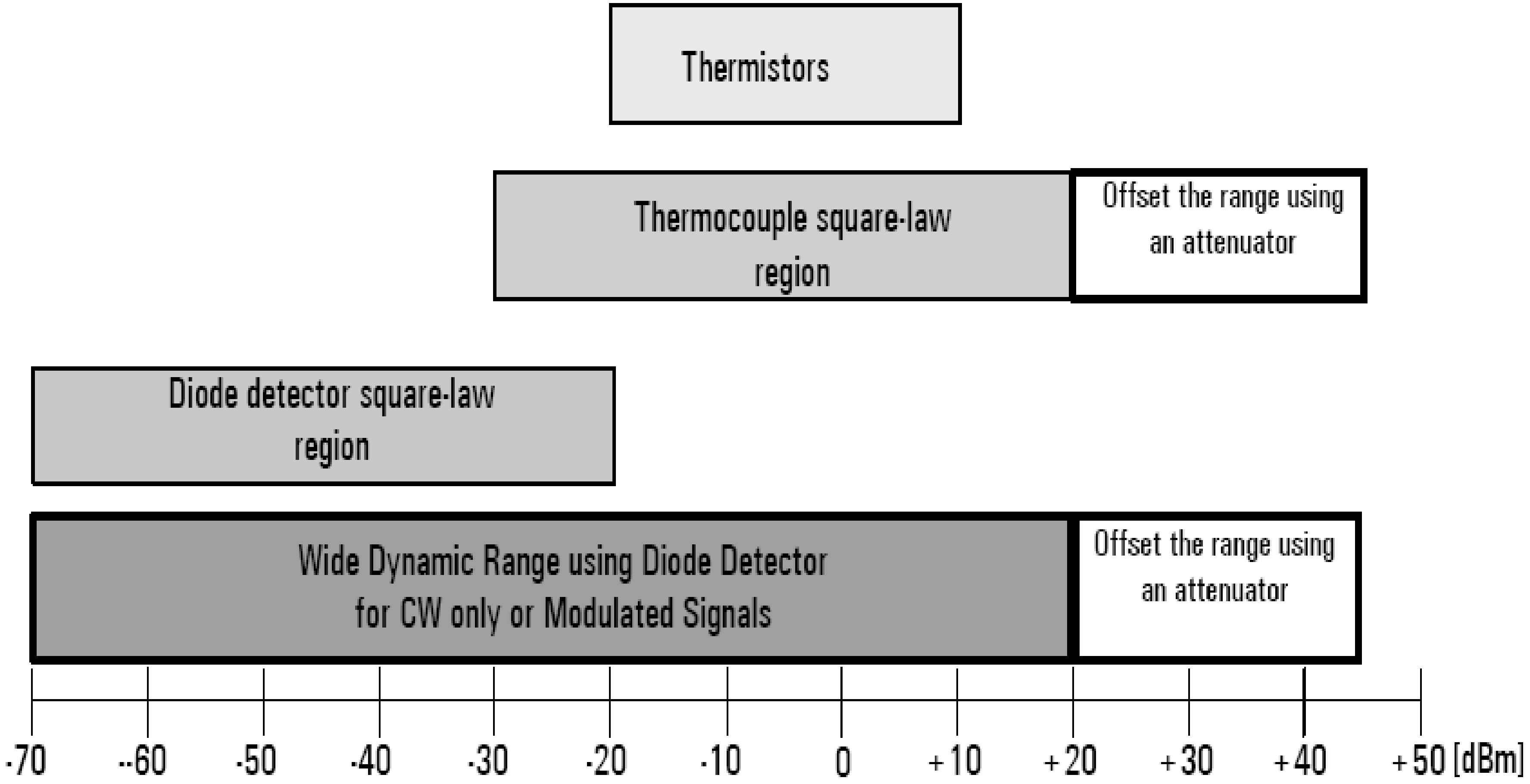
Sensors linearity



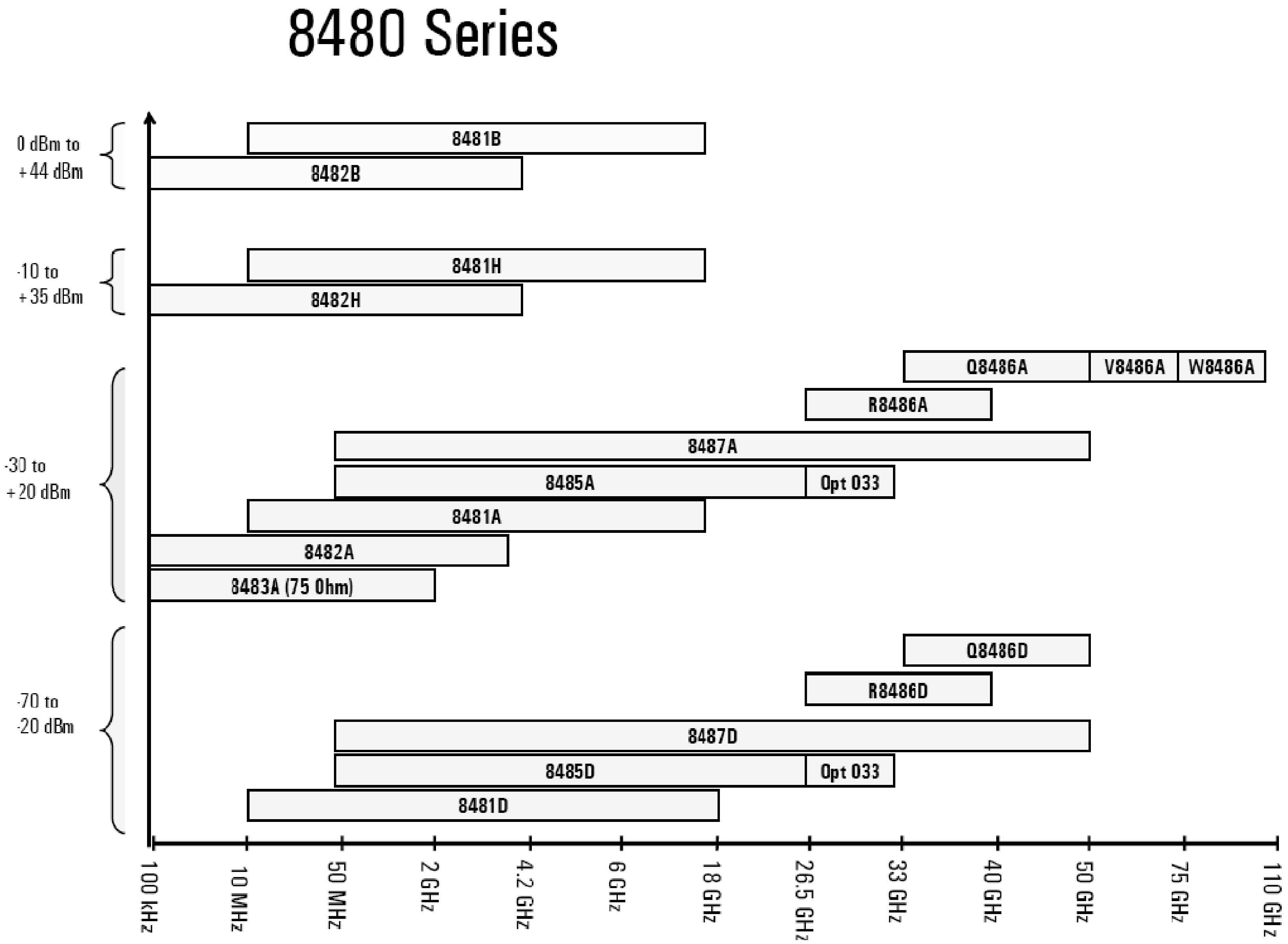
Data courtesy of NPL, Teddington, UK.

Figure 3-10. Mean linearity of four units of model 8481A coaxial thermocouple sensors from 0.1 to 10 mW.

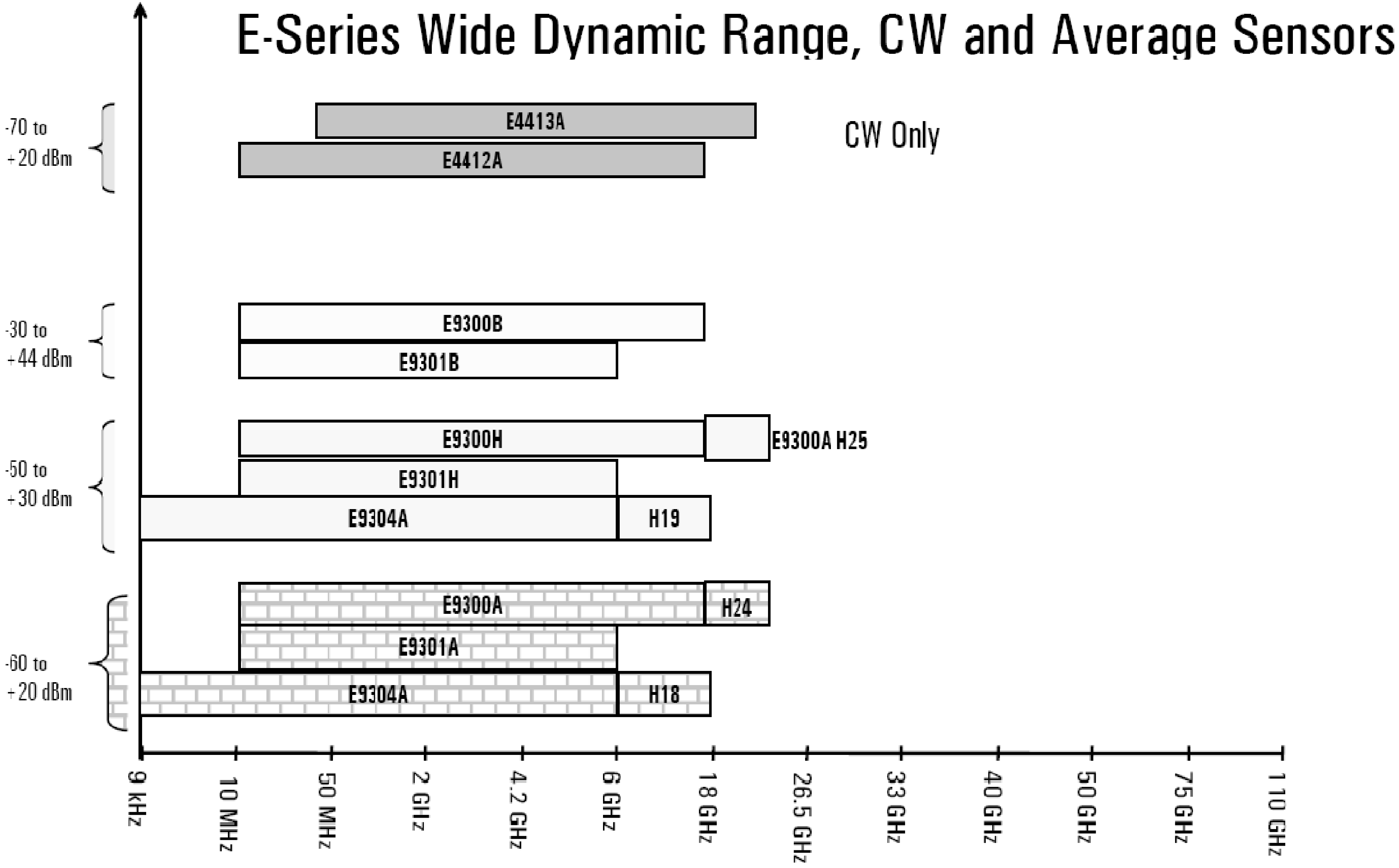
Power Ranges of the Various Sensors



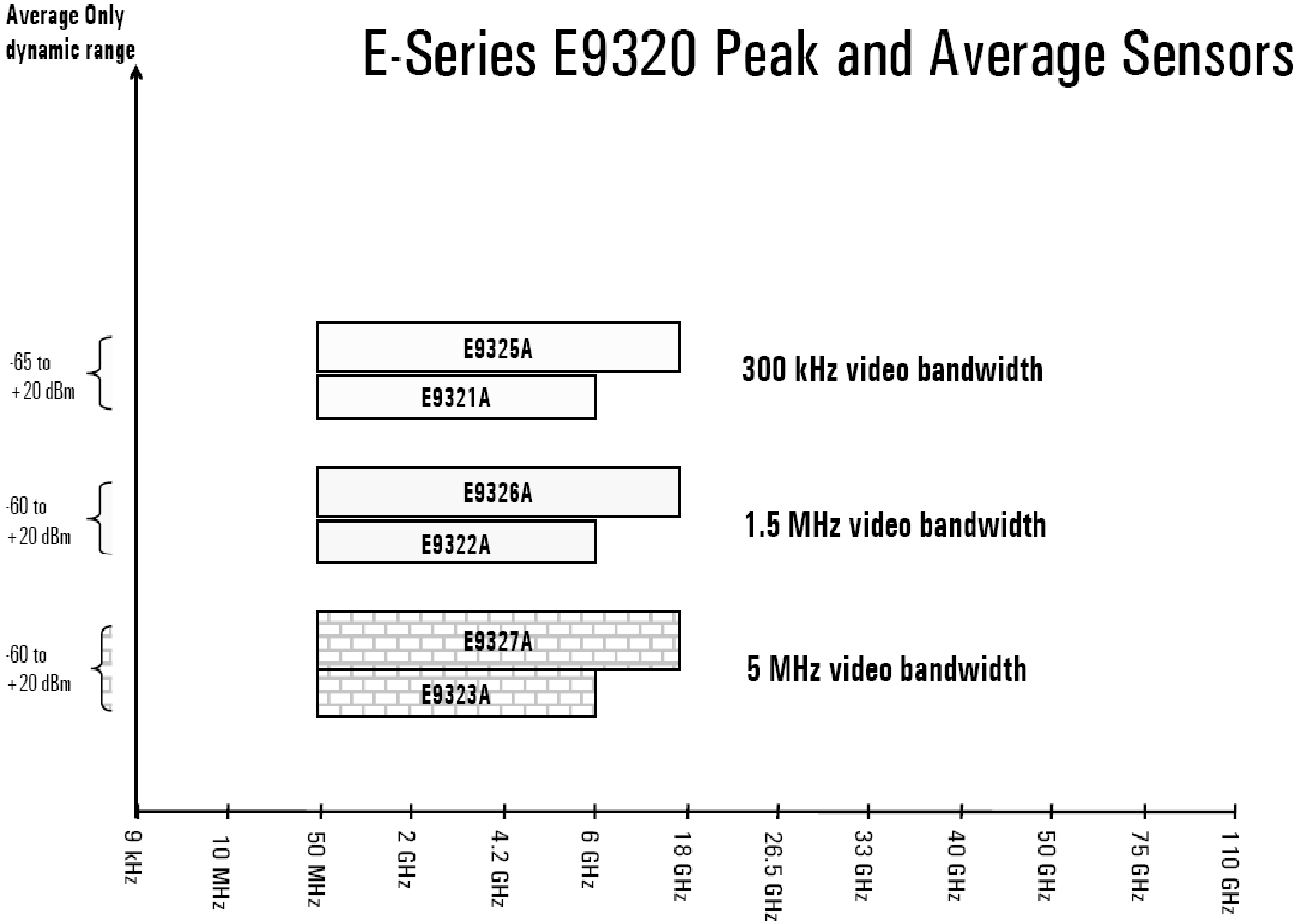
Agilent Power Sensor Selection Guide



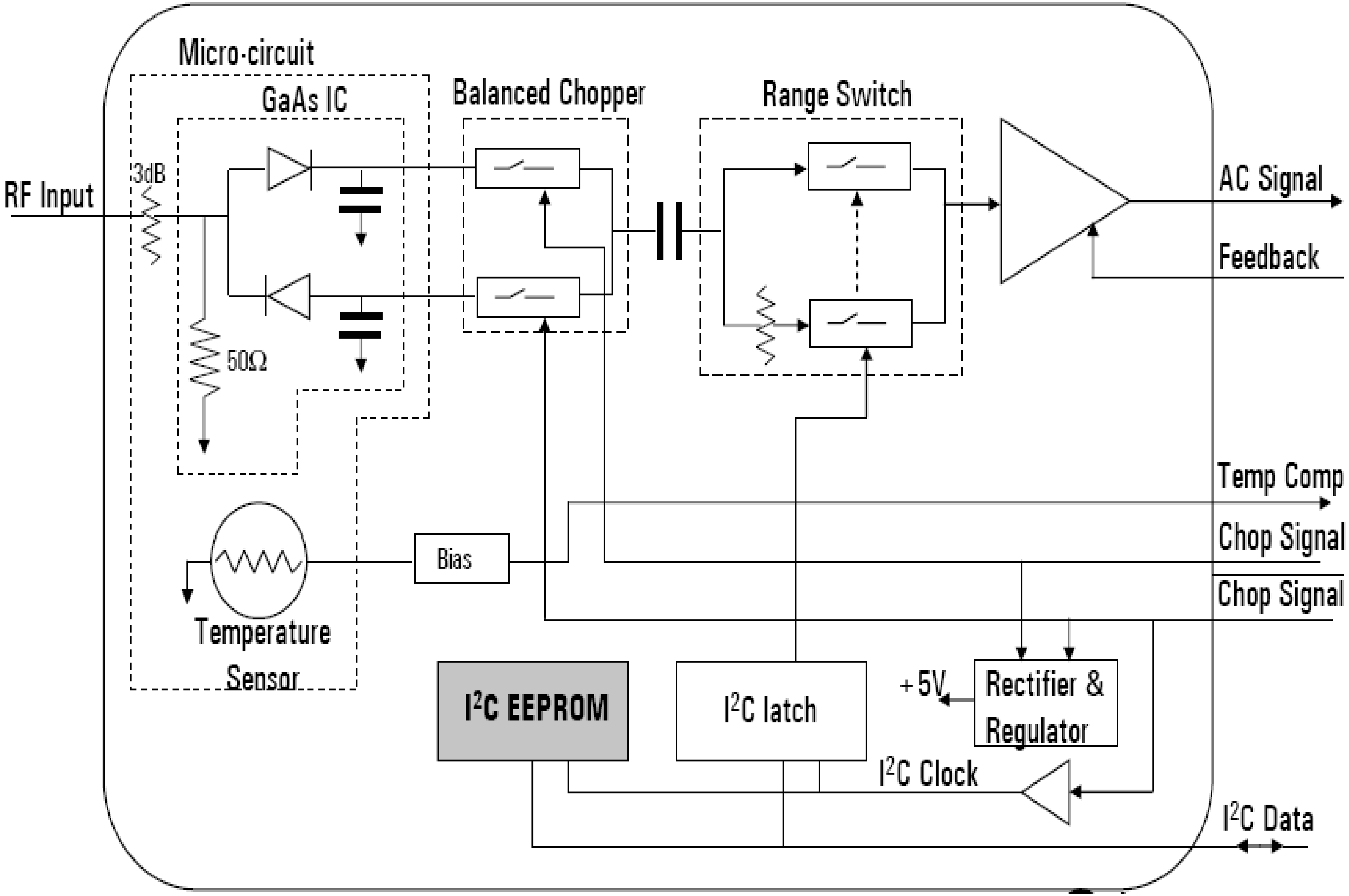
Agilent Power Sensor Selection Guide


E-Series Wide Dynamic Range, CW and Average Sensors

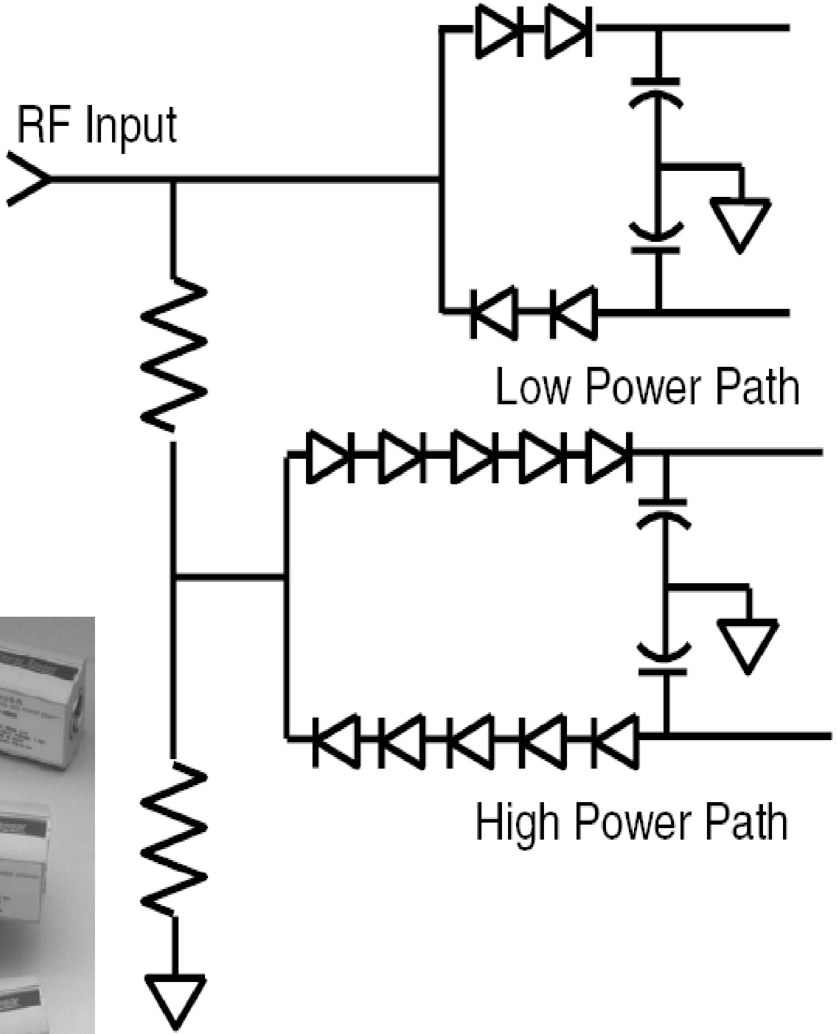
Agilent Power Sensor Selection Guide



Wide-Dynamic-Range CW-only Sensors

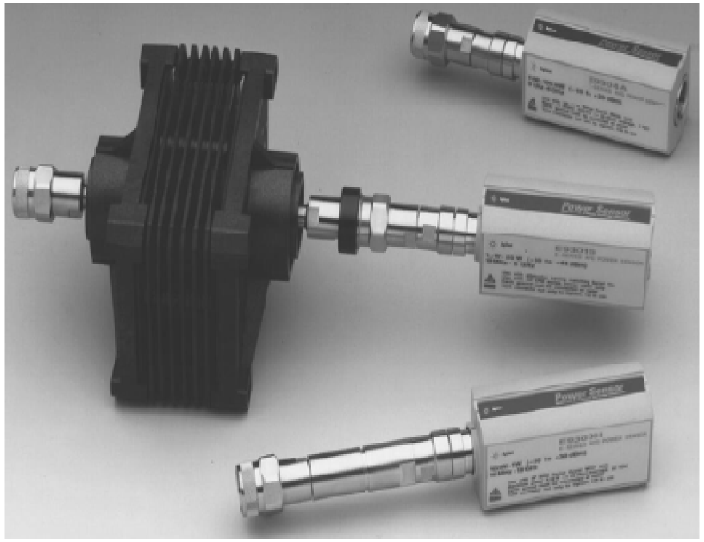


Agilent E9300 Average Power Sensors

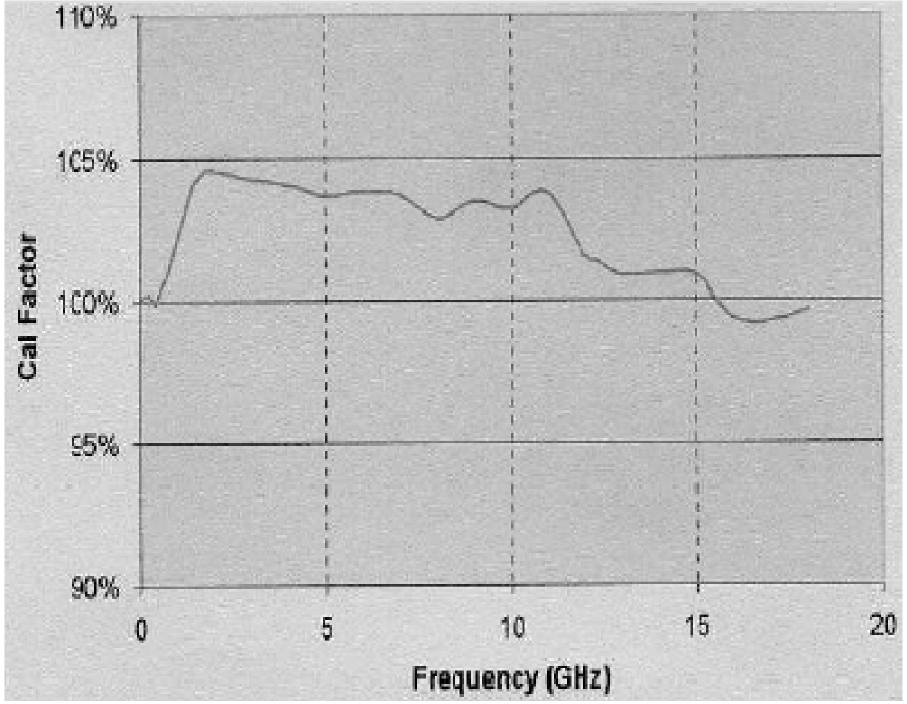


Innovative Design:

- Diode stack- attenuator- diode stack topology
- Two paths with an automatic switch point



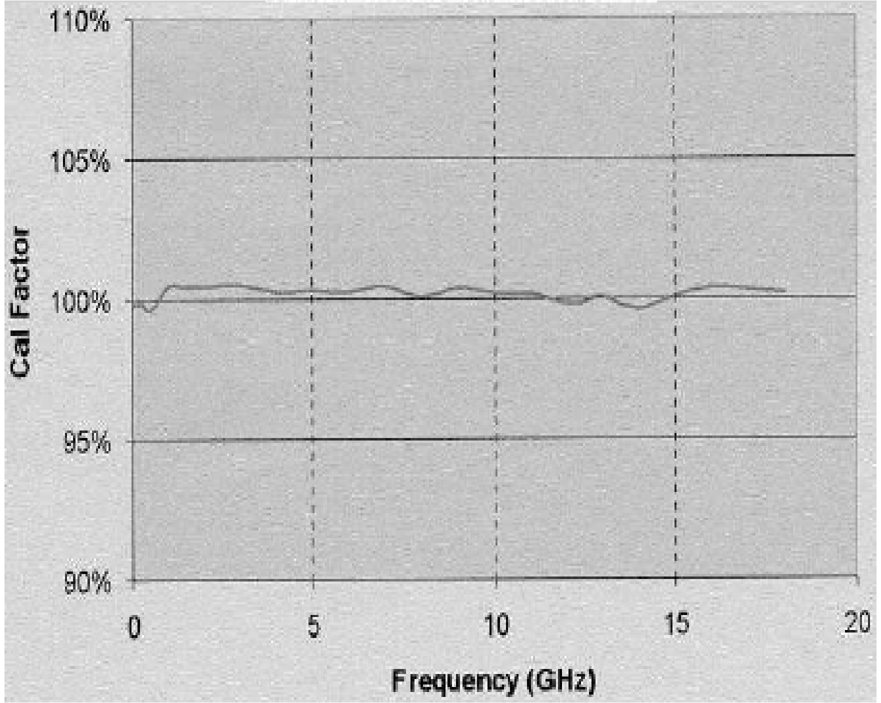
Agilent E9300 Average Power Sensors

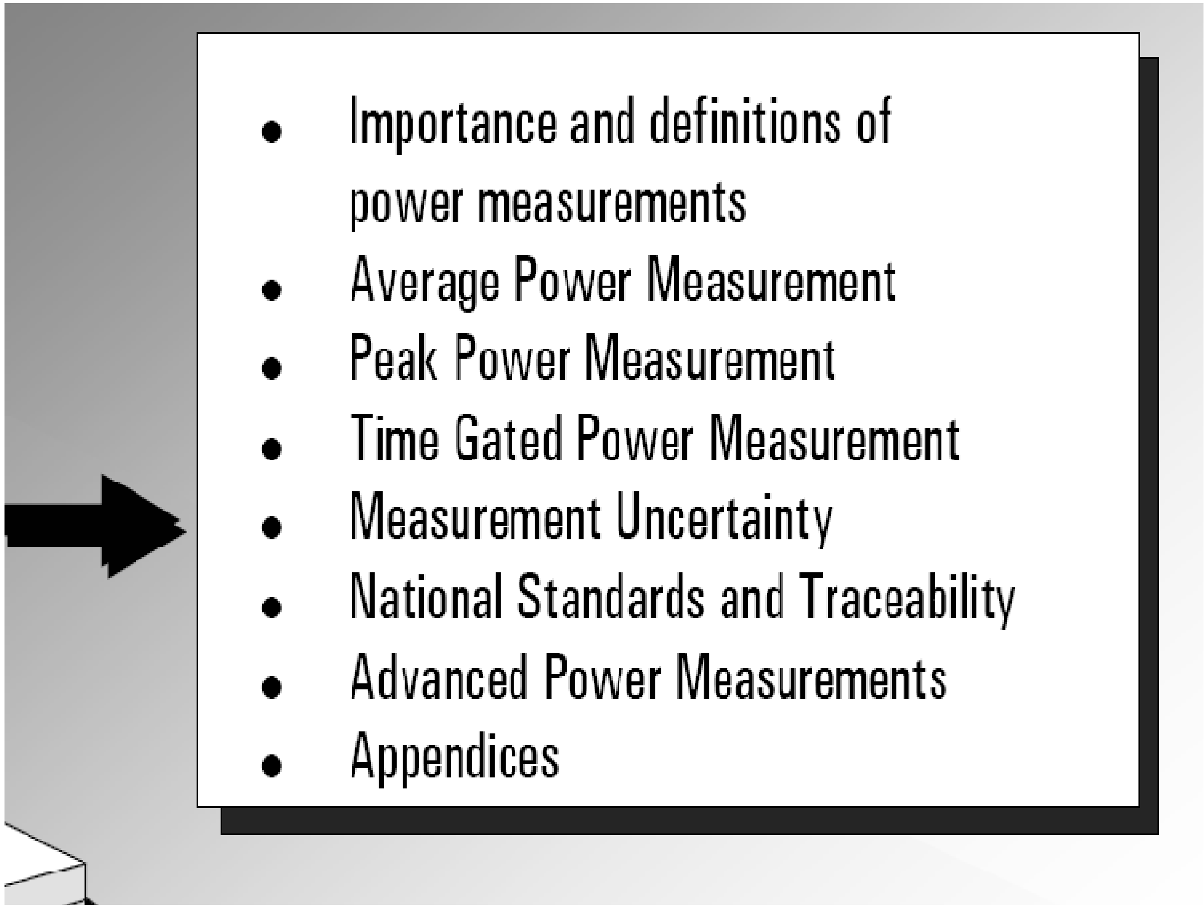


High Path Cal Factor

Flat calibration factors give accurate measurement of multi-tone signals.

Low Path Cal Factor

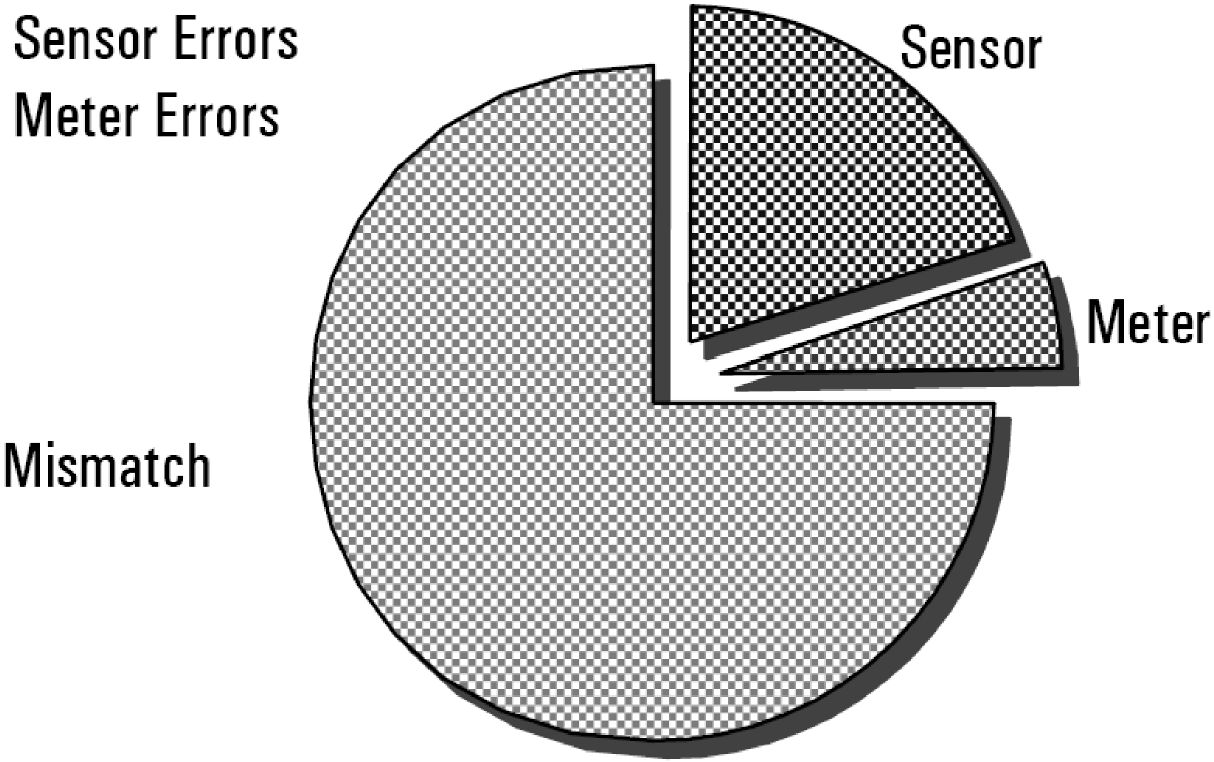




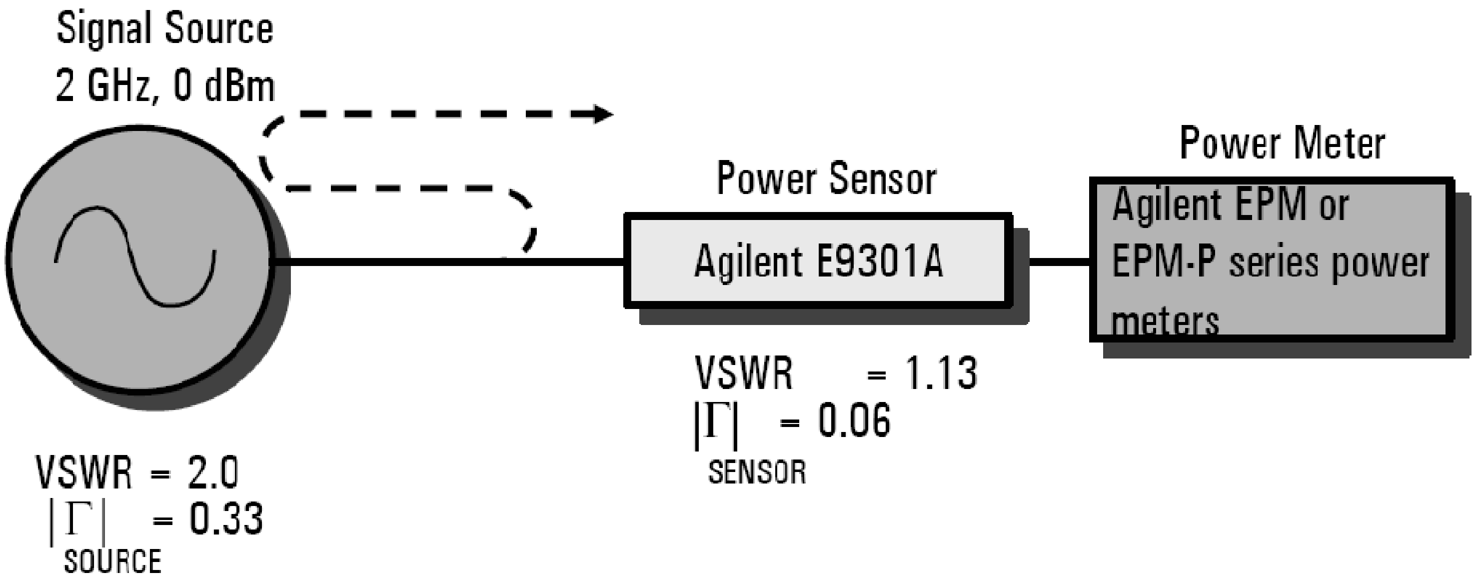
- Importance and definitions of power measurements
- Average Power Measurement
- Peak Power Measurement
- Time Gated Power Measurement
- Measurement Uncertainty
- National Standards and Traceability
- Advanced Power Measurements
- Appendices

Power measurement uncertainty sources

- Sensor and Source Mismatch Errors
- Power Sensor Errors
- Power Meter Errors



Calculation of Mismatch Uncertainty



Signal Source
2 GHz, 0 dBm

Power Sensor

Agilent E9301A

Power Meter

Agilent EPM or EPM-P series power meters

VSWR = 1.13
$|\Gamma|_{\text{SENSOR}} = 0.06$

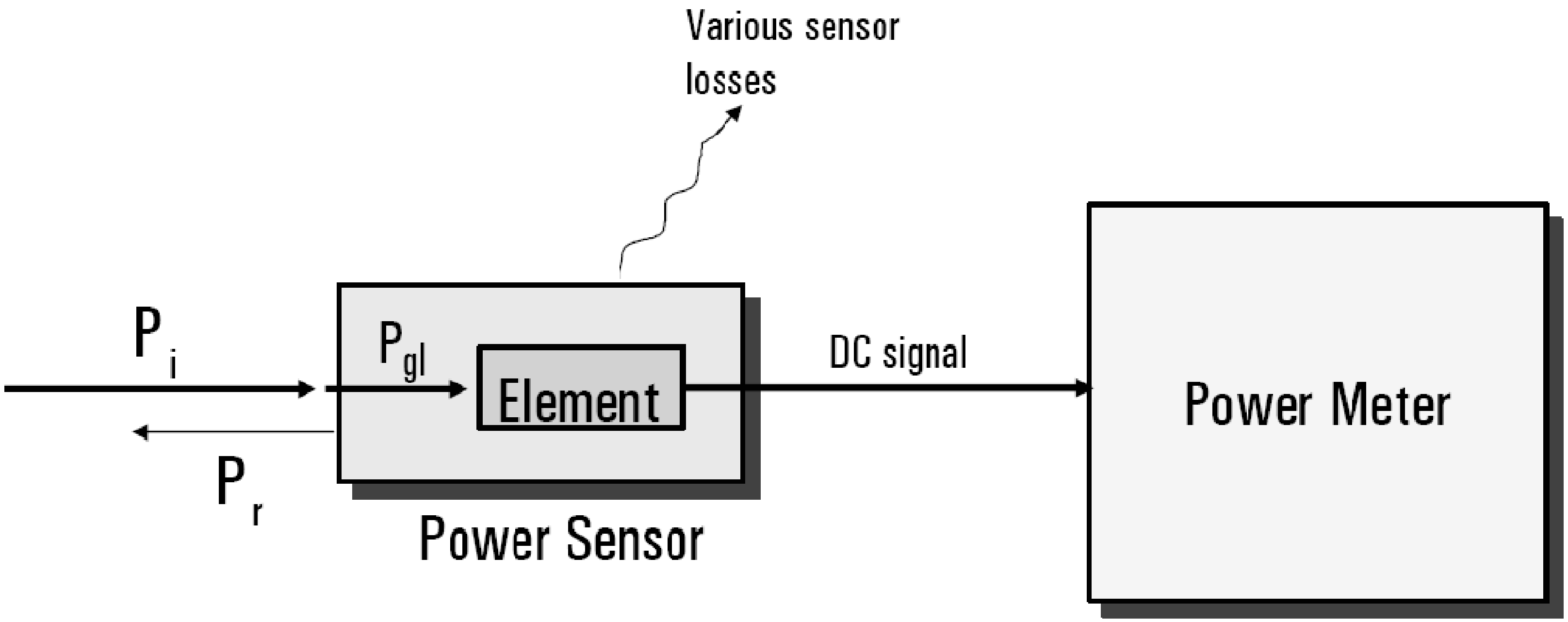
VSWR = 2.0
$|\Gamma|_{\text{SOURCE}} = 0.33$

$$\text{Mismatch Uncertainty} = \pm 2 \times |\Gamma|_{\text{SOURCE}} \times |\Gamma|_{\text{SENSOR}} \times 100\%$$

$$\text{Mismatch Uncertainty} = \pm 2 \times 0.33 \times 0.06 \times 100\% = \pm 3.96\%$$

$$|\Gamma| = \frac{\text{VSWR} - 1}{\text{VSWR} + 1}$$

Power Sensor Uncertainties



Cal Factor: $$K_b = \eta_e \frac{P_{gl}}{P_i}$$

P_i = incident power; P_r = reflected power
P_{gl} = net power transferred to the load from the generator

ηe = Effective Efficiency

Power Meter Instrumentation Uncertainties

Power reference uncertainty

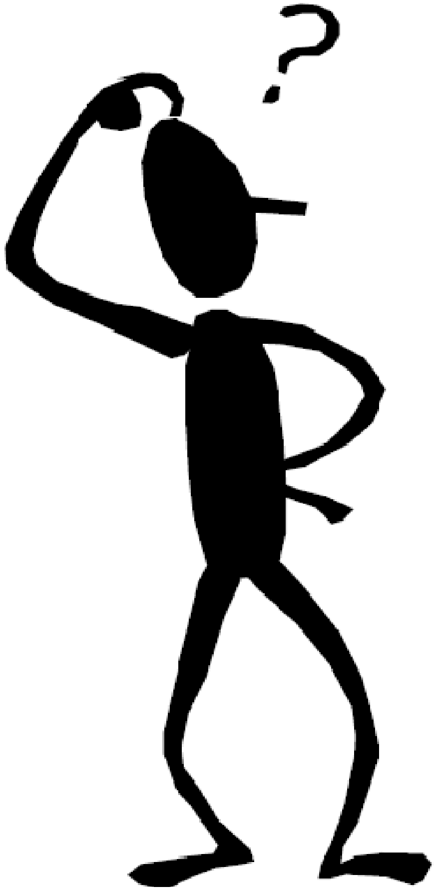
Noise

Drift

Zero Set

Instrumentation uncertainty

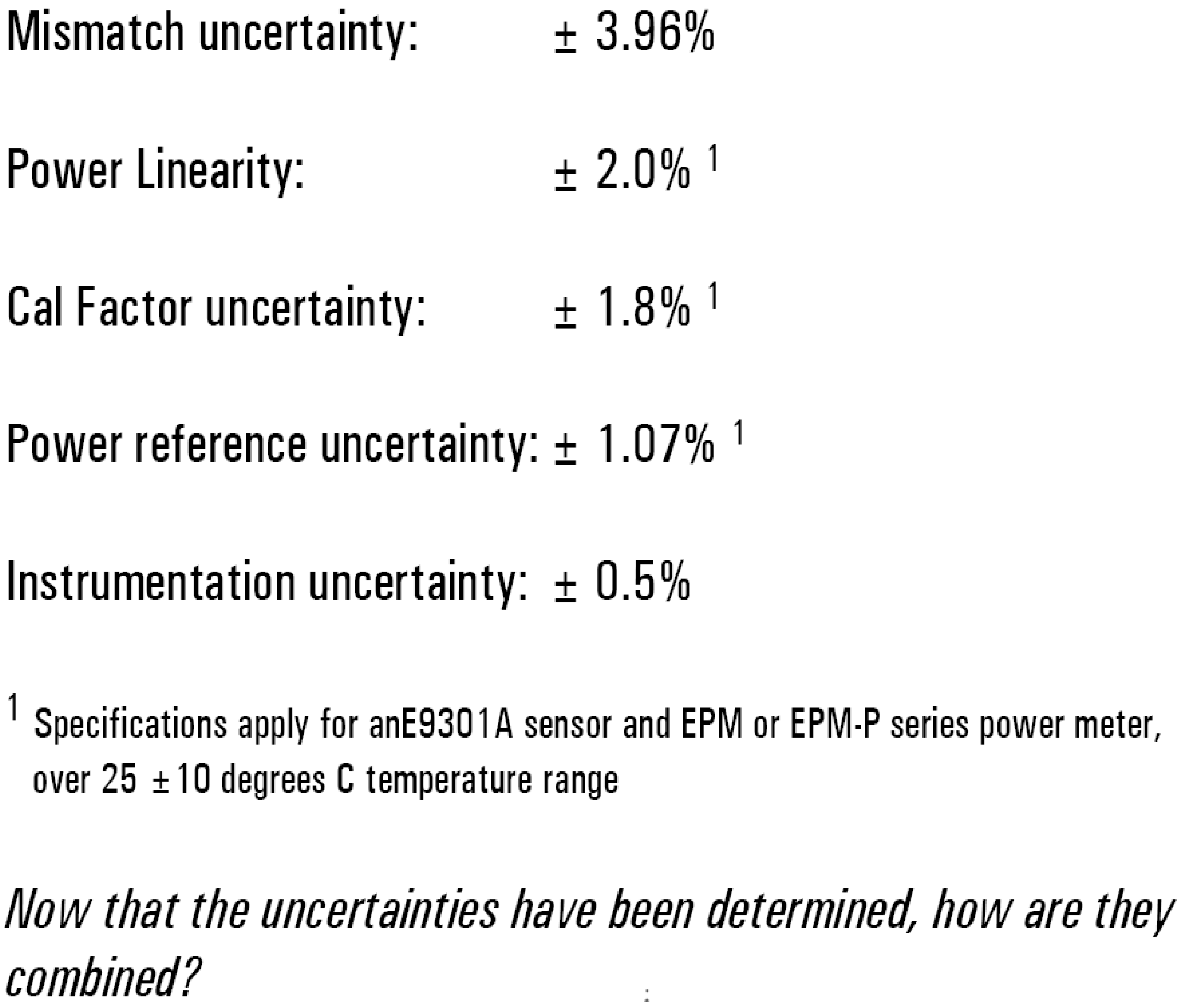
What is an acceptable meas. uncertainty?



- Reasonable Error Limits:
  - 0.5 dB?
  - or 12%

Which is the larger error?

Calculating Power Meas. Uncertainty



Mismatch uncertainty: ± 3.96%

Power Linearity: ± 2.0% [1]

Cal Factor uncertainty: ± 1.8% [1]

Power reference uncertainty: ± 1.07% [1]

Instrumentation uncertainty: ± 0.5%

[1] Specifications apply for anE9301A sensor and EPM or EPM-P series power meter, over 25 ±10 degrees C temperature range

Now that the uncertainties have been determined, how are they combined?

Worst-Case Uncertainty

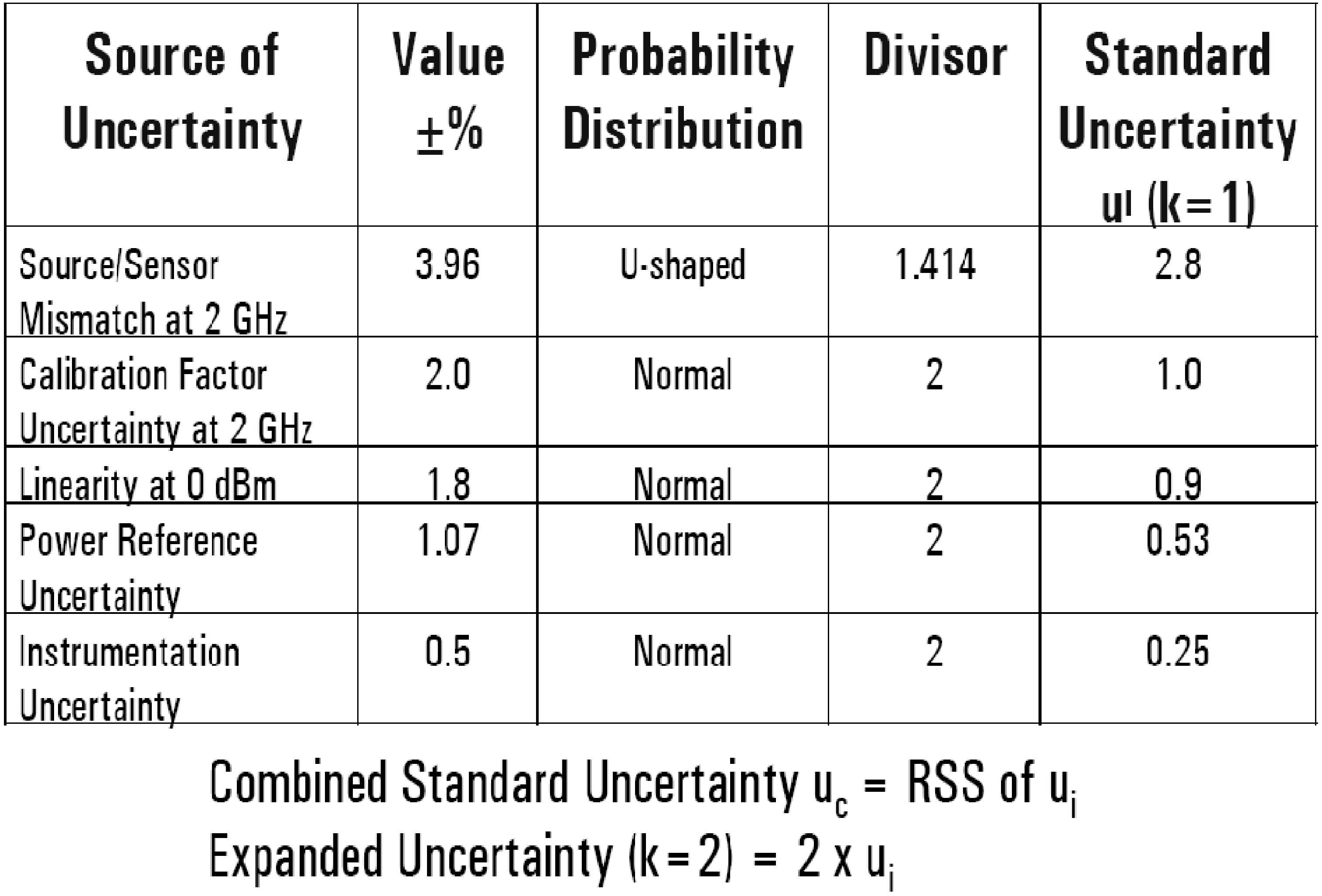
- In our example worst case uncertainty would be:

$$= 3.96\% + 2.0\% + 1.8\% + 1.07\% + 0.5\% = \pm\ 9.33\%$$

$$+9.33\% = 10 \log (1 + 0.093) = +0.39 \text{ dB}$$

$$-9.33\% = 10 \log (1 - 0.093) = -0.42 \text{ dB}$$

Combining the Measurement Uncertainties



Source of Uncertainty	Value ±%	Probability Distribution	Divisor	Standard Uncertainty u_i (k=1)
Source/Sensor Mismatch at 2 GHz	3.96	U-shaped	1.414	2.8
Calibration Factor Uncertainty at 2 GHz	2.0	Normal	2	1.0
Linearity at 0 dBm	1.8	Normal	2	0.9
Power Reference Uncertainty	1.07	Normal	2	0.53
Instrumentation Uncertainty	0.5	Normal	2	0.25

Combined Standard Uncertainty u_c = RSS of u_i

Expanded Uncertainty (k=2) = 2 x u_i

Combined Standard Uncertainty

- In our example, the u_c would be:

$$= \sqrt{(2.8)^2 + (1.0)^2 + (0.9)^2 + (0.53)^2 + (0.25)^2}$$

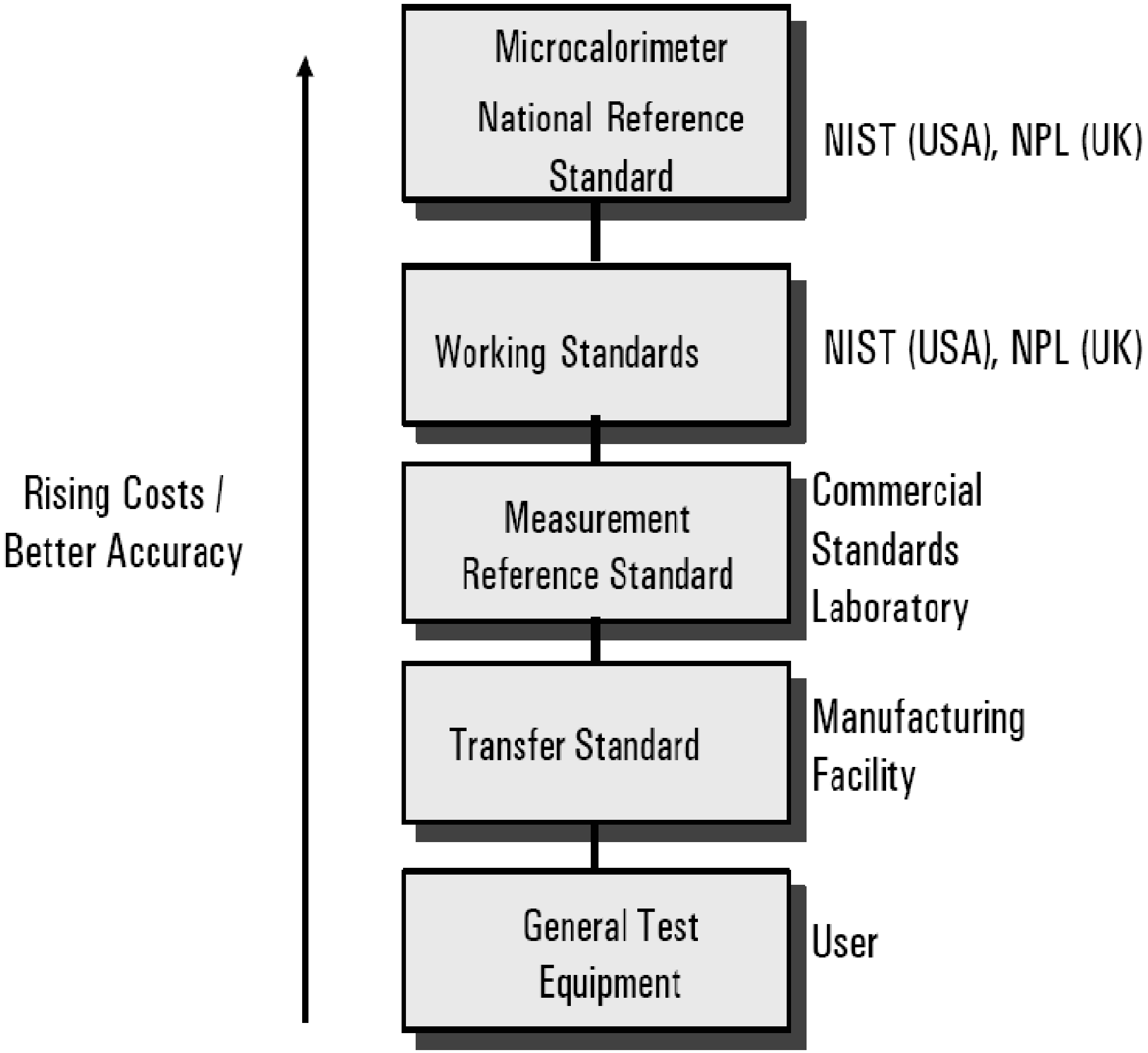
$$= \pm\, 3.16\%$$

- The Expanded Uncertainty (u) = 2 x 3.16 = ± 6.32%

$+\ 6.3\% = 10 \log (1 + 0.063) = +0.27$ dB *(+0.39 dB worst case)*

$-\ 6.3\% = 10 \log (1 - 0.063) = -0.28$ dB *(-0.42 dB worst case)*

National Standards and Traceability



Rising Costs / Better Accuracy

Microcalorimeter

National Reference Standard

NIST (USA), NPL (UK)

Working Standards

NIST (USA), NPL (UK)

Measurement Reference Standard

Commercial Standards Laboratory

Transfer Standard

Manufacturing Facility

General Test Equipment

User

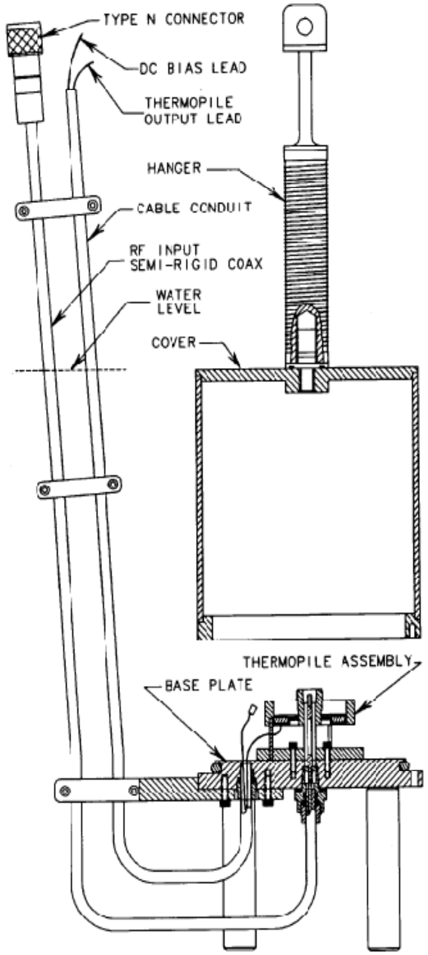


Figure 3-2. Schematic cross-section of the NIST coaxial microcalorimeter at Boulder, CO. The entire sensor configuration is maintained under a water bath with a highly-stable temperature so that RF to DC substitutions may be made precisely.