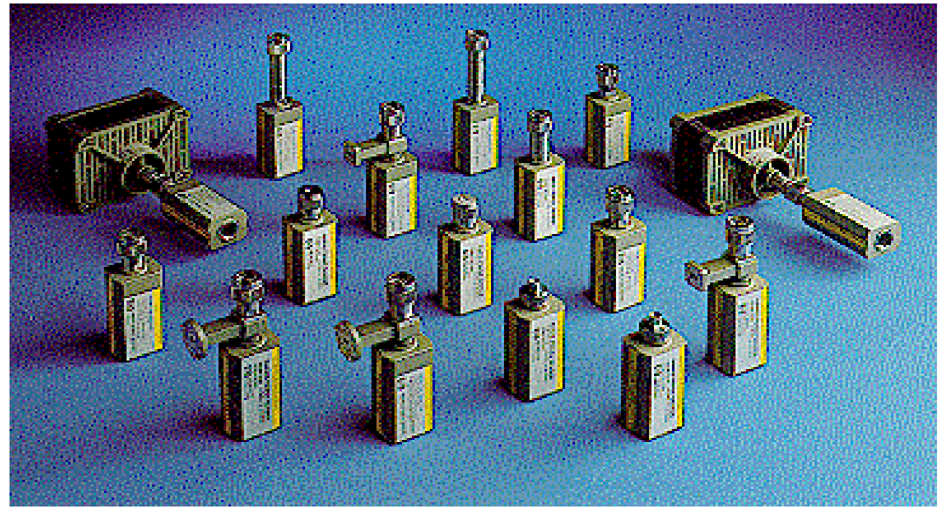
Power Measurement Basics



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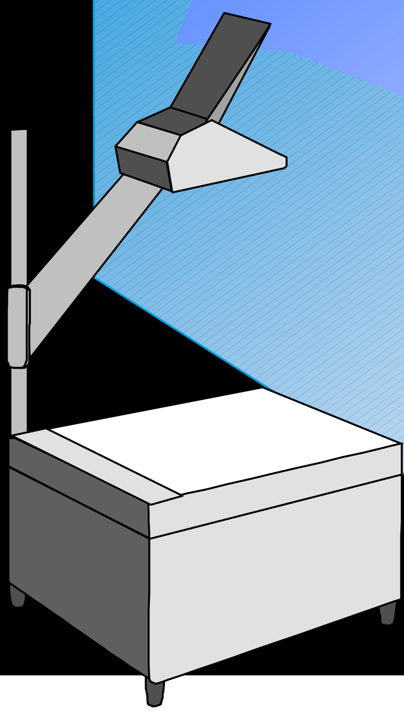
Agenda

- Importance and definitions of power measurements
- Measurement hardware
- Measurement uncertainty
- Considerations in choosing power measurement equipment



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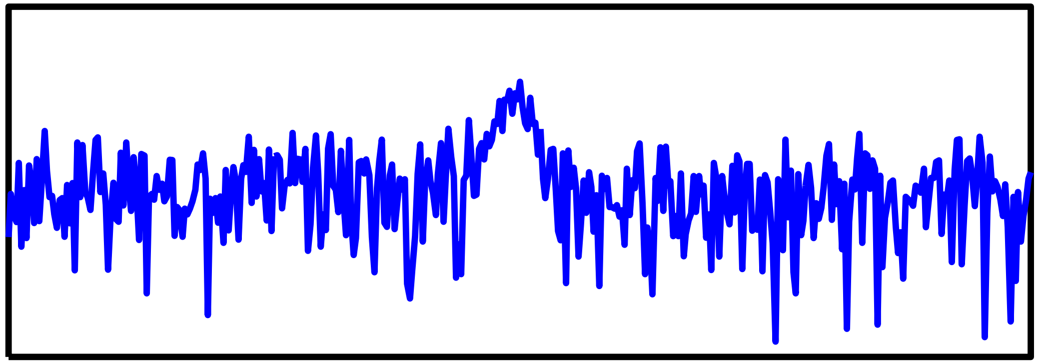
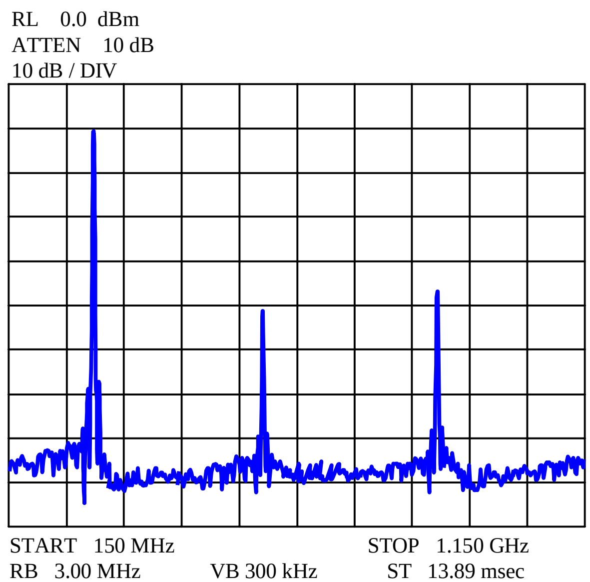
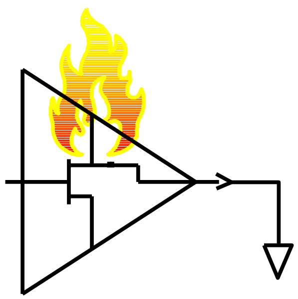
Importance of Proper Signal Levels

- Too low
  - Signal buried in noise



- Too high
  - Nonlinear distortion can occur

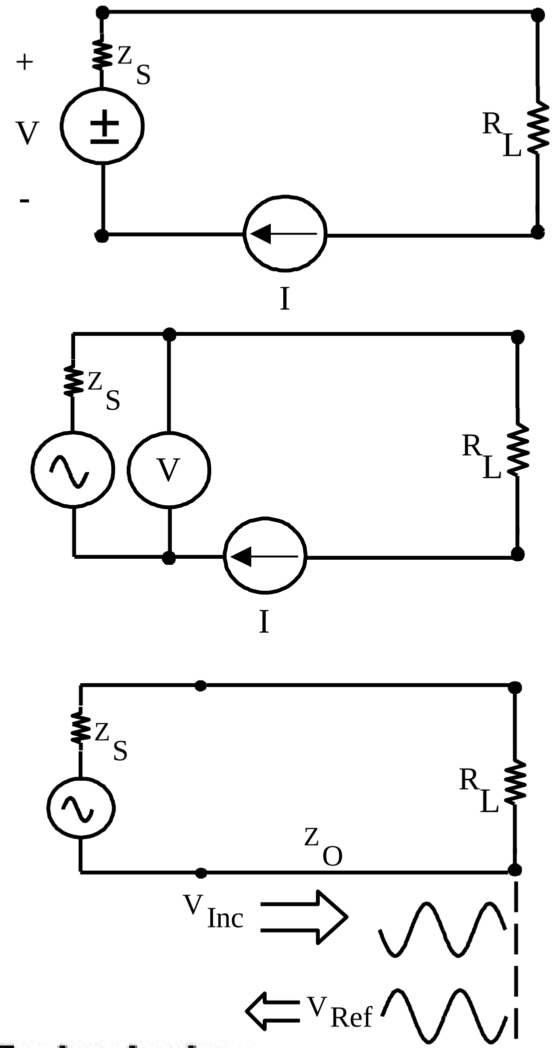




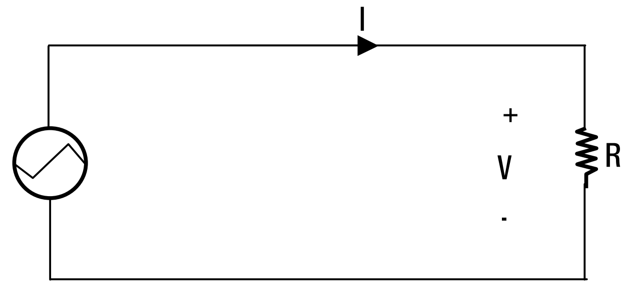
- Or even worse!

Why Not Measure Voltage?

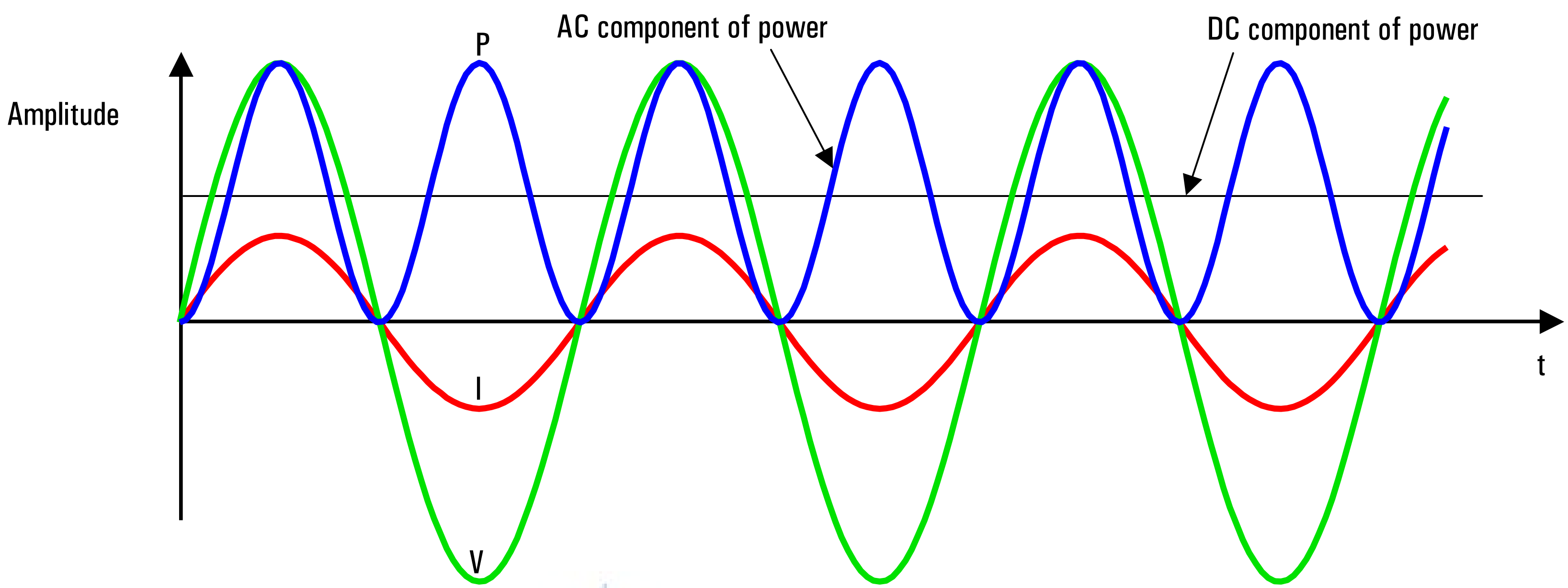
- DC
- Low Frequency
- High Frequency



Power: P = (I)(V)



I
+
V
-
R



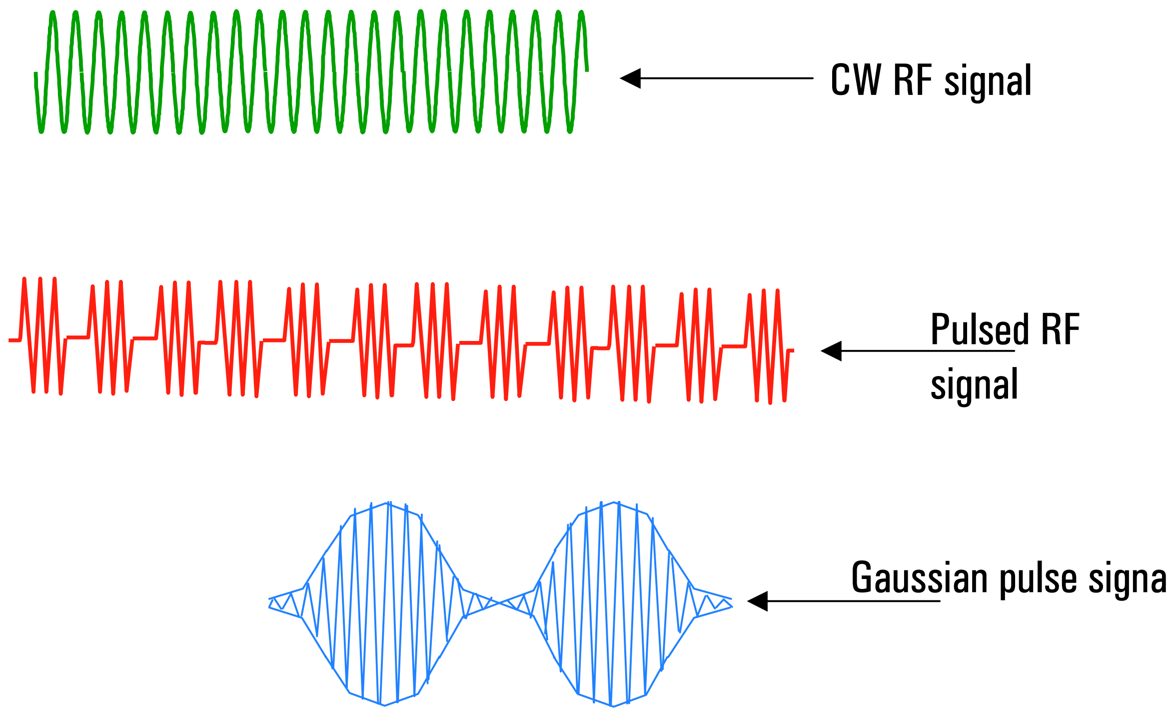
Amplitude
P
AC component of power
DC component of power
I
V
t

Units and Definitions

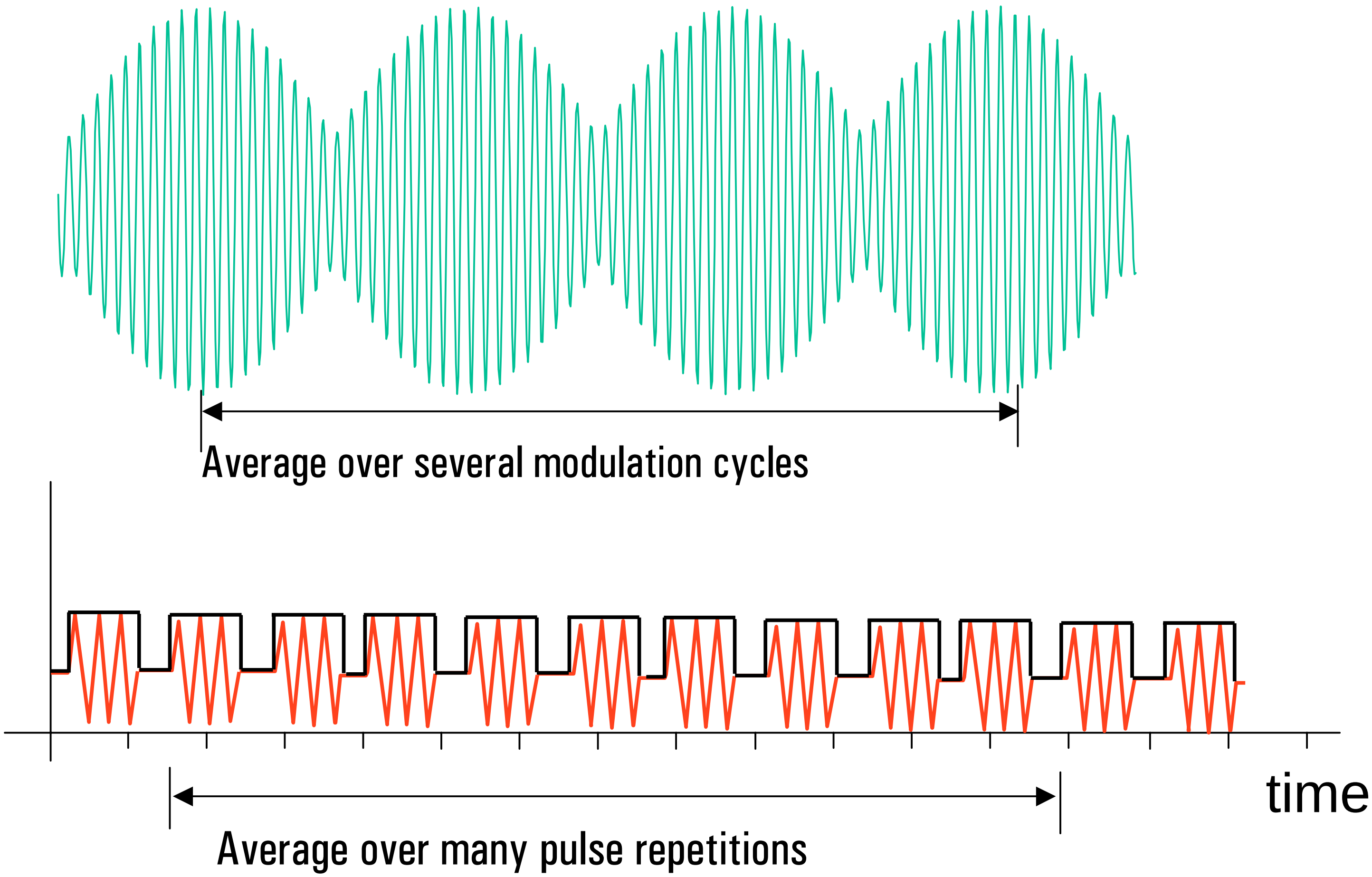
- Unit of power is the watt (W): 1W = 1 joule/sec
- Some electrical units are derived from the watt:
  1 volt = 1 watt/ampere
- Relative power measurements are expressed in dB:
  P(dB) = 10 log(P/Pref)
- Absolute power measurements are expressed in dBm:
  P(dBm) = 10 log(P/1 mW)

Types of Power Measurements

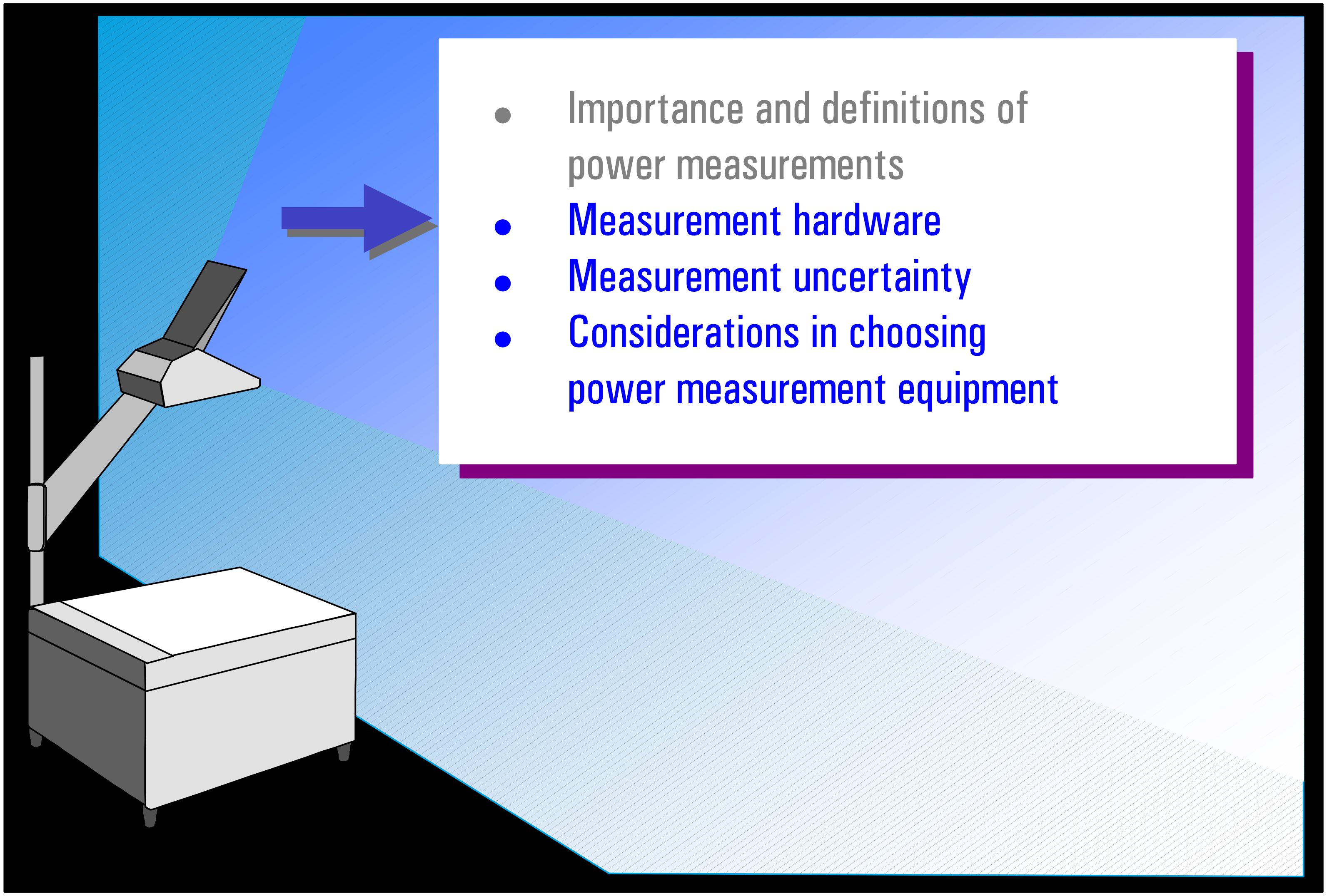
- Average Power
- Pulse Power
- Peak Envelope Power



Average Power



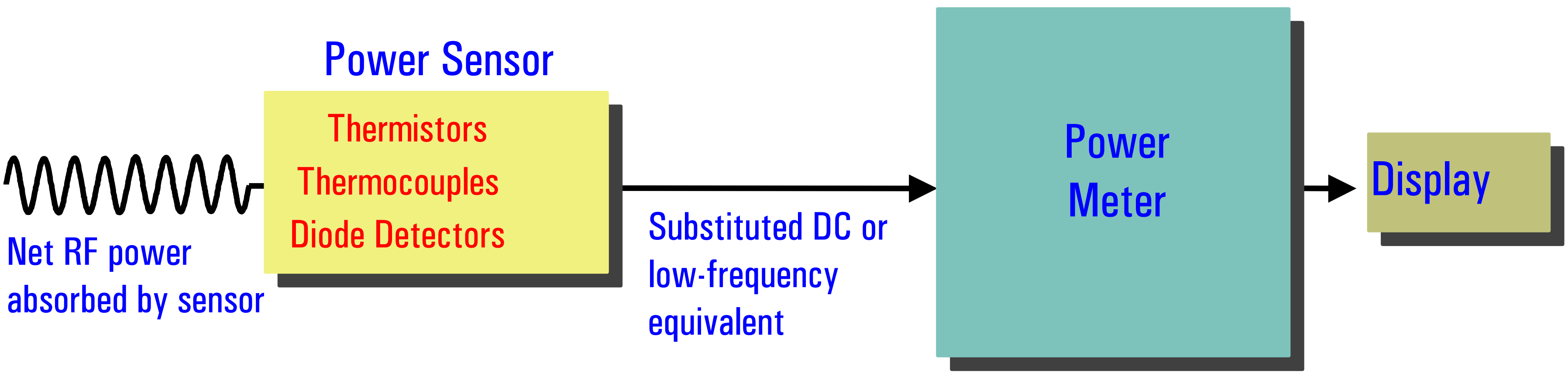
Agenda


• Importance and definitions of power measurements
• Measurement hardware
• Measurement uncertainty
• Considerations in choosing power measurement equipment

Instruments used to Measure RF and Microwave Power

- Oscilloscope w/ detector
- Spectrum analyzer
- Network analyzer
- Power meter

Basic Measurement Method - Using a Power Meter

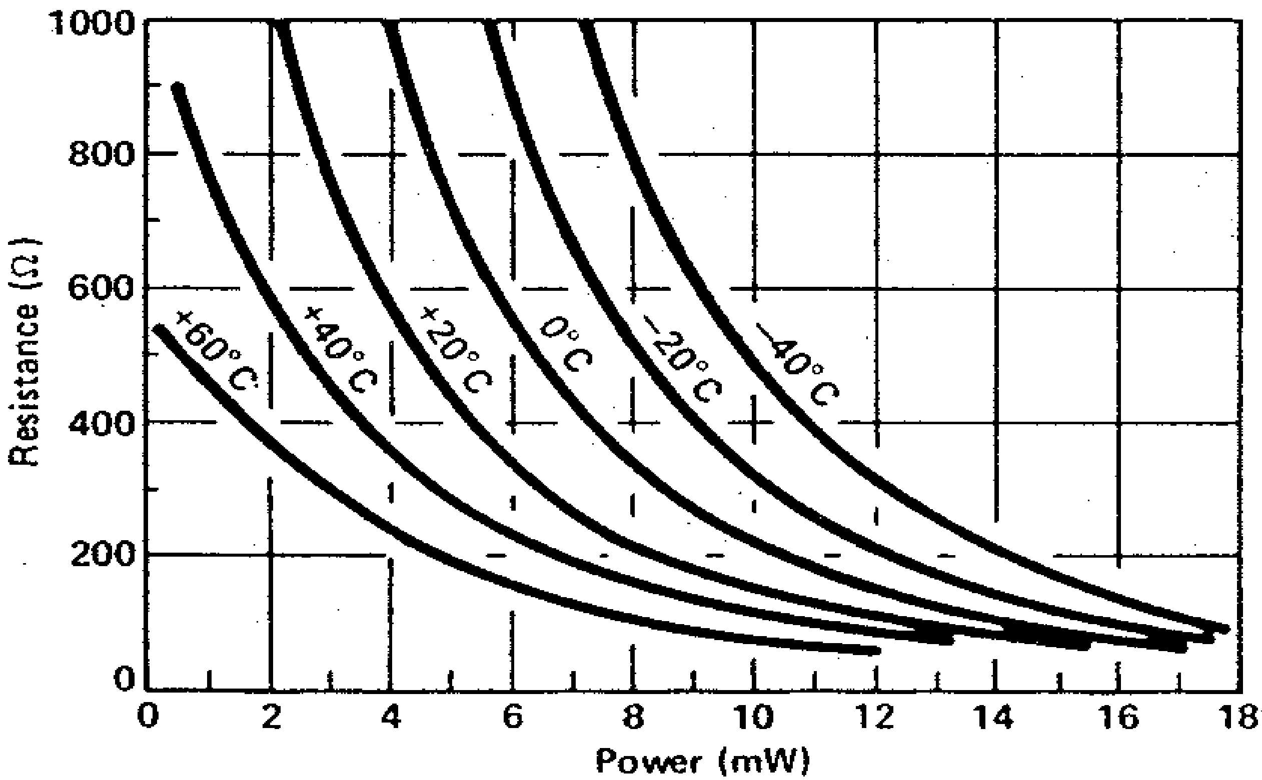


Thermistors

Thermocouples

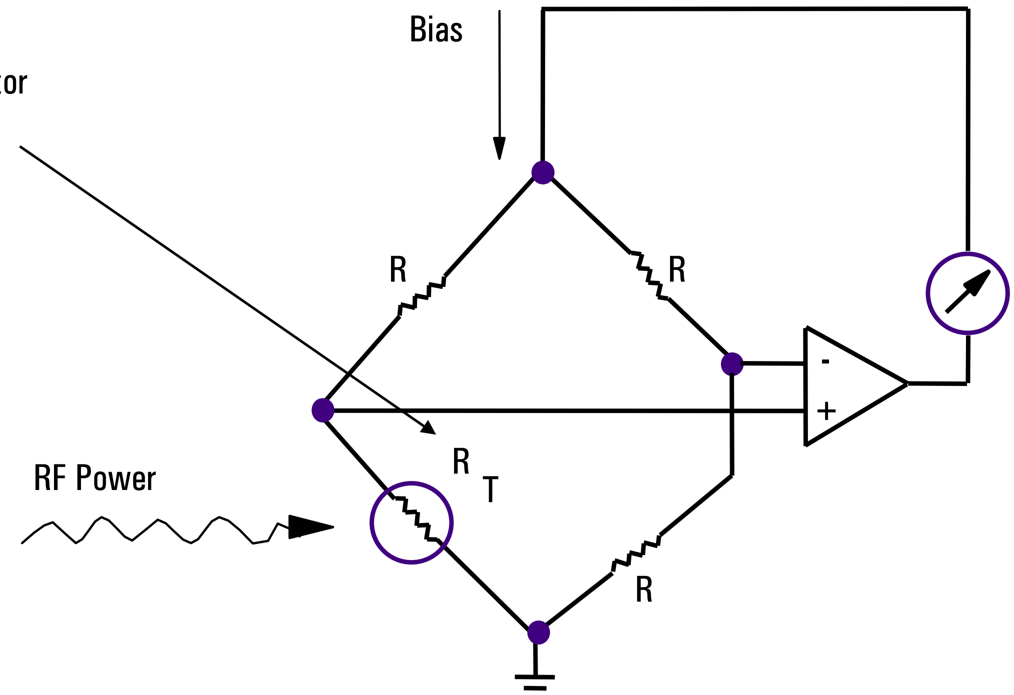
Diode Detectors

Characteristic curves of a typical thermistor element



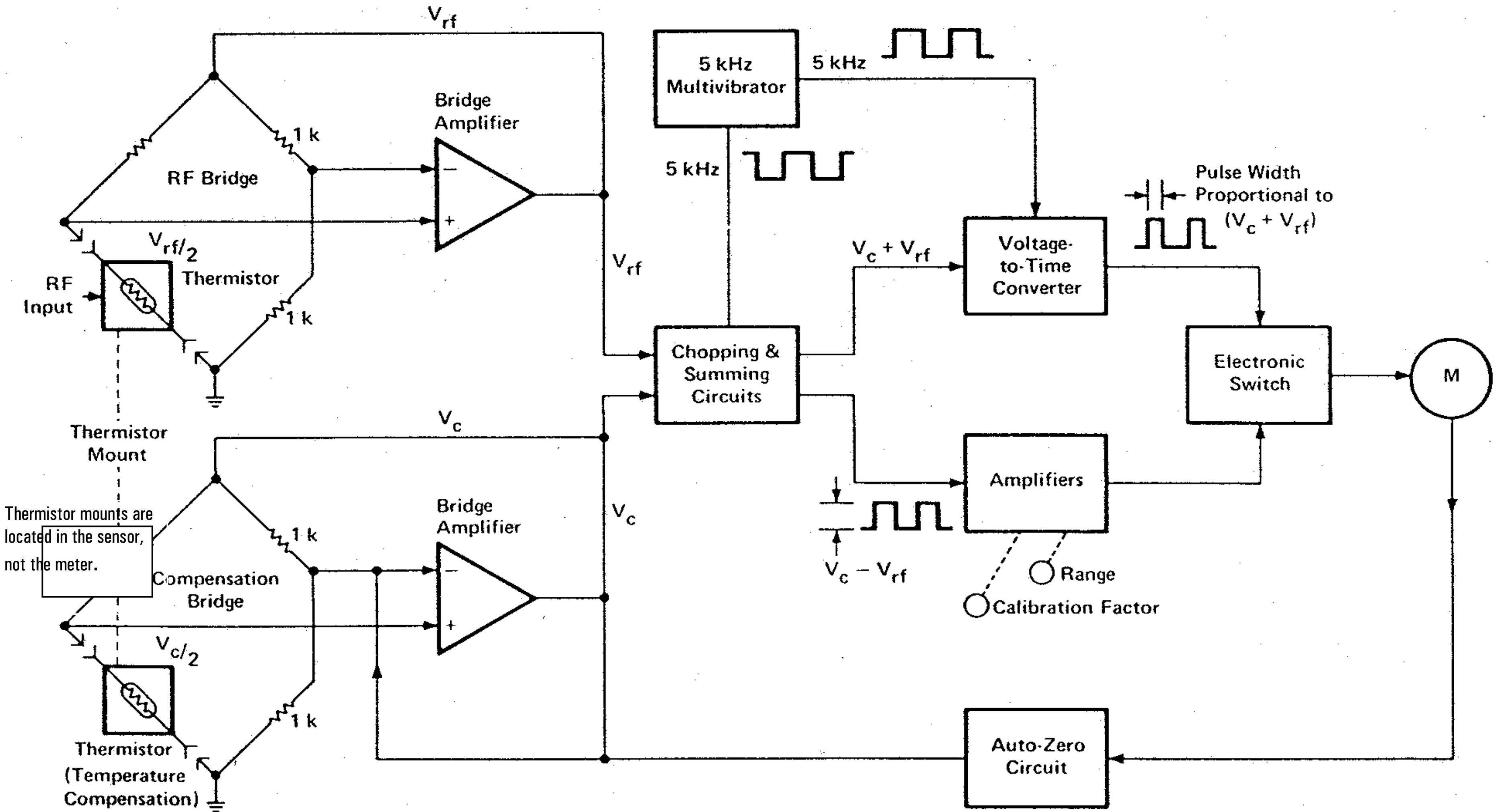
Thermistors
Thermocouples
Diode Detectors

A self-balancing bridge containing a thermistor



Power Meters for Thermistor Mounts

- 432A Power Meter



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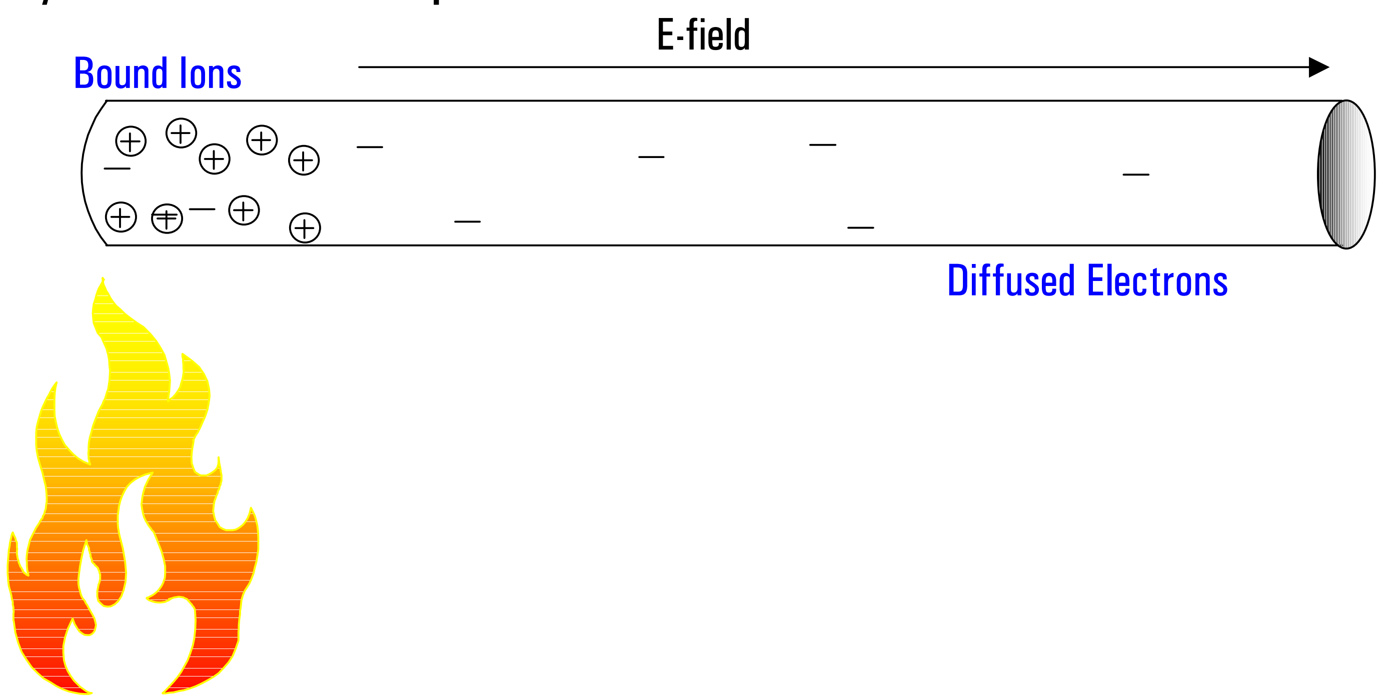
Thermistors

Thermocouples

Diode Detectors

- Physics of a thermocouple

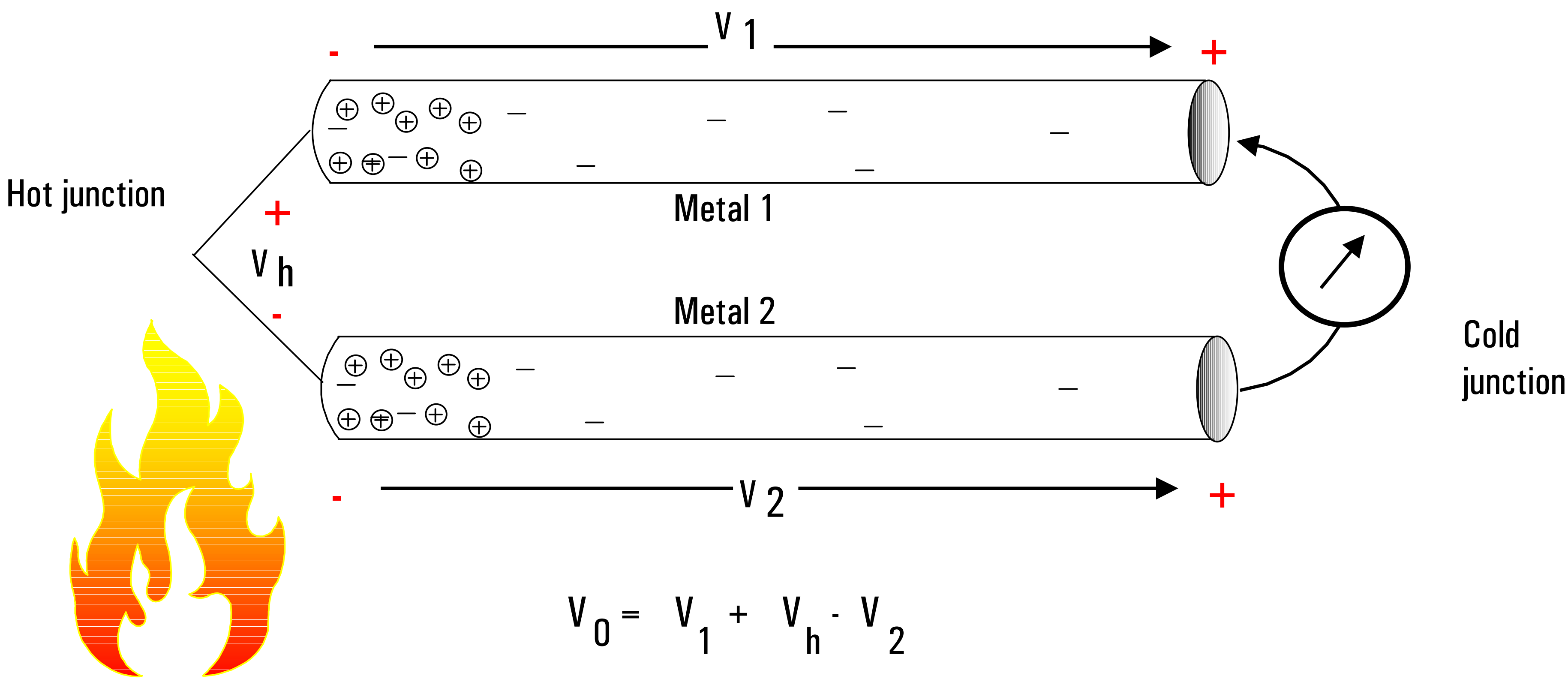


Thermistors

Thermocouples

Diode Detectors

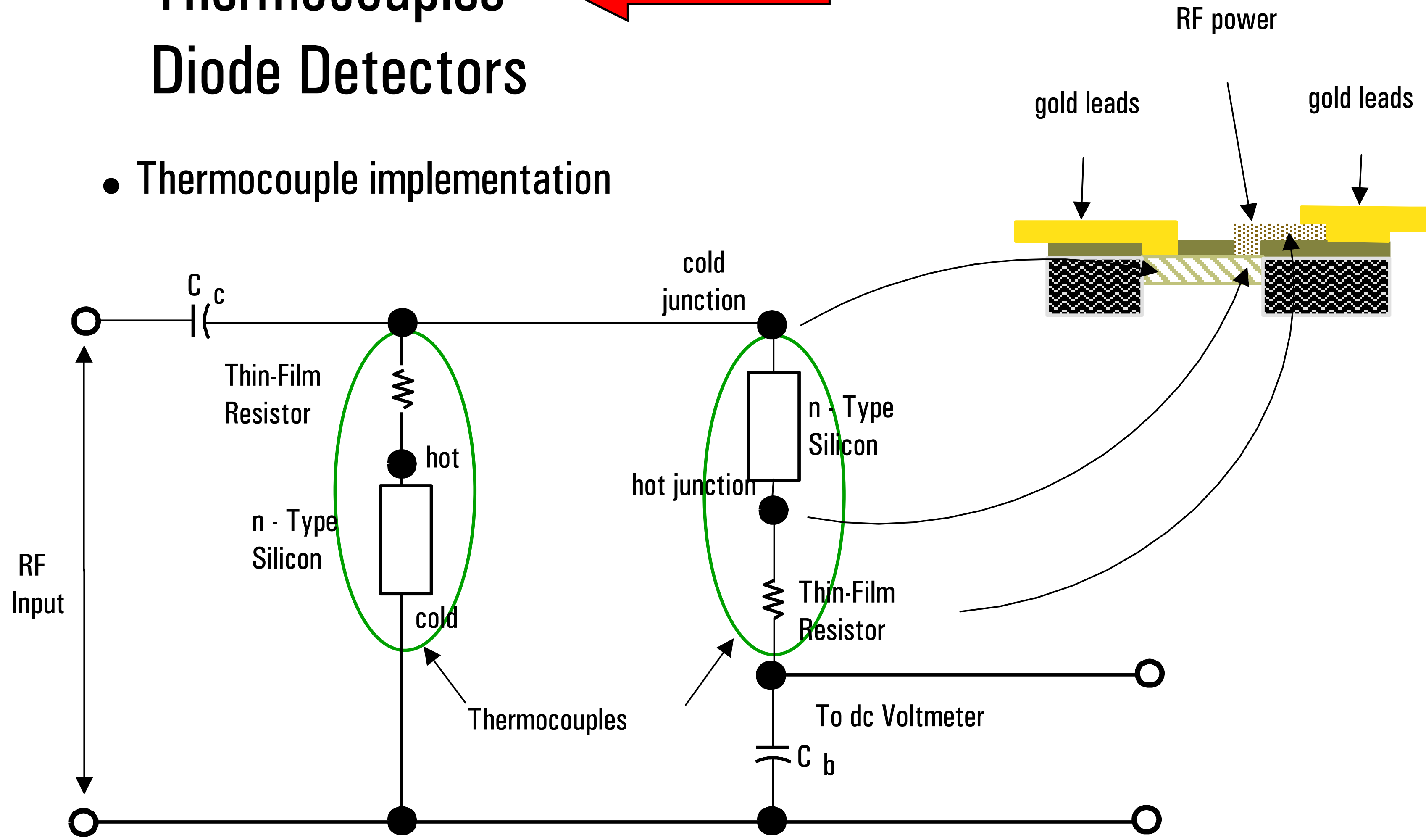
- The principles behind the thermocouple



$$V_0 = V_1 + V_h - V_2$$

Thermistors
Thermocouples
Diode Detectors

- Thermocouple implementation



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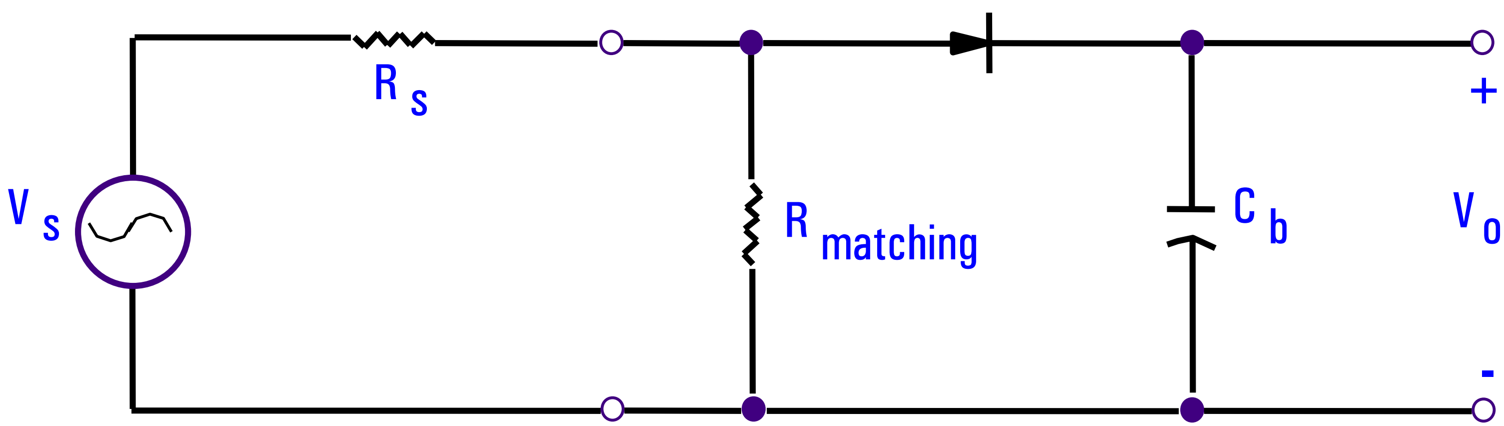
Thermistors

Thermocouples

Diode Detectors

- How does a diode detector work?



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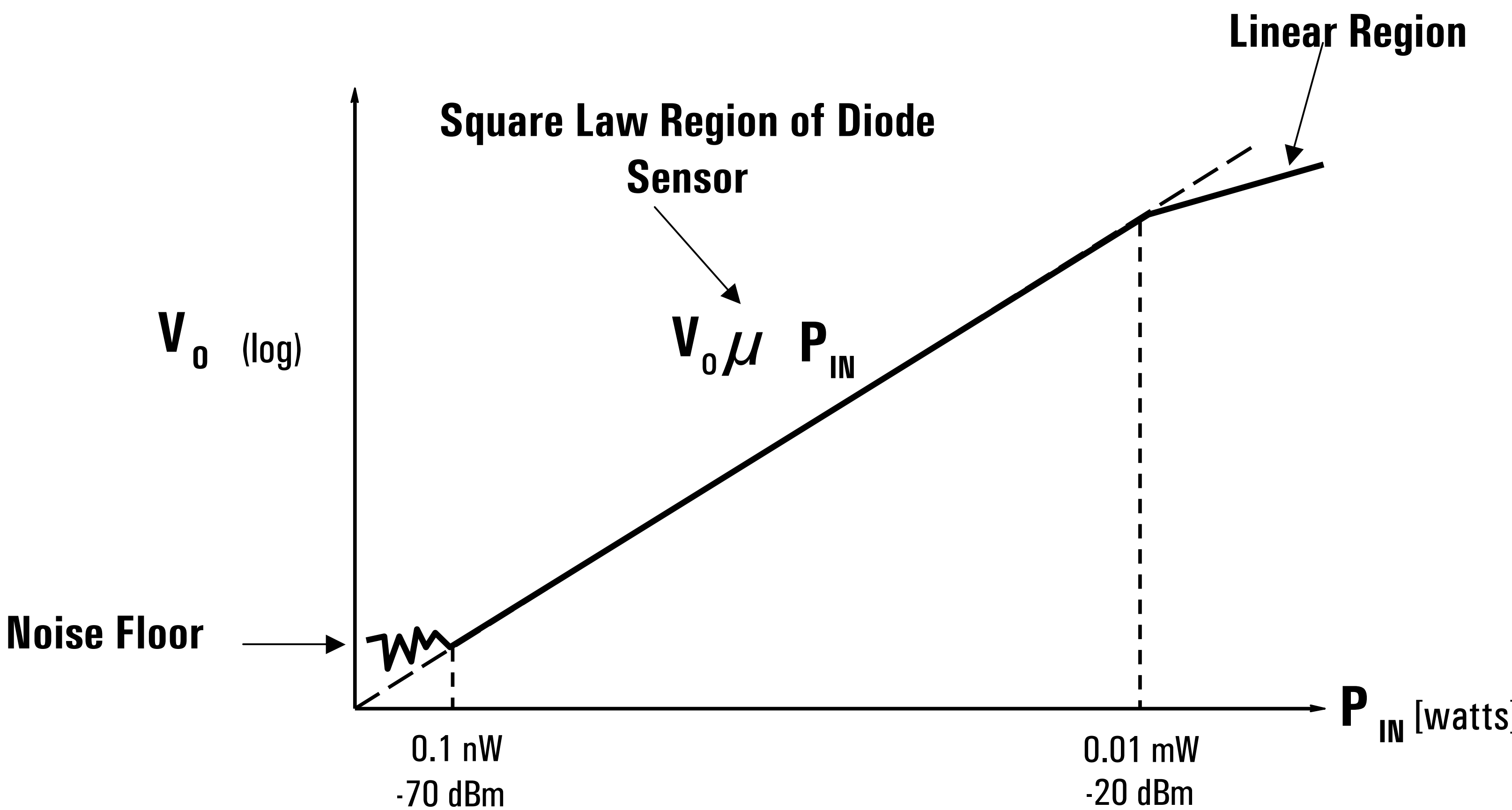
Thermistors

Thermocouples

Diode Detectors



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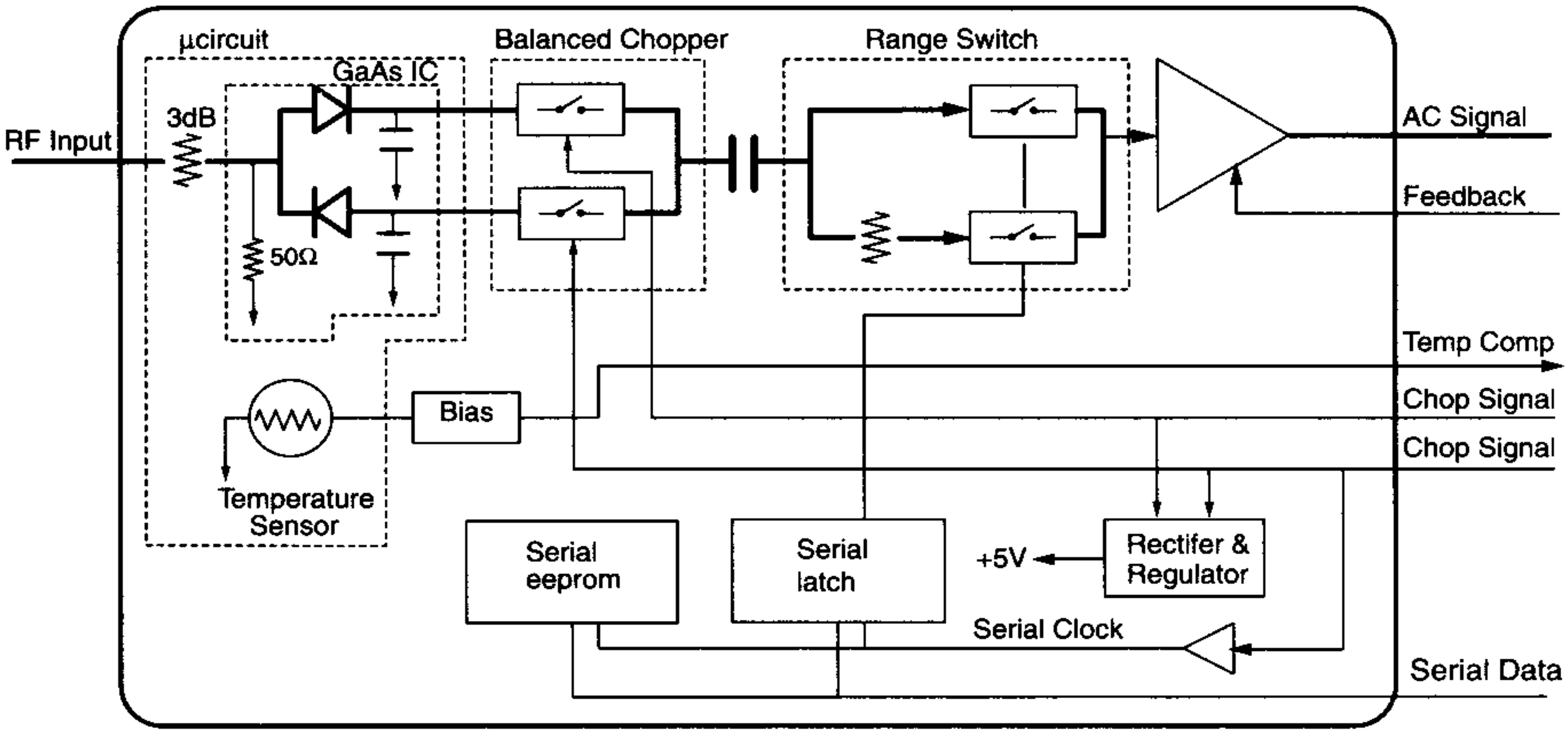
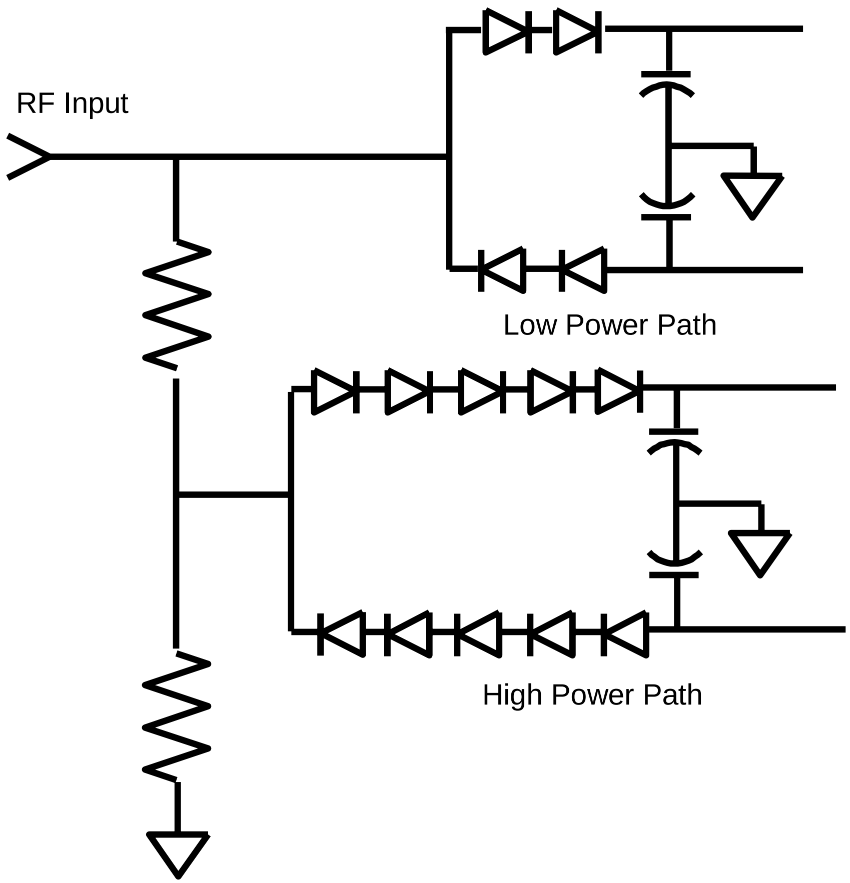
Wide-Dynamic-Range CW-only Power Sensors



E-series E9300 Power Sensors Technology



Innovative Design:

- Diode stack- attenuator- diode stack topology
- Unique to Agilent
- US Patent applied for

Agilent Technologies

Advantages of the E-series E9300 sensor architecture

- Sensor diodes always kept in square law region.
- Accurate measurement of signals with high peak to average ratios.
- Accurate measurement of signals with arbitrarily wide modulation bandwidth.
- Flat calibration factors give accurate measurement of multi-tone signals.

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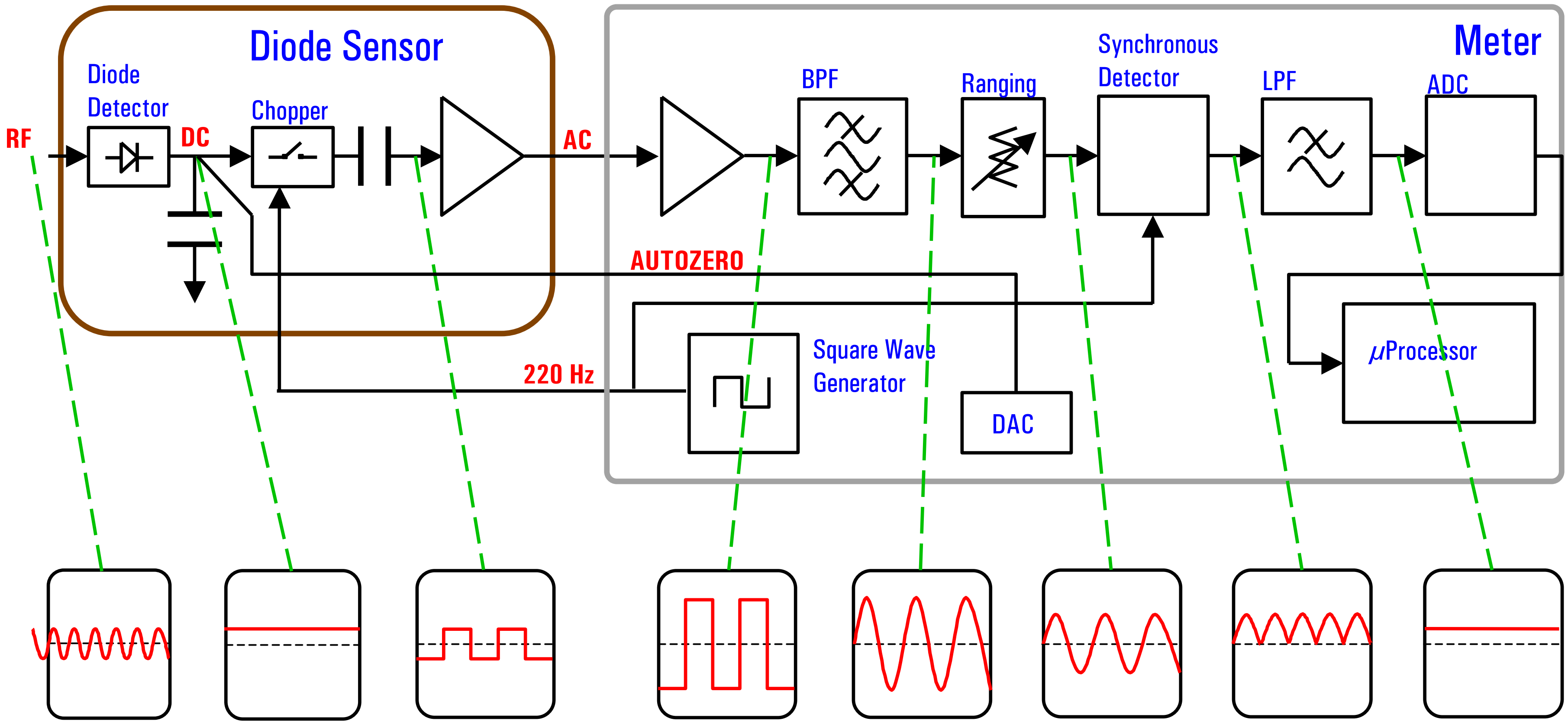
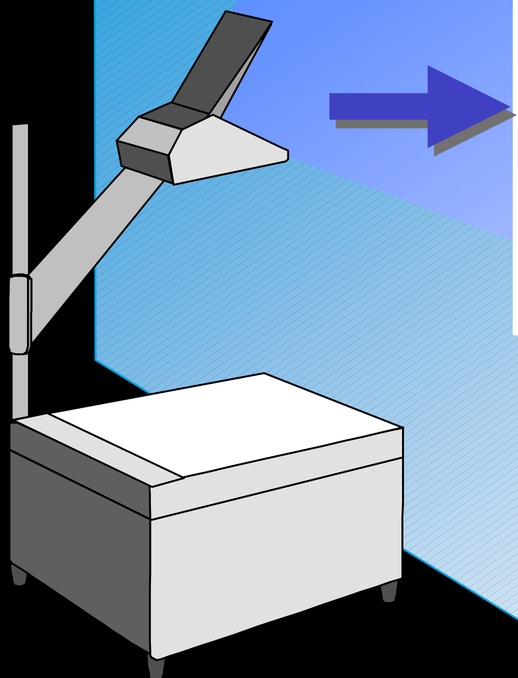
Basic Measurement Method Explained



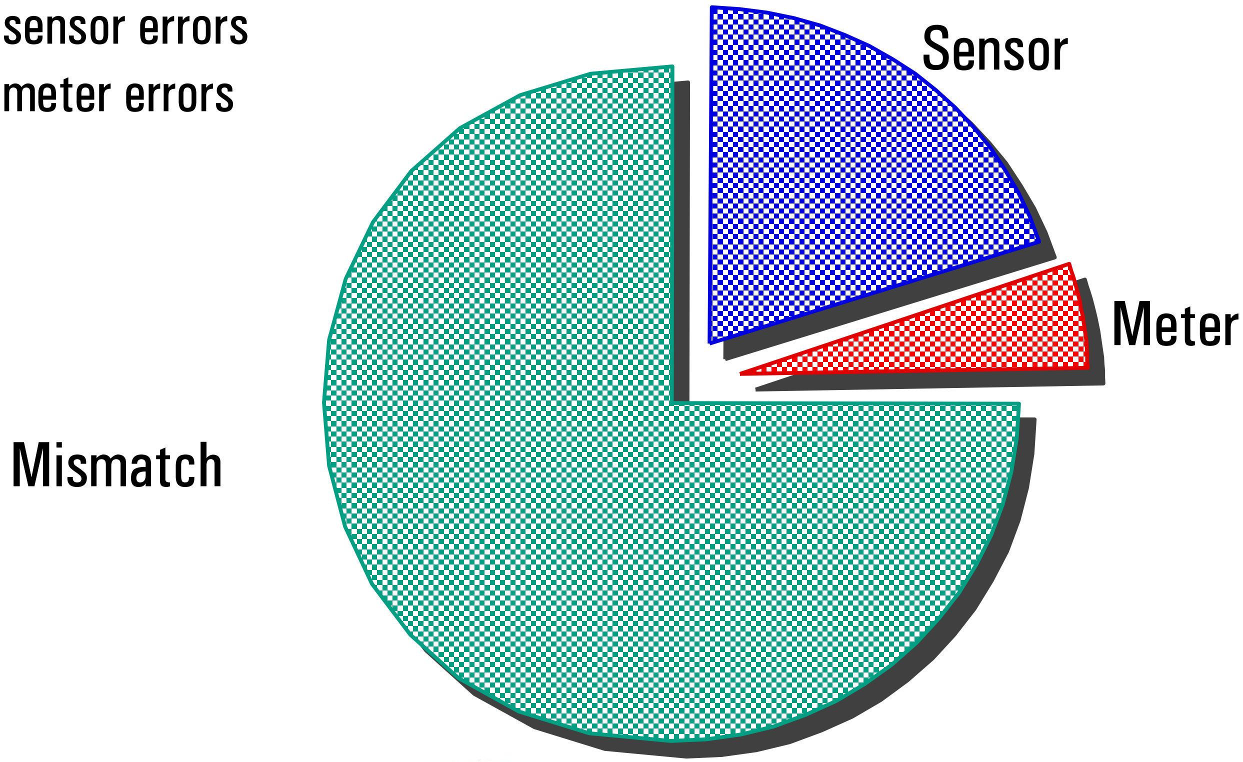
Agenda



- Importance and definitions of power measurements
- Types of power measurements
- Measurement hardware
- Measurement uncertainty
- Considerations in choosing power measurement equipment

Sources of Power Measurement Uncertainty

- Sensor and source mismatch errors
- Power sensor errors
- Power meter errors



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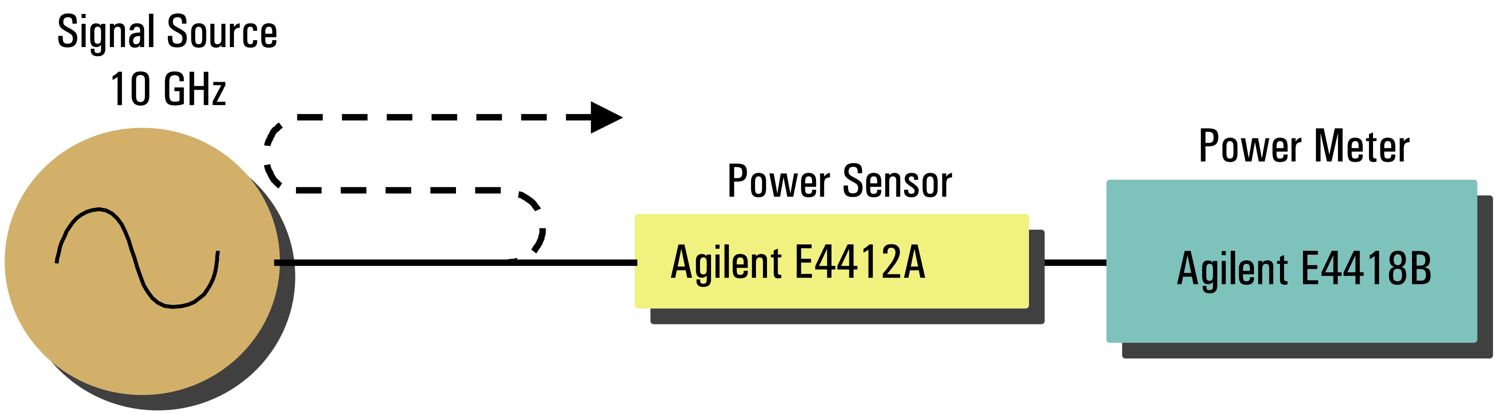
Calculation of Mismatch Uncertainty



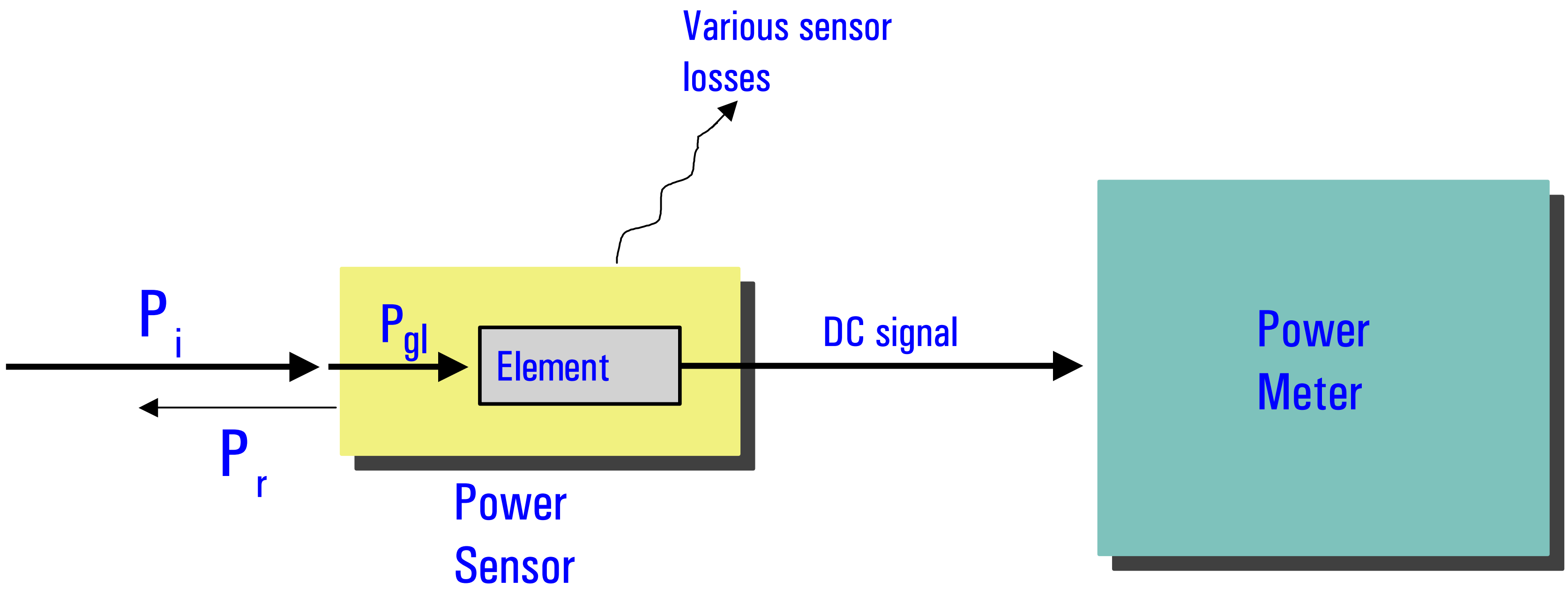
SWR = 2.0
$\rho_{SOURCE} = 0.33$

SWR = 1.22
$\rho_{SENSOR} = 0.10$

$$\text{Mismatch Uncertainty} = \pm 2 \cdot \rho_{SOURCE} \cdot \rho_{SENSOR} \cdot 100\%$$

$$\text{Mismatch Uncertainty} = \pm 2 \cdot 0.33 \cdot 0.10 \cdot 100\% = \pm 6.6\%$$

Power Sensor Uncertainties
(Effective Efficiency)



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

Power Meter Instrumentation Uncertainties

+/- 1 count

Power reference uncertainty

Zero Carryover

Drift

Noise

Zero Set

Instrumentation uncertainty

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Calculating Power Measurement Uncertainty

Mismatch uncertainty:	± 6.6%
Cal factor uncertainty:	± 3.1%
Power reference uncertainty:	± 1.2%
Instrumentation uncertainty:	± 0.5%

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

Worst-Case Uncertainty

- In our example worst case uncertainty would be:

$$= 6.6\% + 3.1\% + 1.2\% + 0.5\% = \pm 11.4\%$$

$$+11.4\% = 10 \log (1 + 0.114) = + 0.47 \text{ dB}$$

$$- 11.4\% = 10 \log (1 - 0.114) = - 0.53 \text{ dB}$$

RSS Uncertainty

- In our example RSS uncertainty would be:

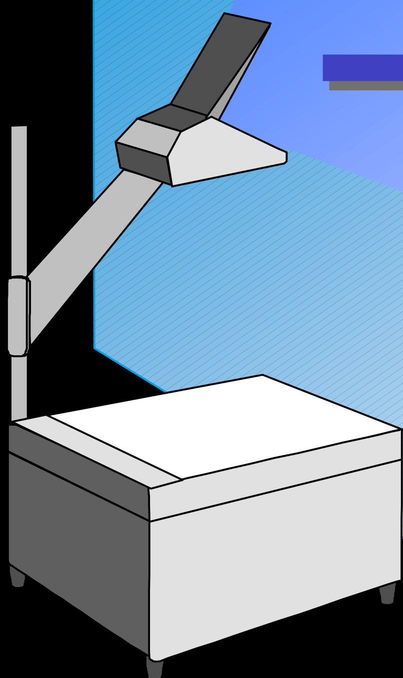
$$= \sqrt{(6.6\%)^2 + (3.1\%)^2 + (1.2\%)^2 + (0.5\%)^2}$$

$$= \pm\ 7.4\%$$

$$+\ 7.4\% = 10 \log (1 + 0.074) = +0.31 \text{ dB}$$

$$-\ 7.4\% = 10 \log (1 - 0.074) = -0.33 \text{ dB}$$

Agenda



- Importance and definitions of power measurements
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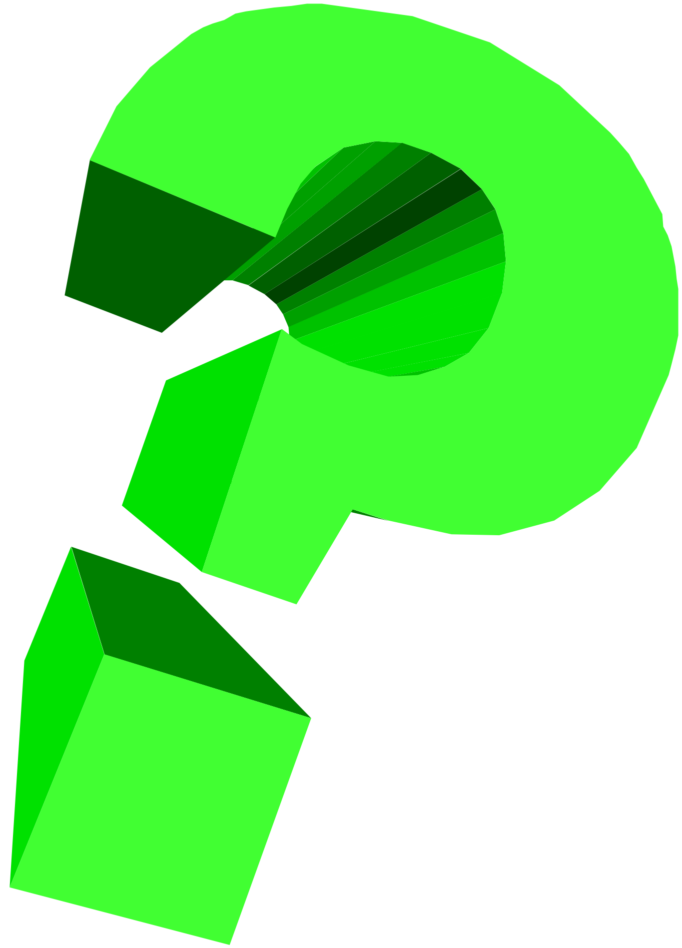
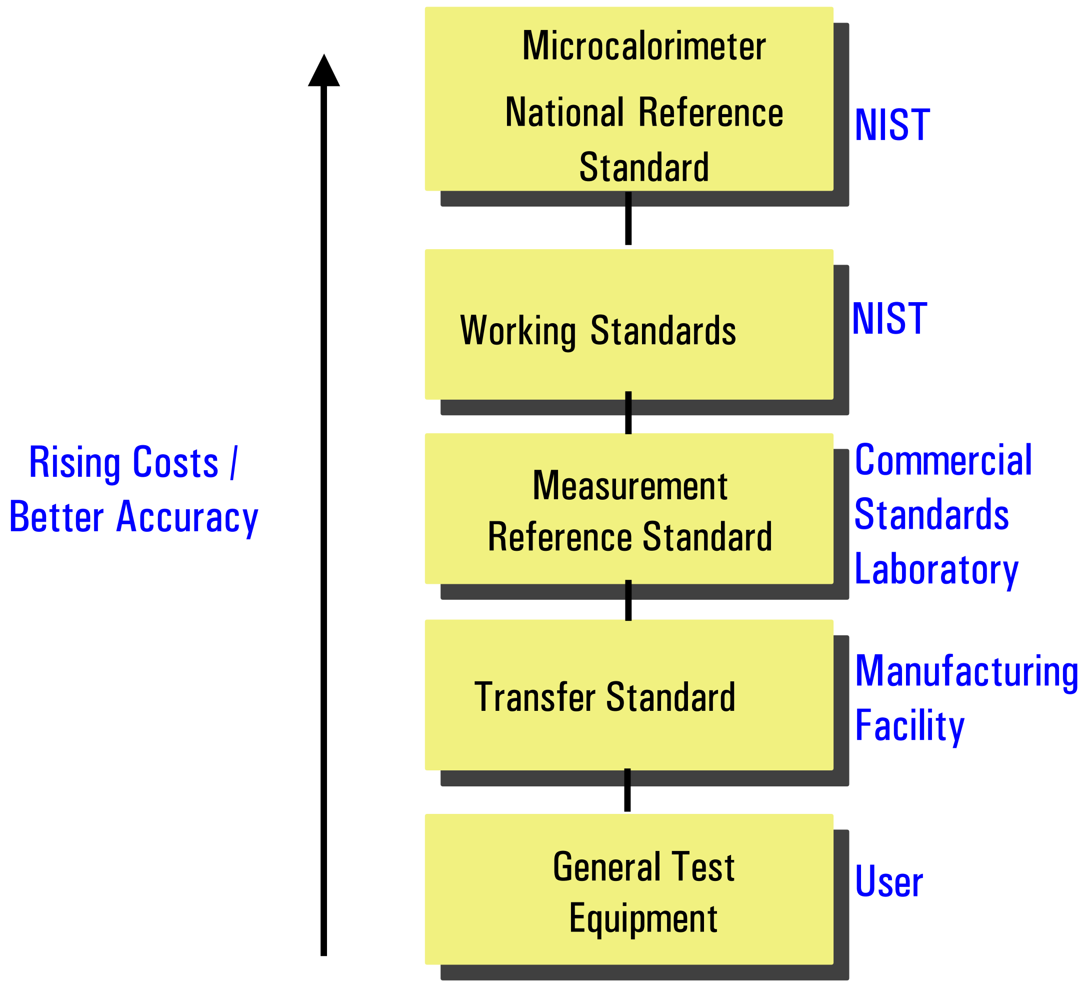
Considerations in Choosing Power Measurement Equipment



Thermistors as Transfer Standards



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SWR (Reflection Coefficient)

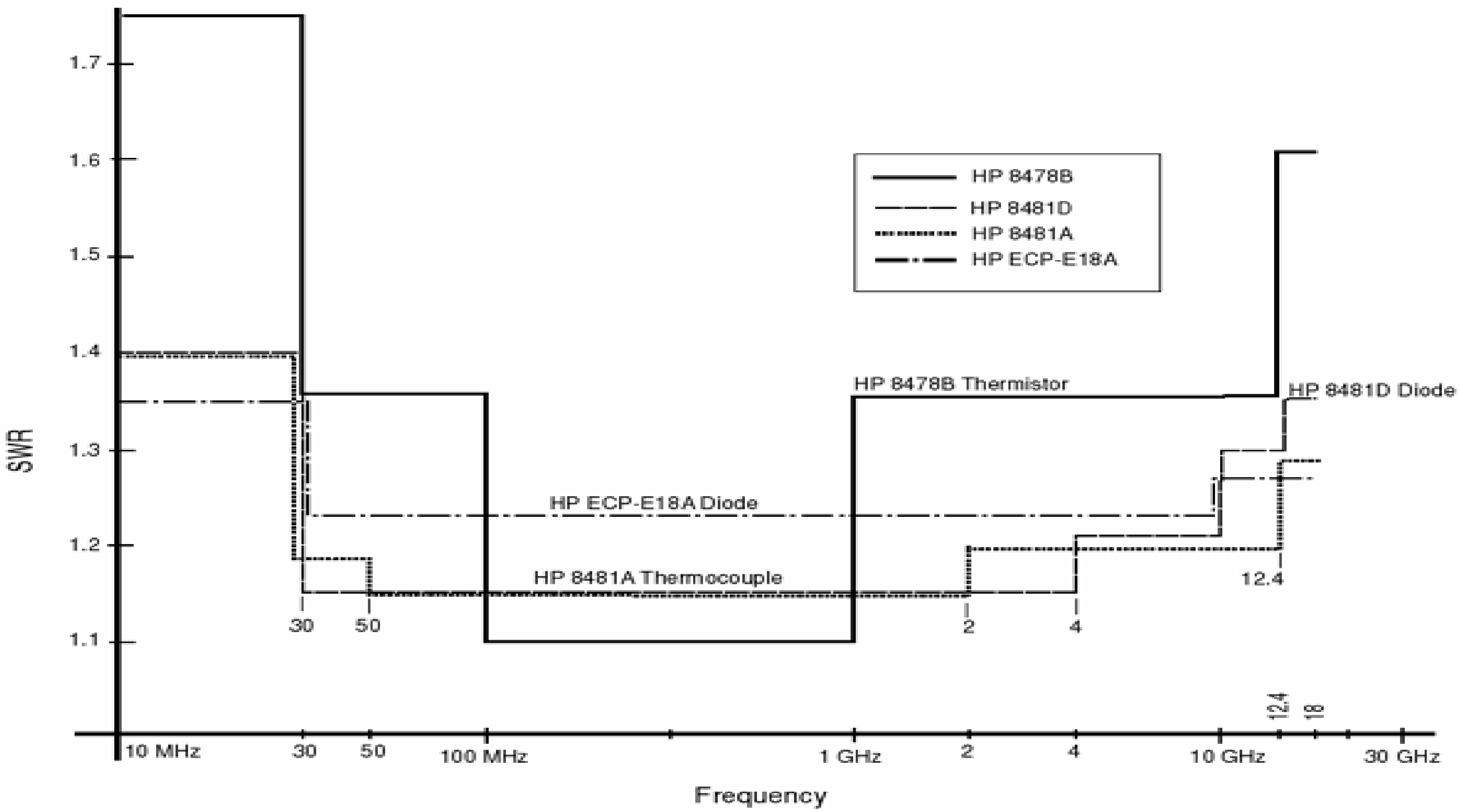
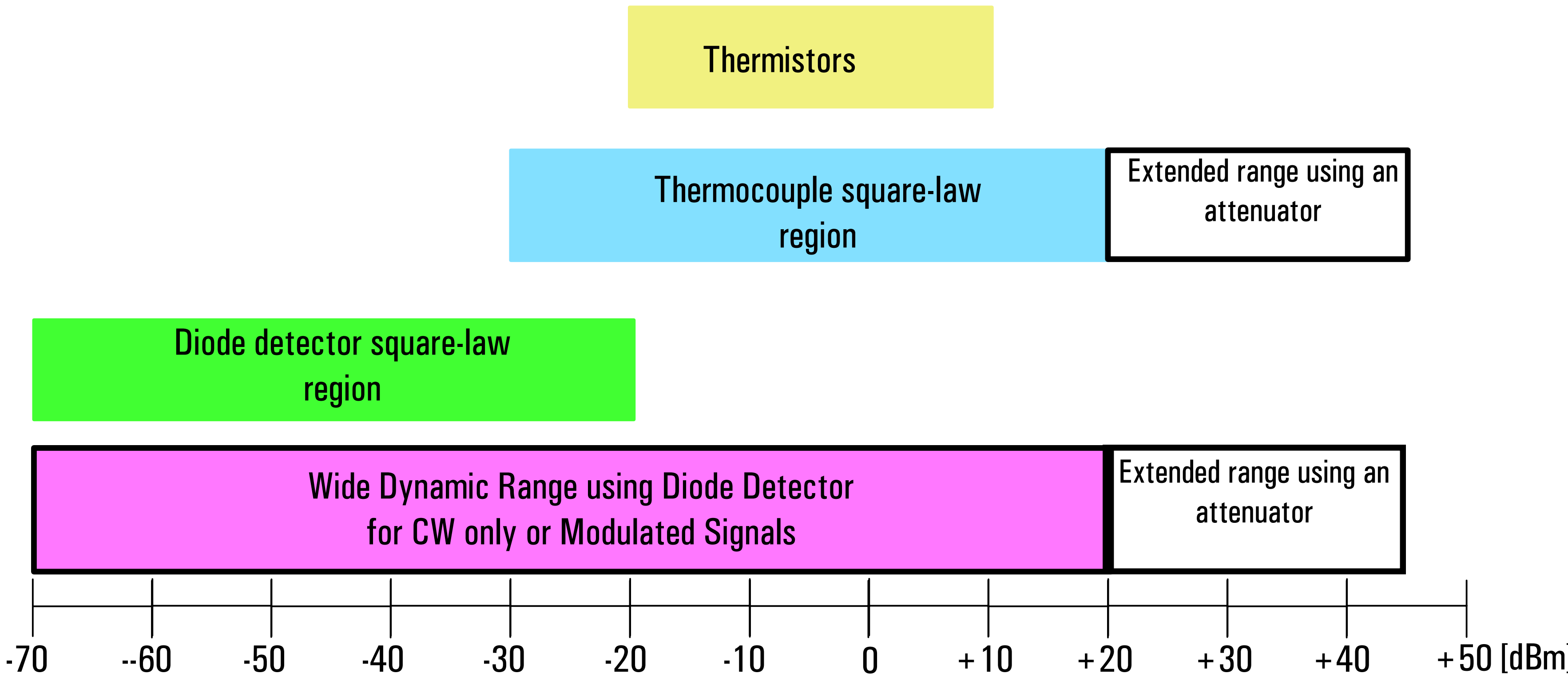


Fig 7-2

Power Ranges of the Various Sensor Types

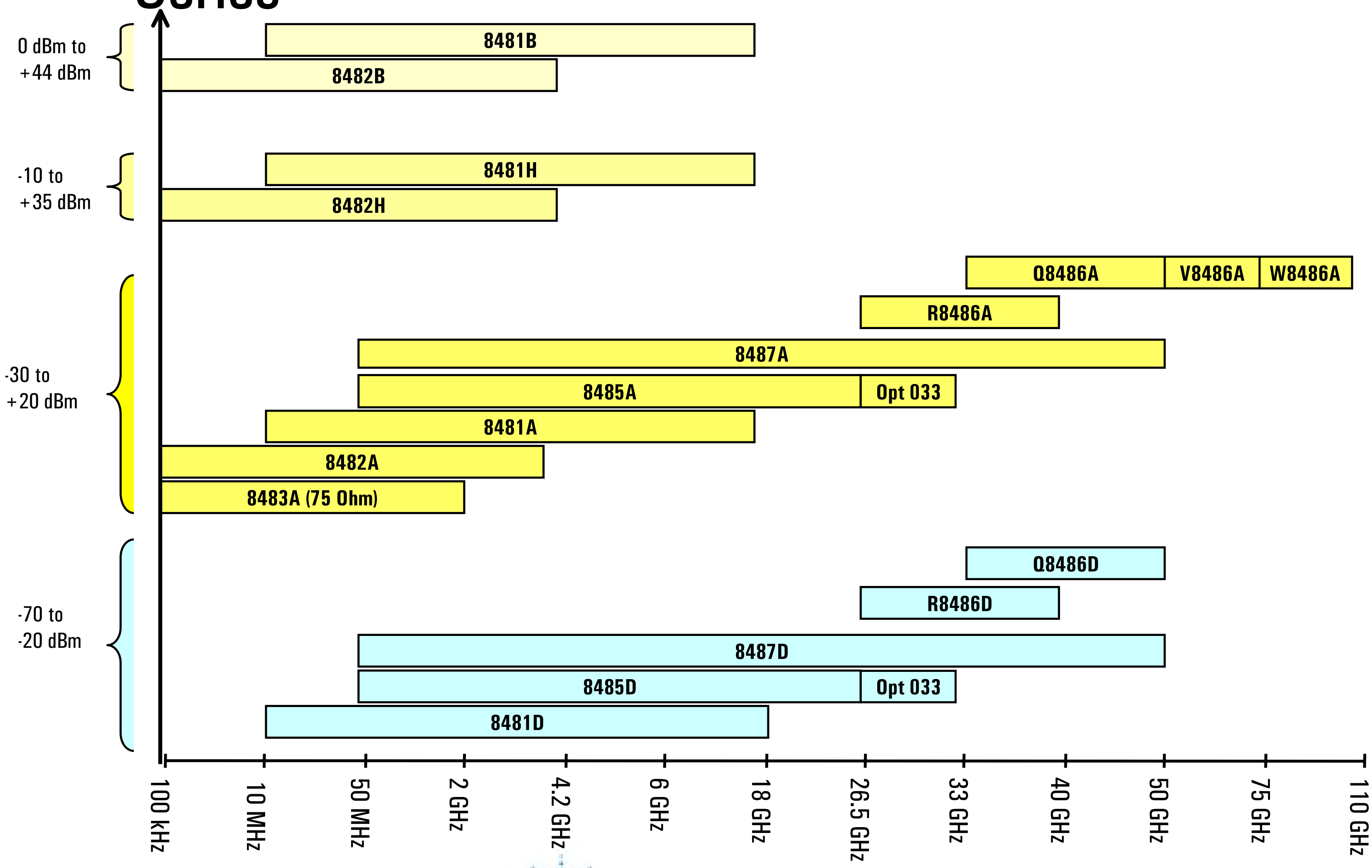


Susceptibility to Overload

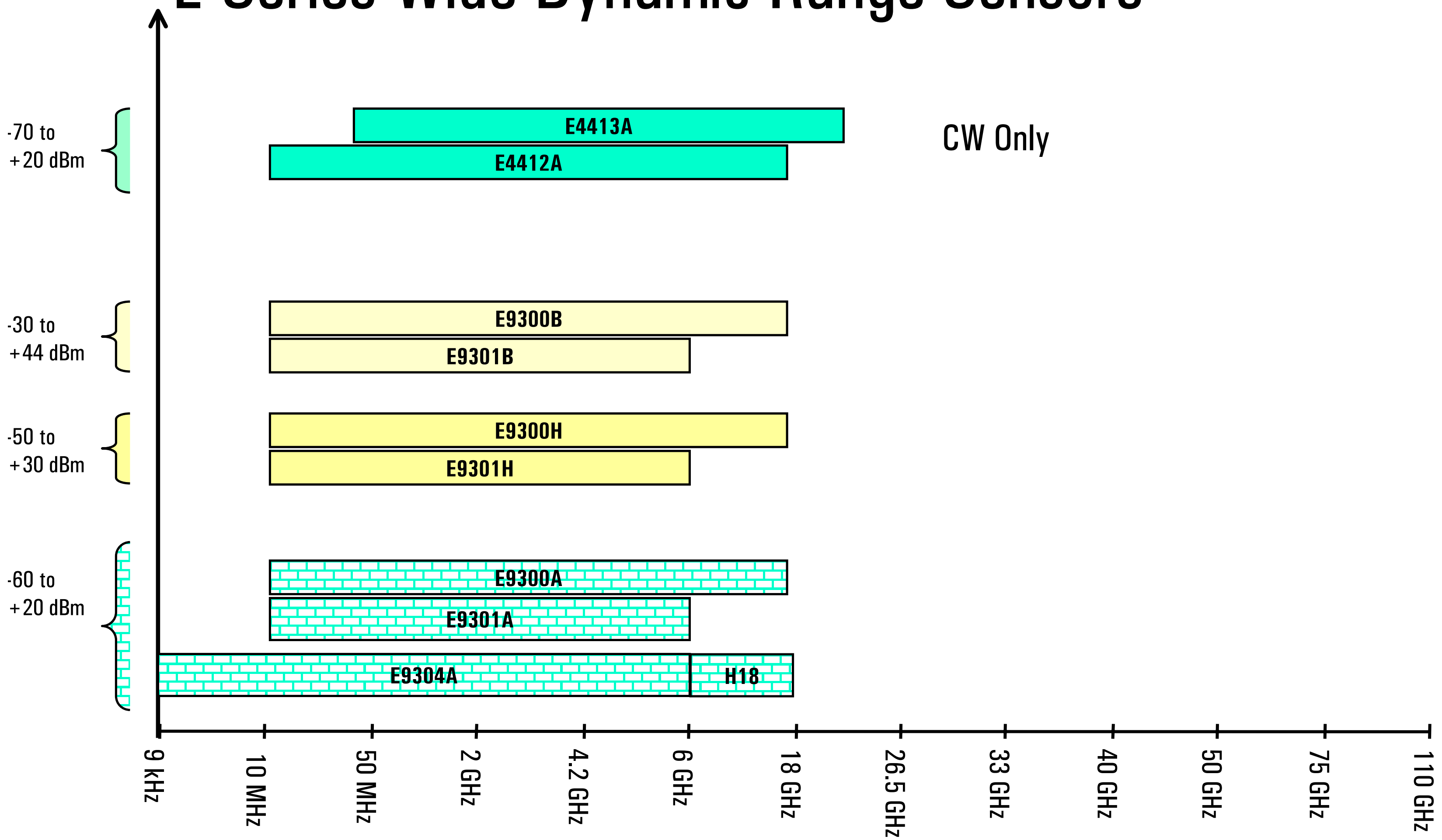
	8478B Thermistor Sensor	8481A Thermocouple Sensor	8481H Thermocouple Sensor	8481D Diode Sensor	E4412A Wide Dynamic Range Diode Sensor	E9300A Wide Dynamic Range Diode Sensor
Maximum Average Power	30 mW	300 mW	3.5 W	100 mW	200 mW	315 mW
Maximum Energy per Pulse	10 W·µs	30 W·µs	100 W·µs	(1)	(1)	(1)
Peak Envelope Power	200 W	15 W	100 W	100 mW	200 mW	2W

(1) Diode device response is so fast, device cannot average out high-energy pulses

Agilent Power Sensor Selection Guide - 8480 Series



Agilent Power Sensor Selection Guide
E-Series Wide Dynamic Range Sensors



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