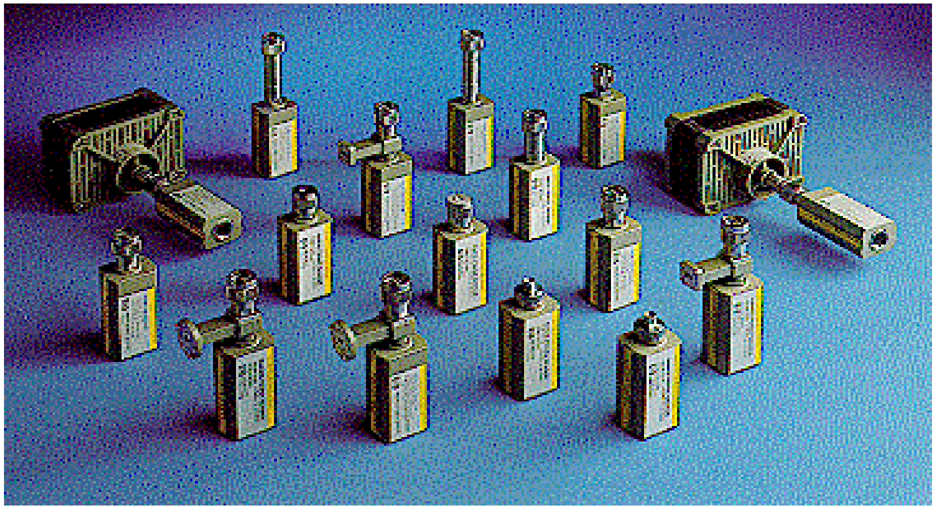
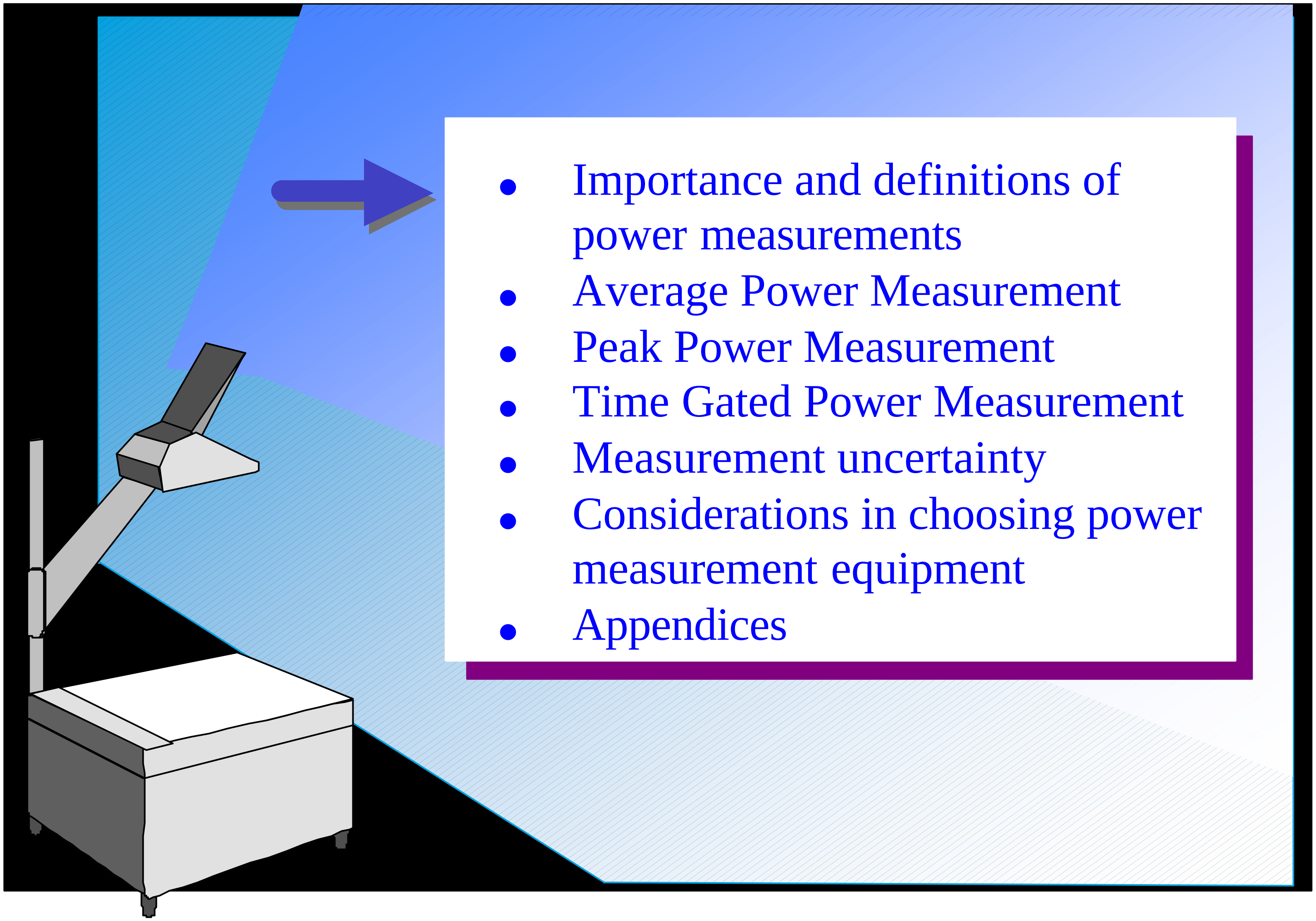
Power Measurement Basics



Agenda



- Importance and definitions of power measurements
- Average Power Measurement
- Peak Power Measurement
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- Measurement uncertainty
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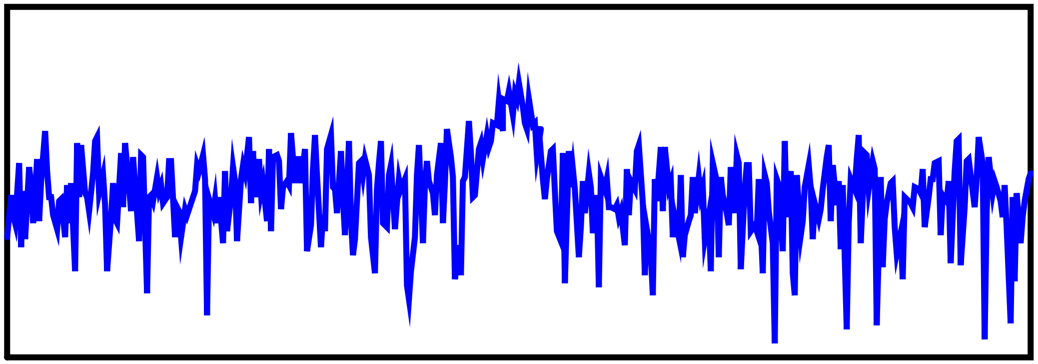
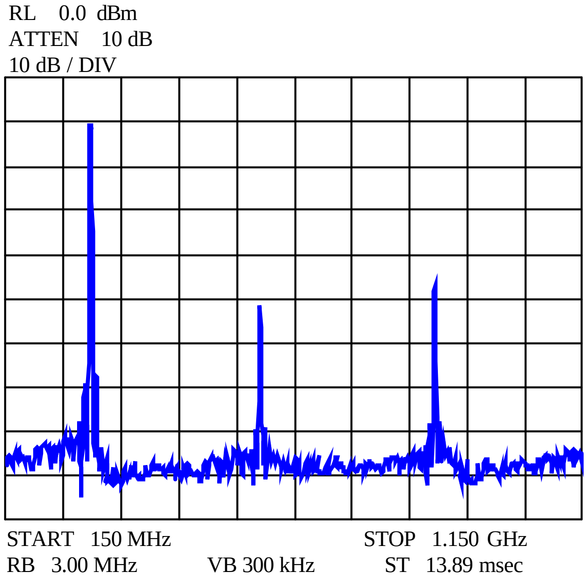
- Appendices

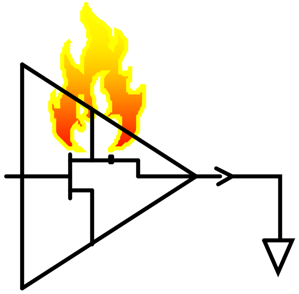
Importance of Proper Signal Levels

- Too low
  - Signal buried in noise



- Too high
  - Nonlinear distortion can occur

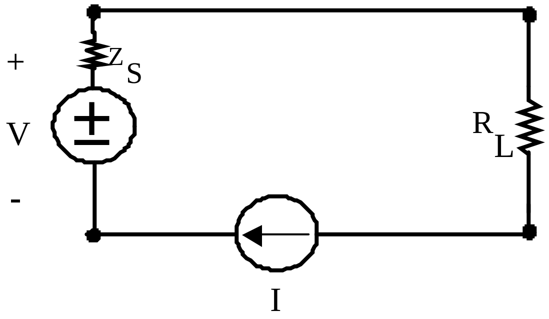




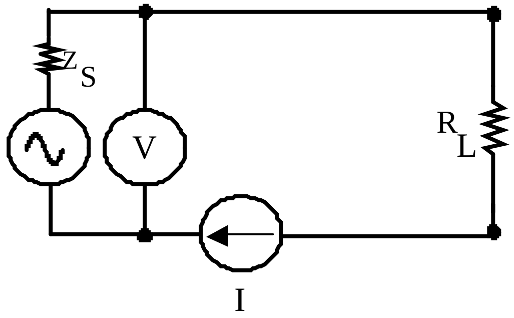
- Or even worse!

Why Not Measure Voltage?

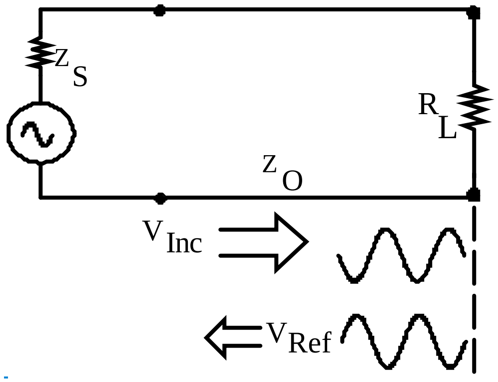
- DC



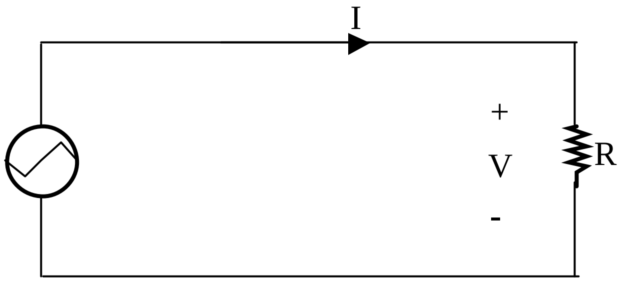
- Low Frequency

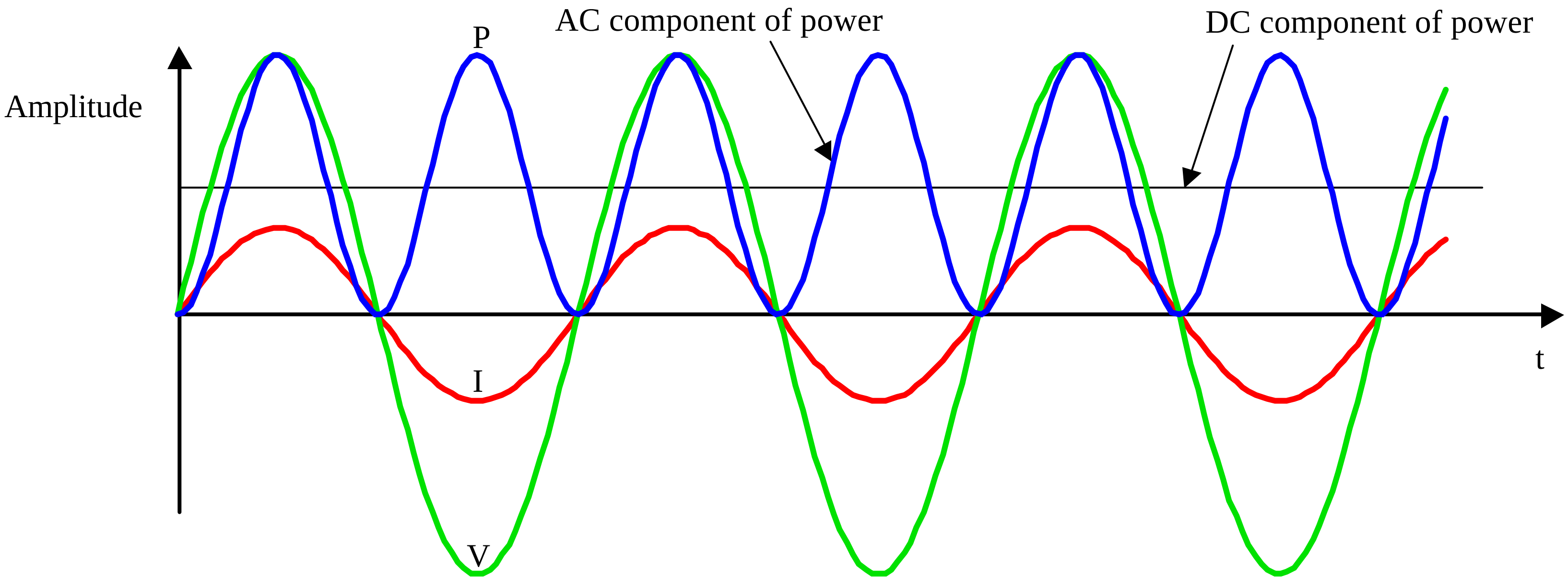


- High Frequency



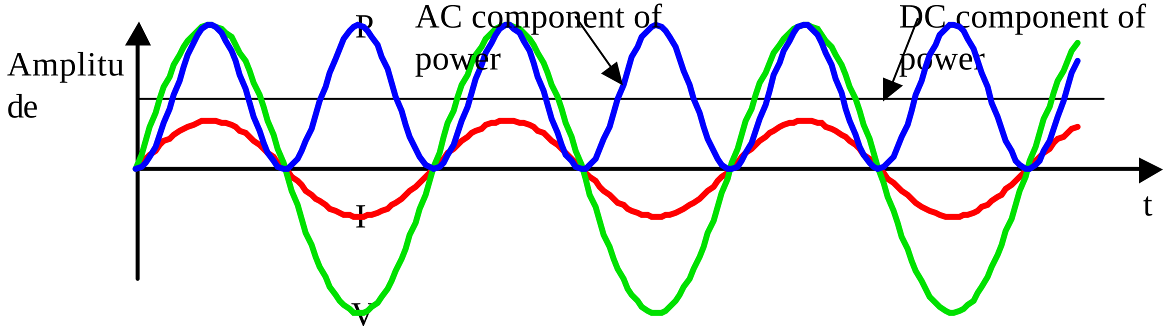
Power: P = (I)(V)


I
+
V
-
R


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

Units and Definitions

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

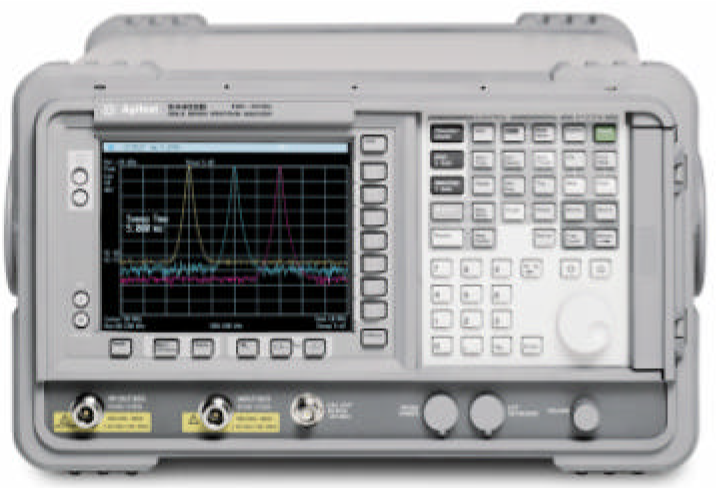
Duty Cycle

Pulse Delay

PRI

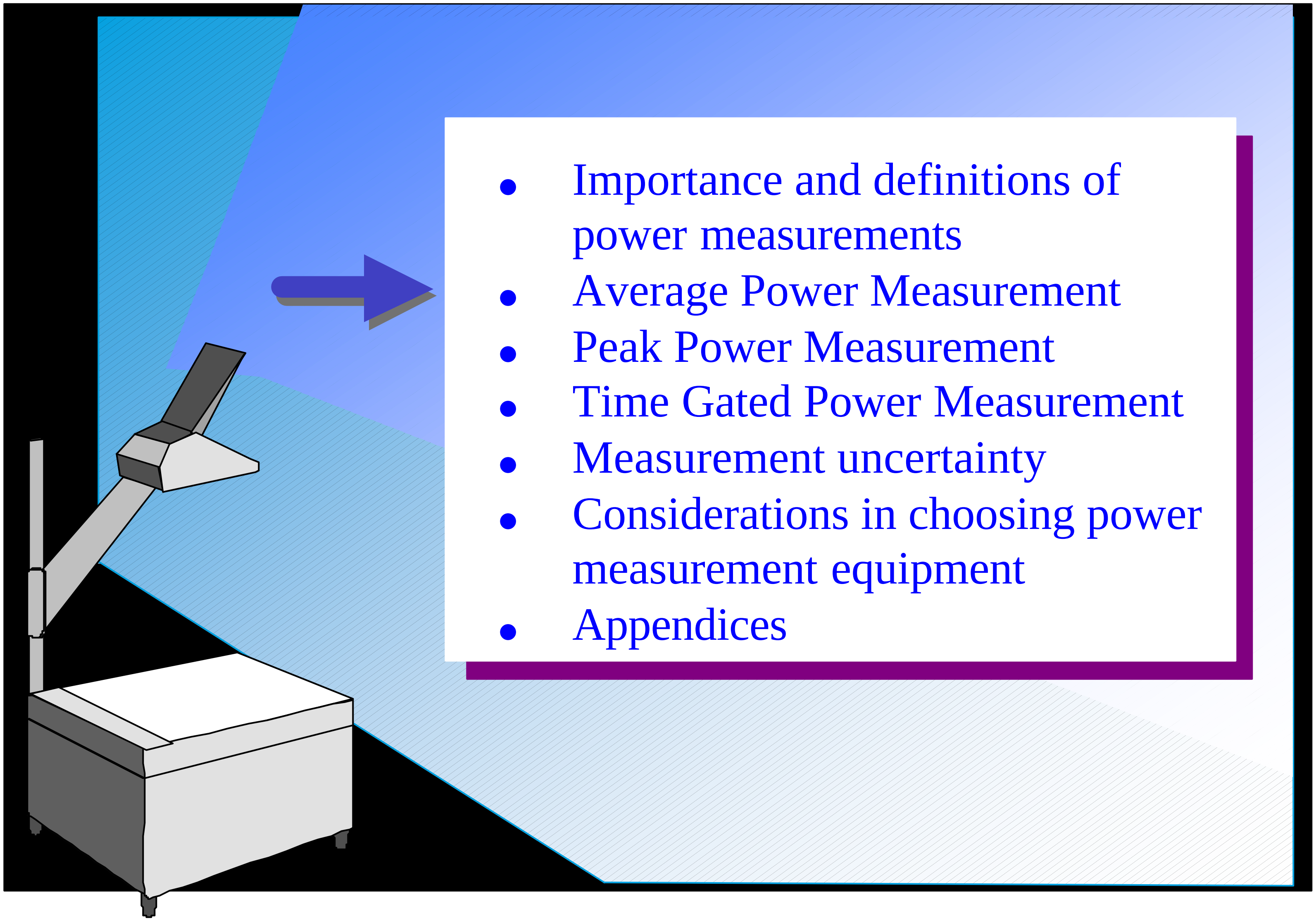
PRF

Instruments used to Measure RF and Microwave Power



- Vector Signal Analyzer
- Spectrum analyzer
- Network analyzer
- Power meter

Agenda



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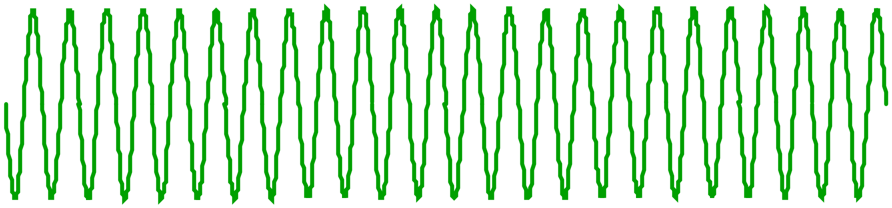
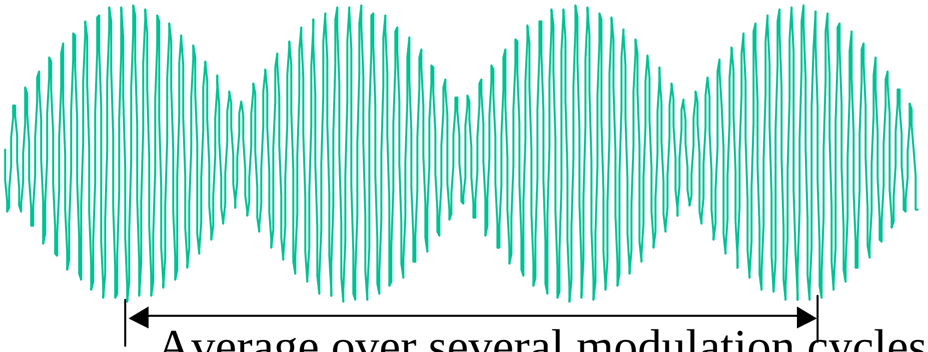
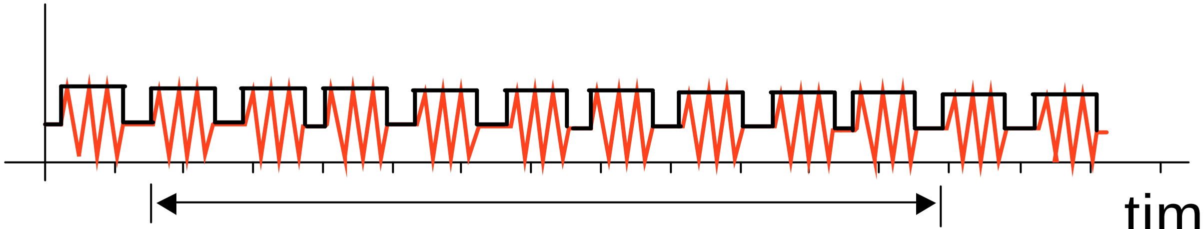
Average Power



CW Signal



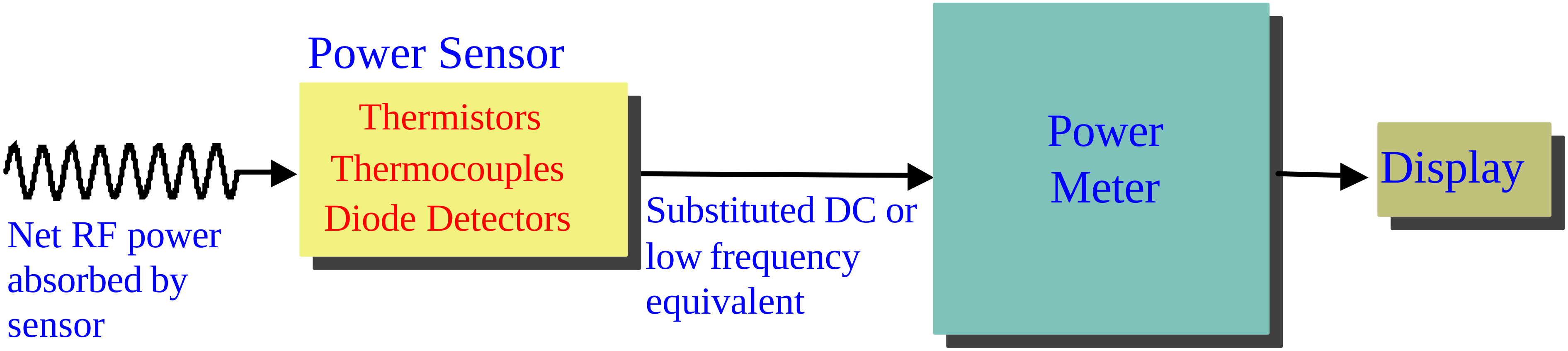
Average over several modulation cycles



time

Average over many pulse repetitions

Basic Measurement Method - Using a Power Meter



Power Sensor

Thermistors

Thermocouples

Diode Detectors

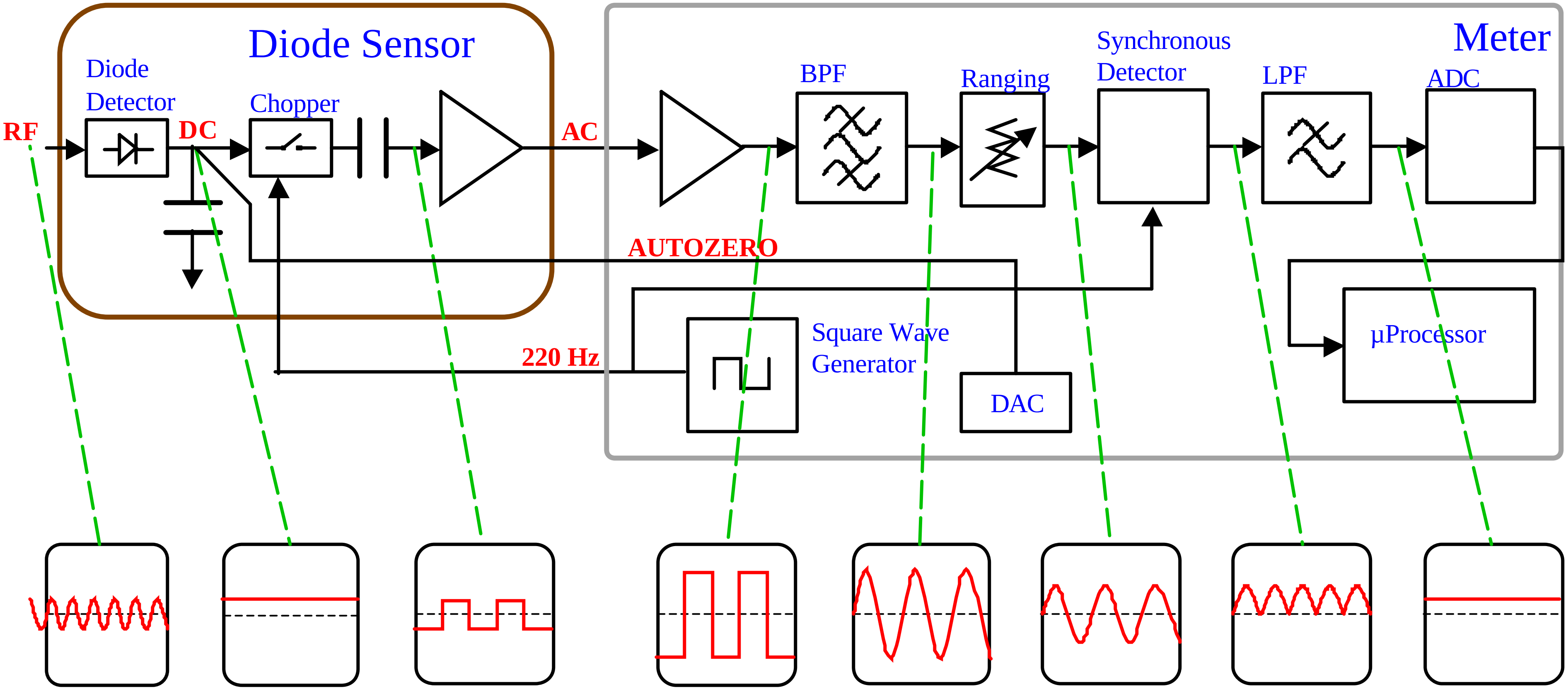
Net RF power absorbed by sensor

Substituted DC or low frequency equivalent

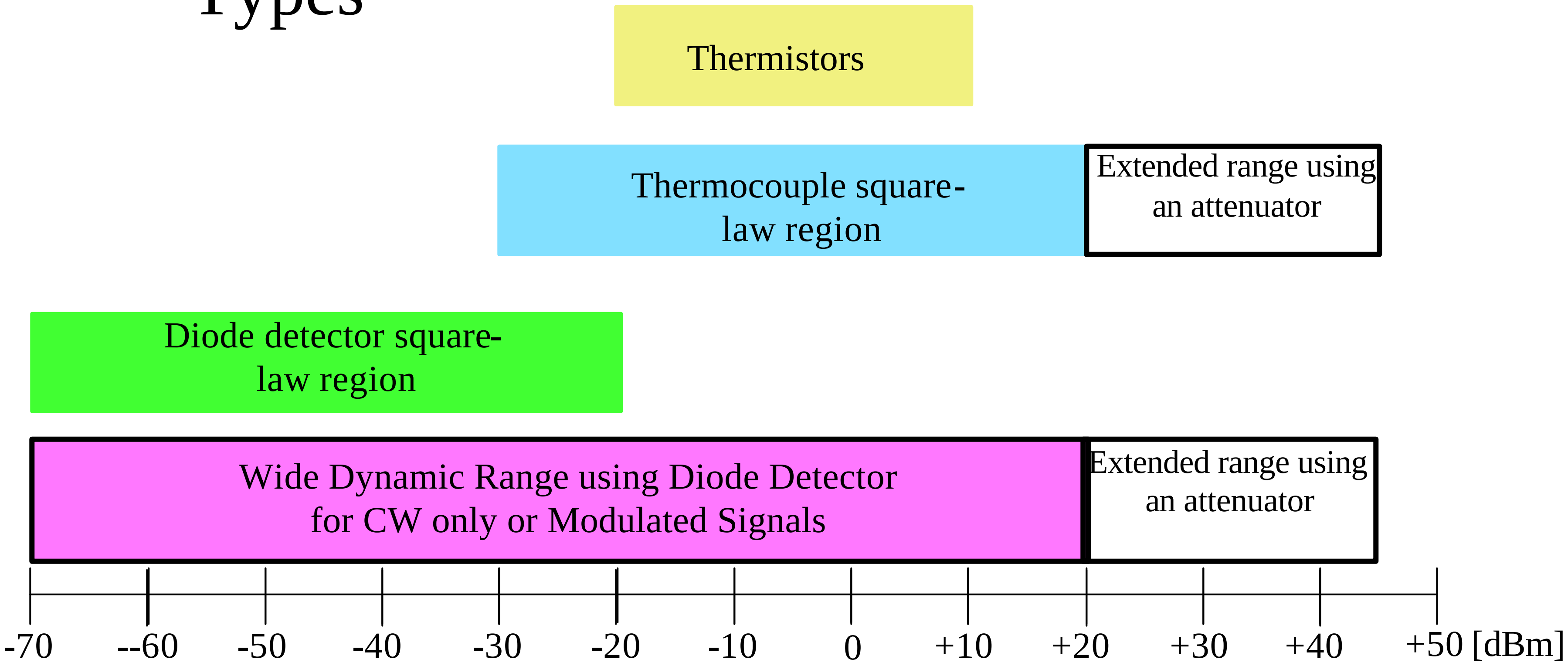
Power Meter

Display

Basic Measurement Method Explained



Power Ranges of the Various Sensor Types



Thermistors

Thermocouple square-law region

Extended range using an attenuator

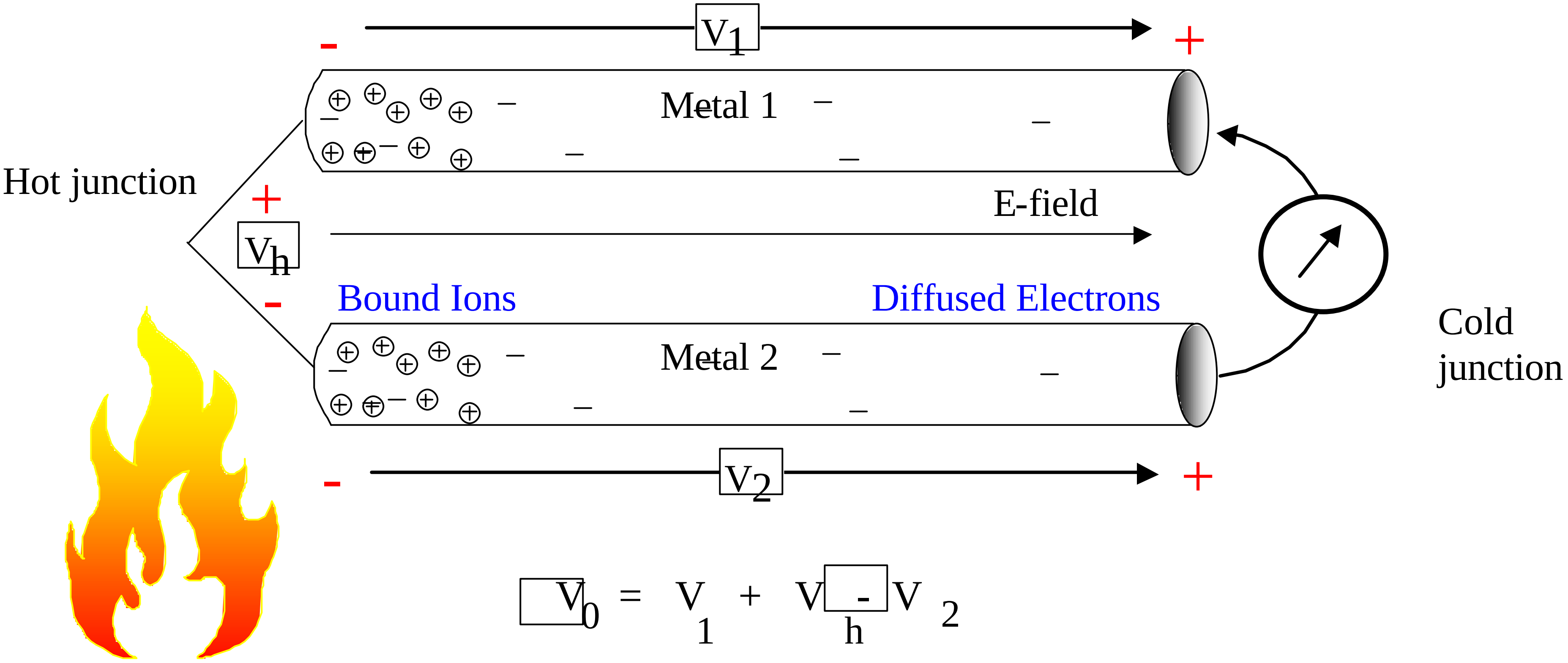
Diode detector square-law region

Wide Dynamic Range using Diode Detector for CW only or Modulated Signals

Extended range using an attenuator

Thermocouples

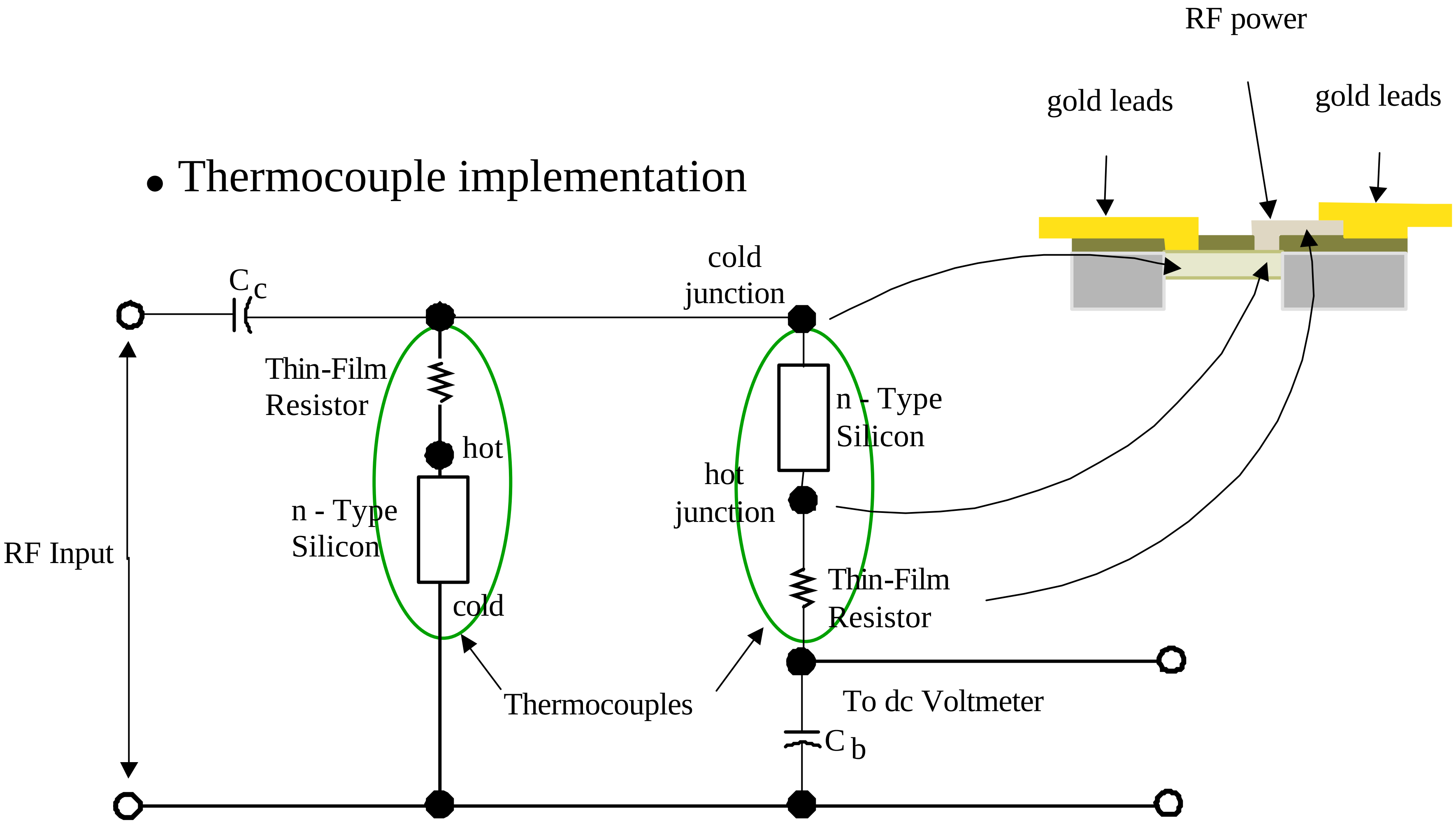
- The principles behind the thermocouple



$$V_0 = V_1 + V_h - V_2$$

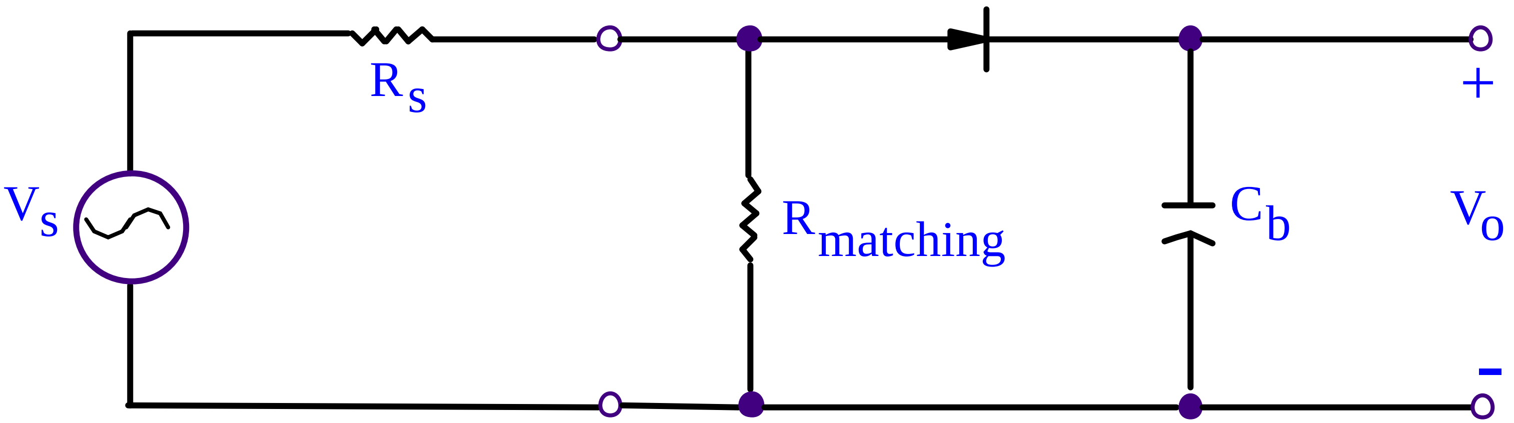
Thermocouples

- Thermocouple implementation

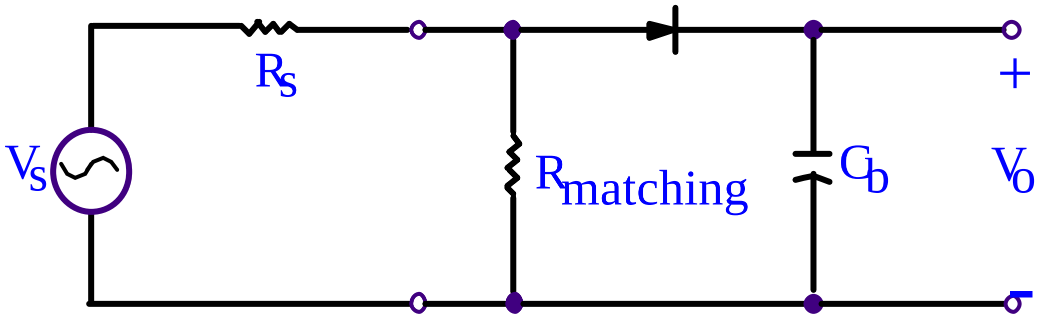


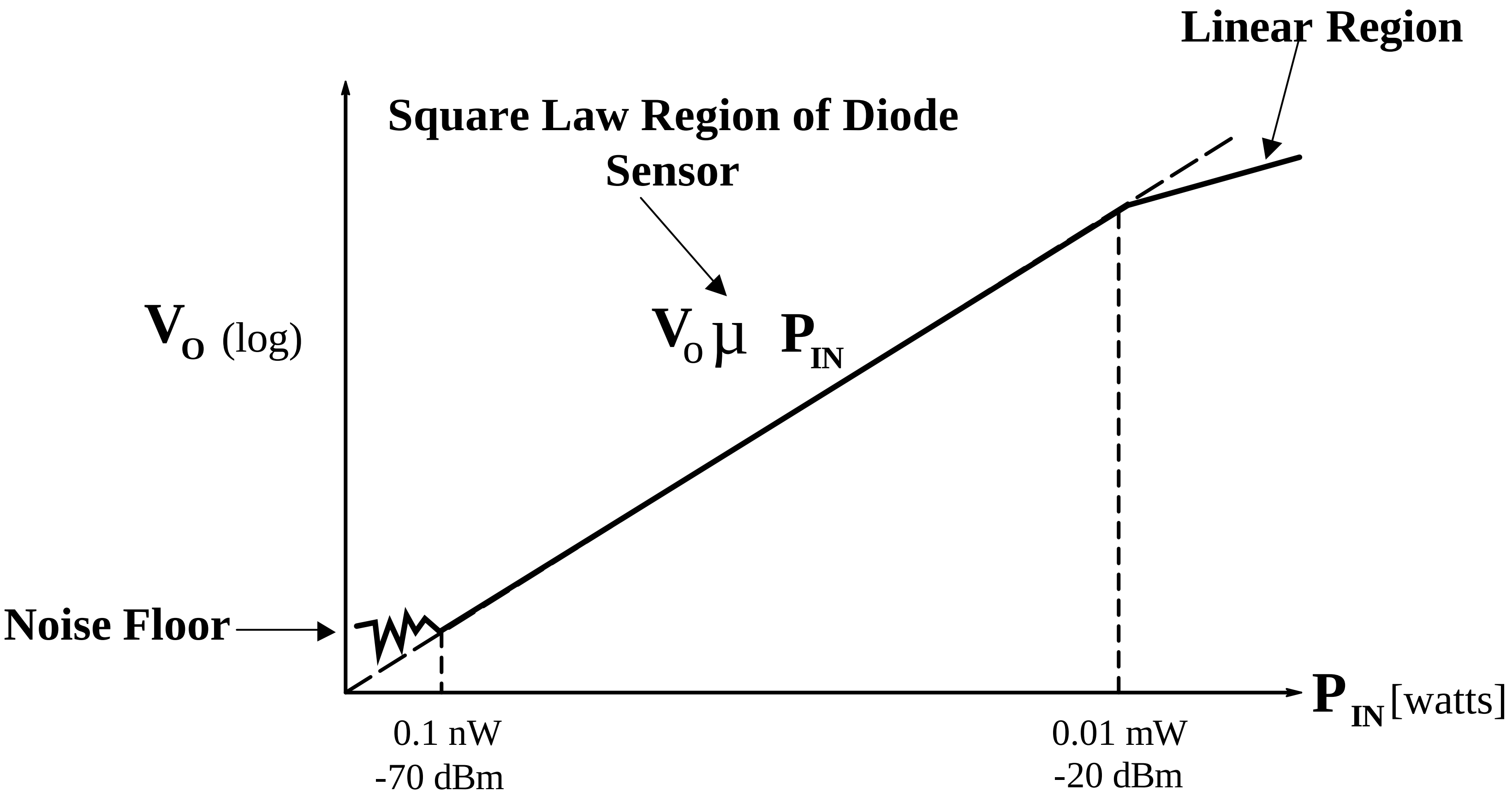
Diode Detectors

- How does a diode detector work?

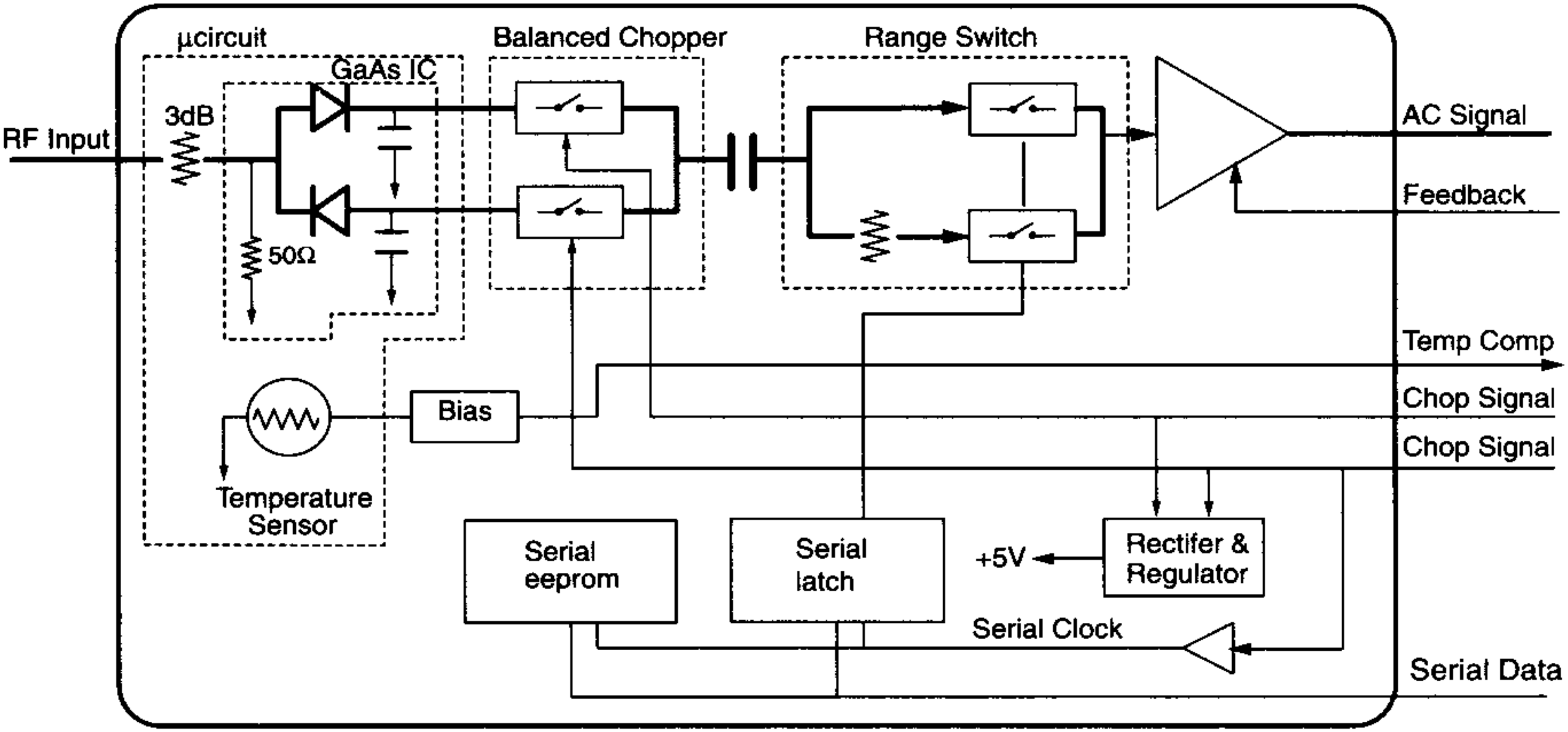


Diode Detectors

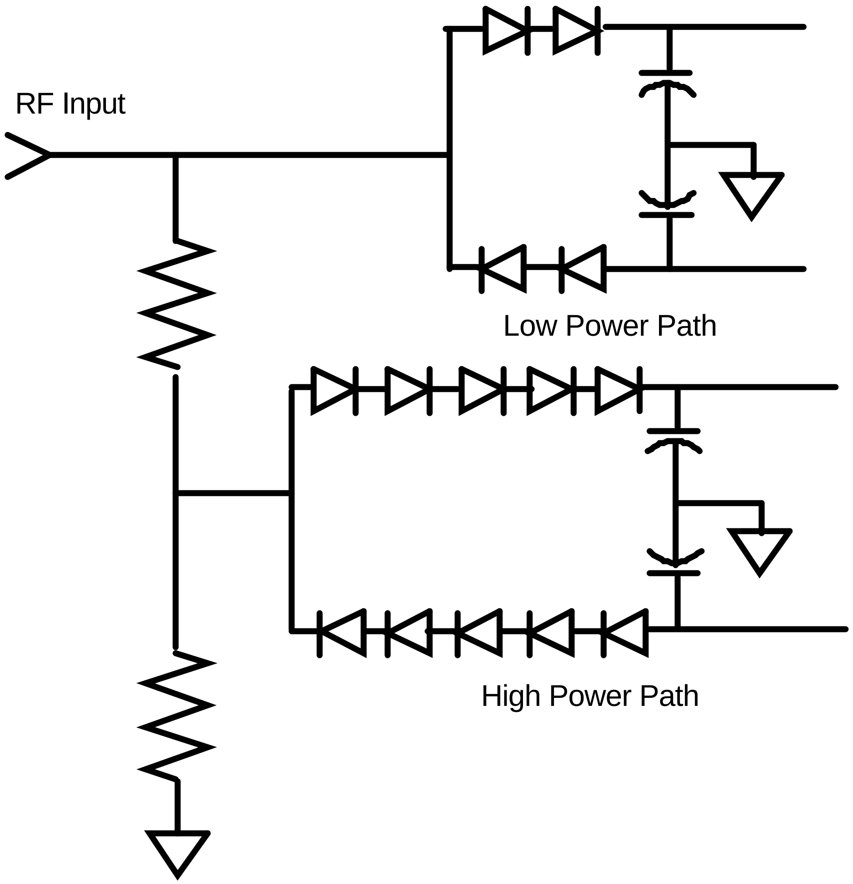




Wide-Dynamic-Range CW-only Power Sensors



E-series E9300 Power Sensors Technology



Innovative Design:

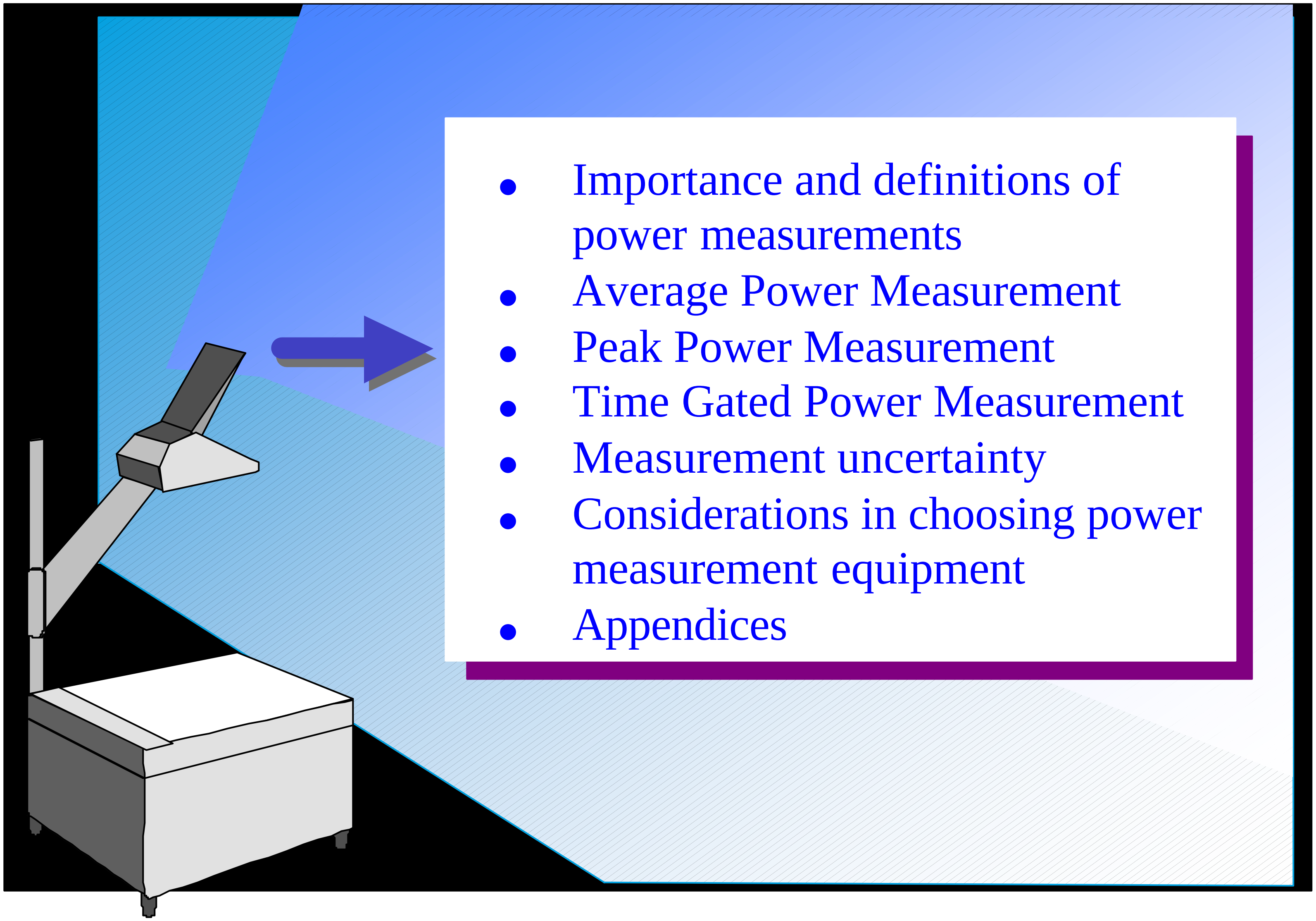
- Diode stack- attenuator-diode stack topology

- Two paths with an automatic switch point

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.

Agenda



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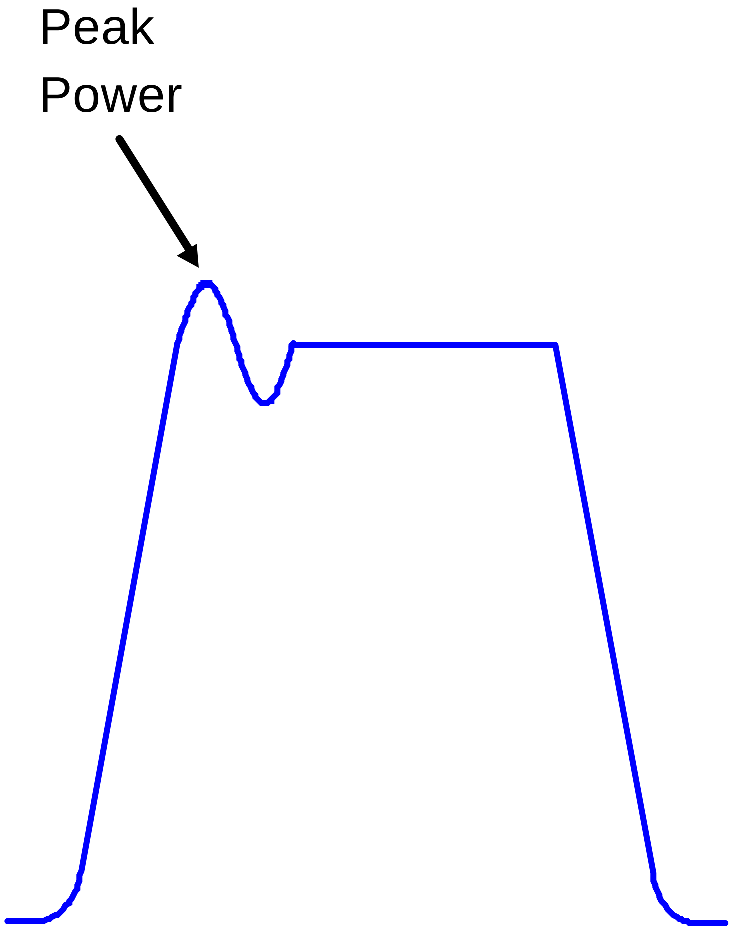
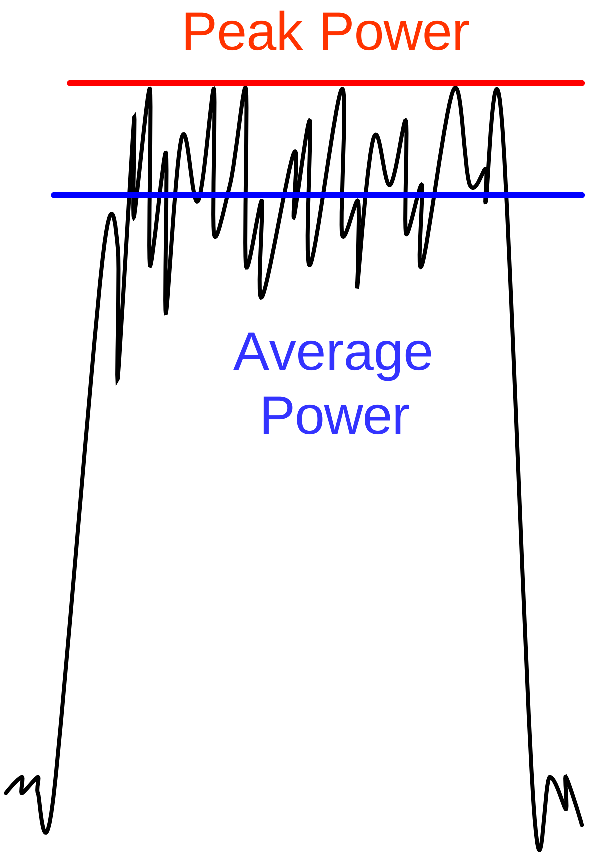
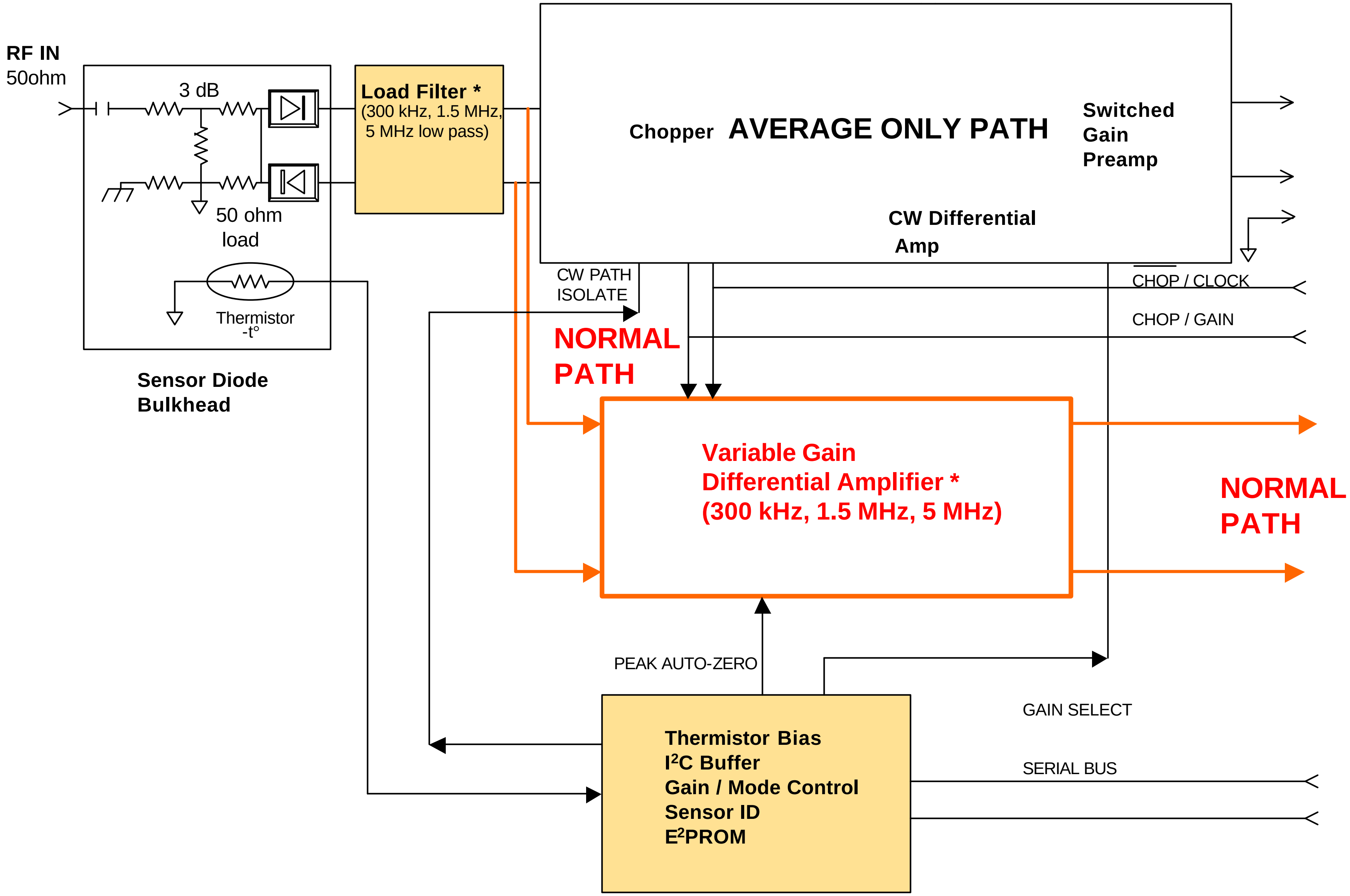
Peak Power Measurement

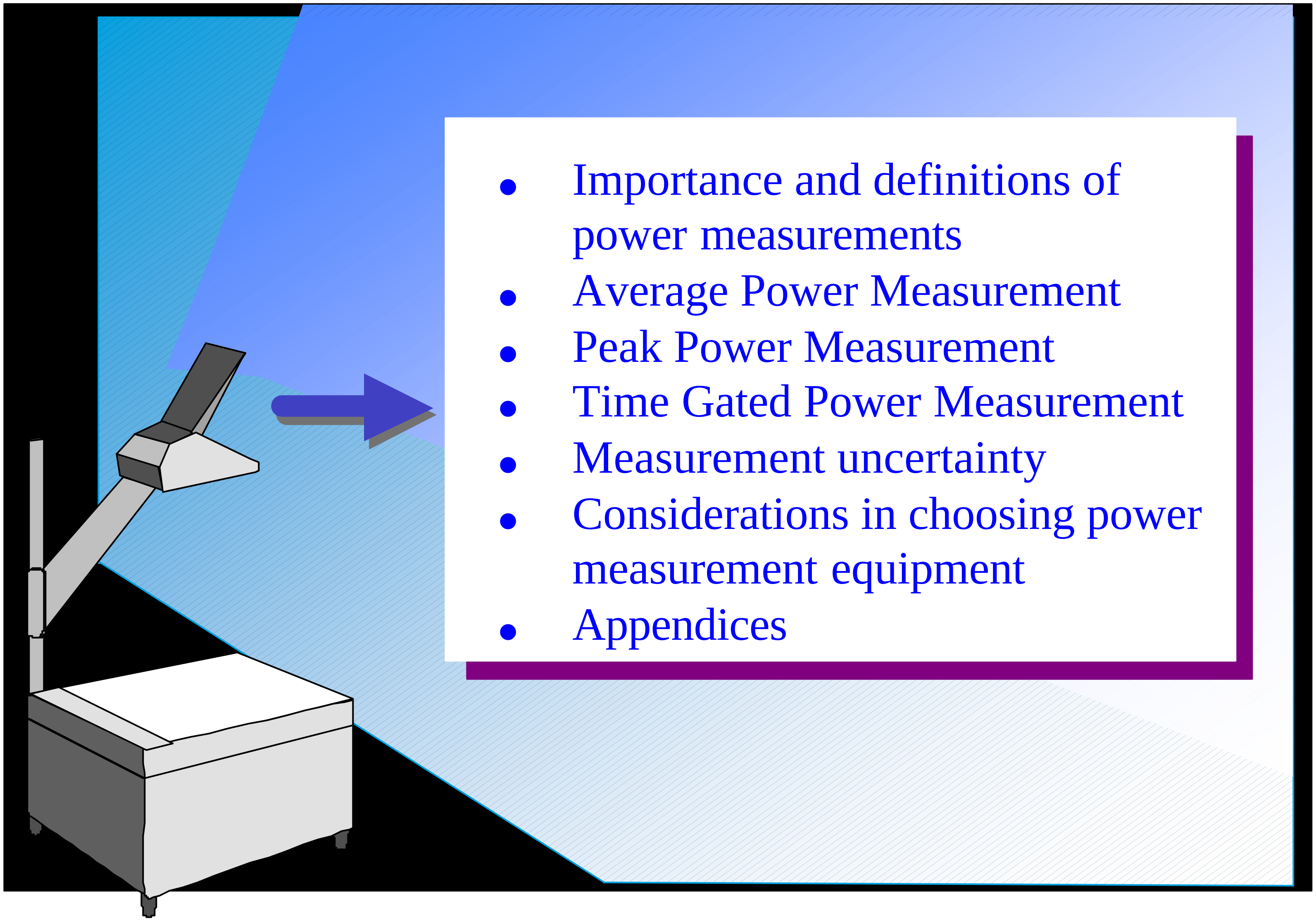




Peak Power Measurement



Agenda



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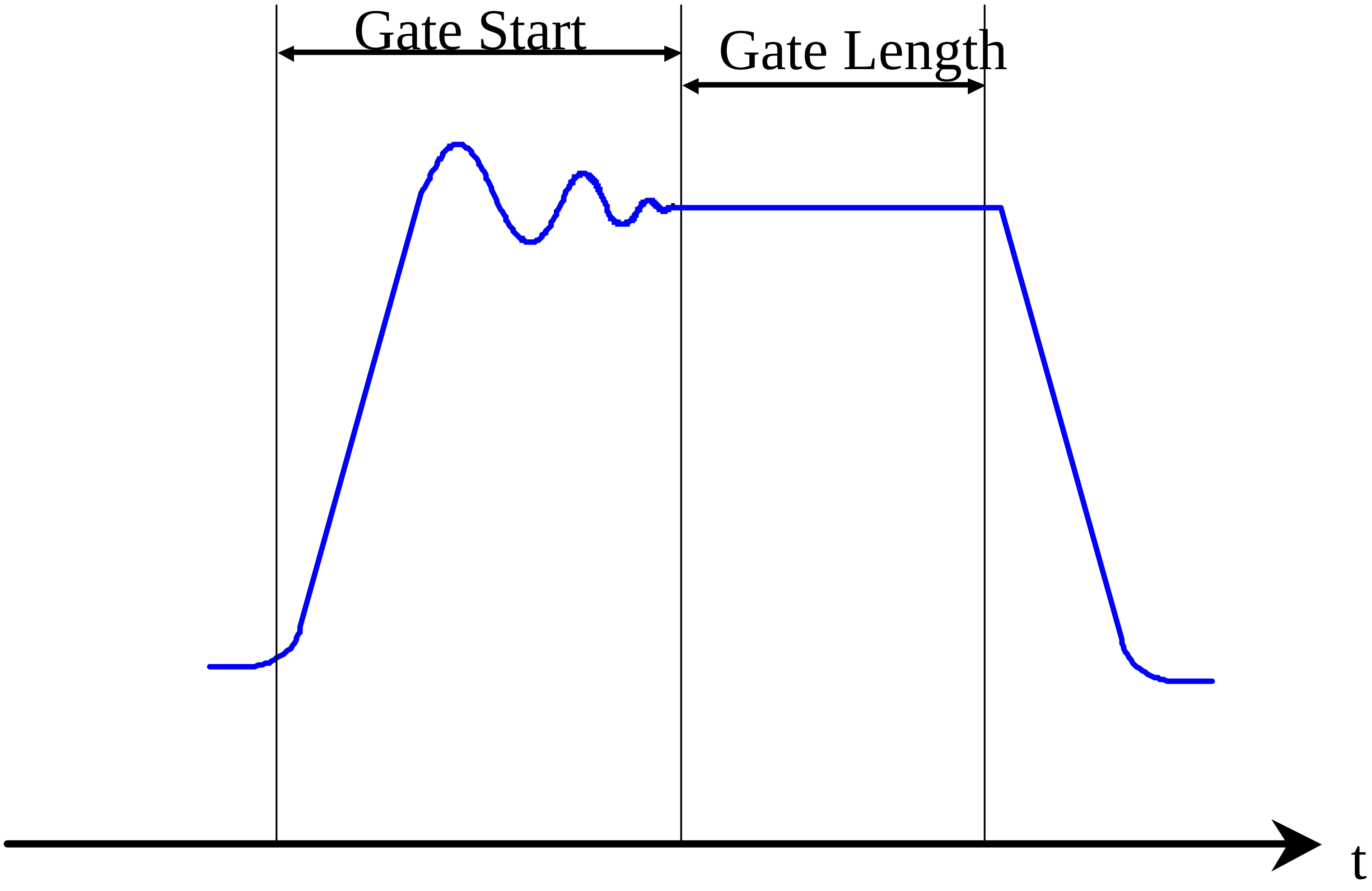
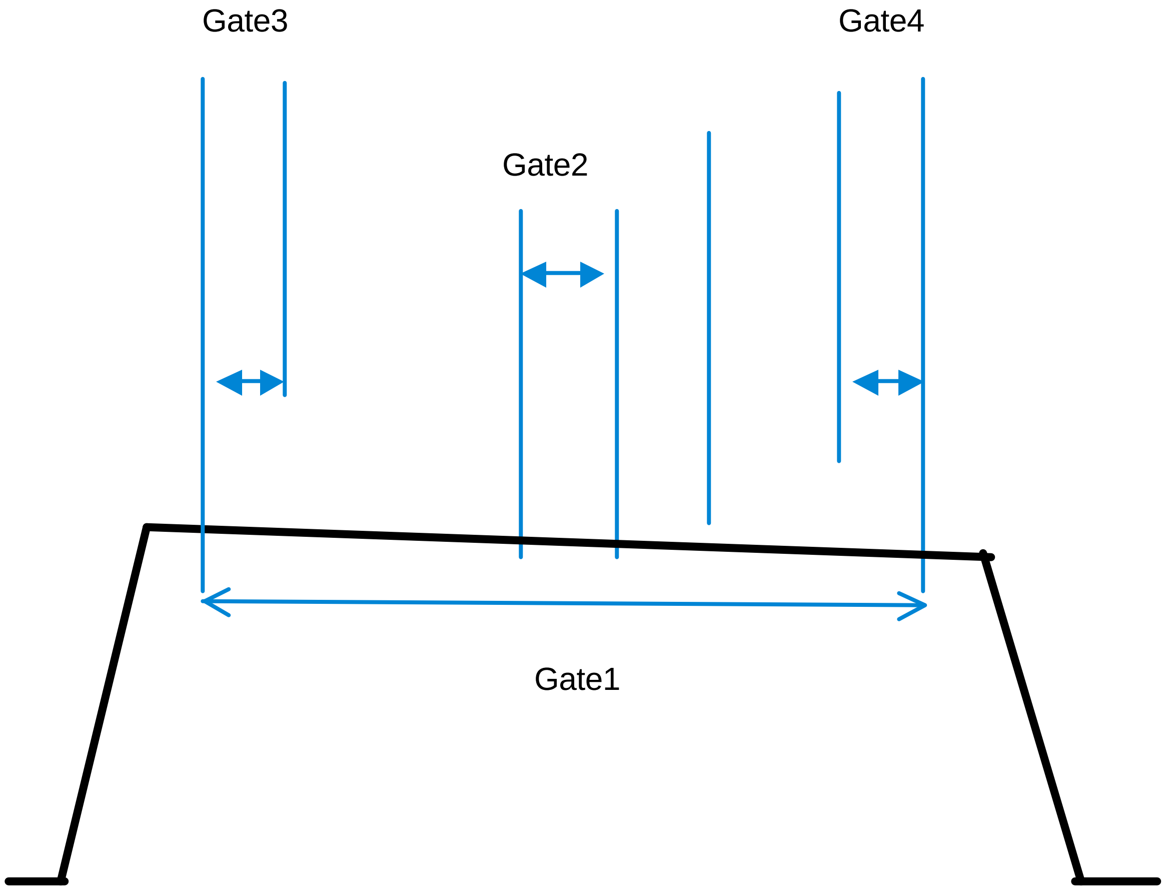
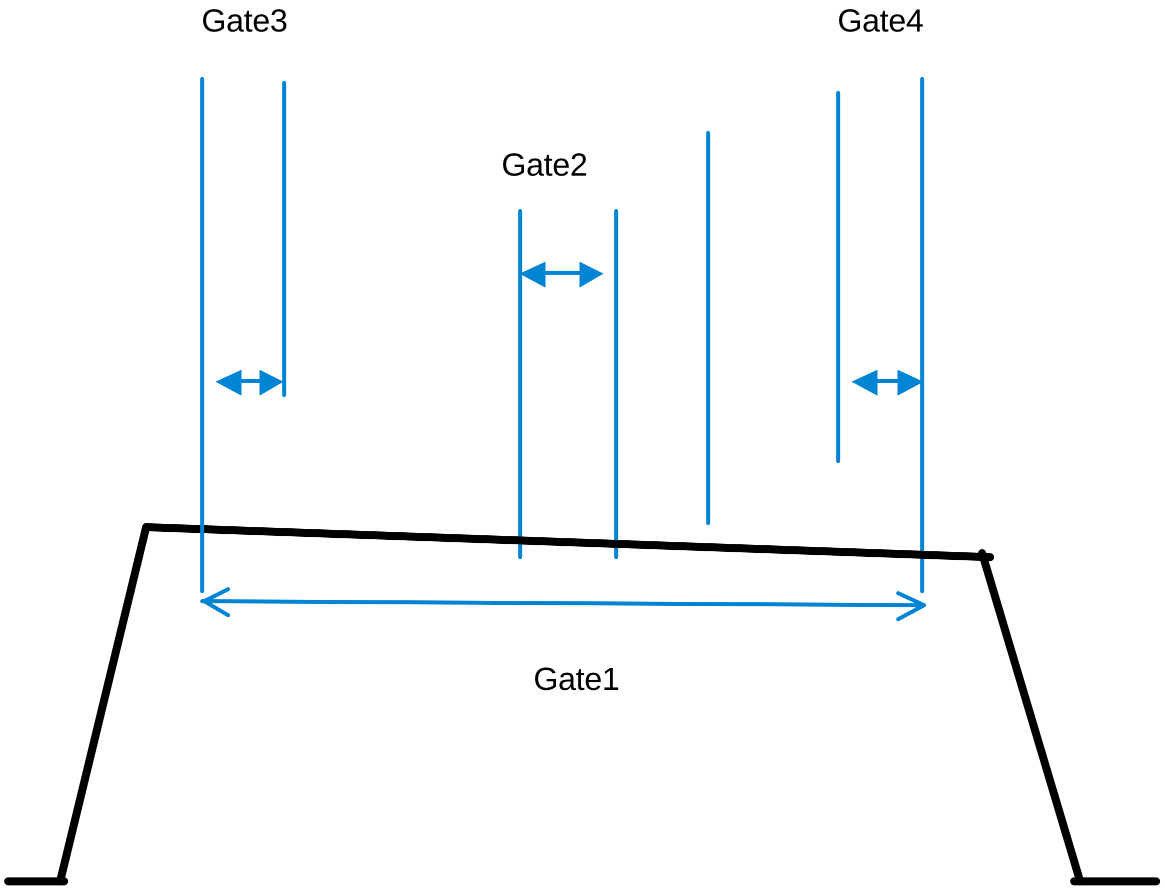
Time Gated Power Measurements



Time Gated Power Measurements

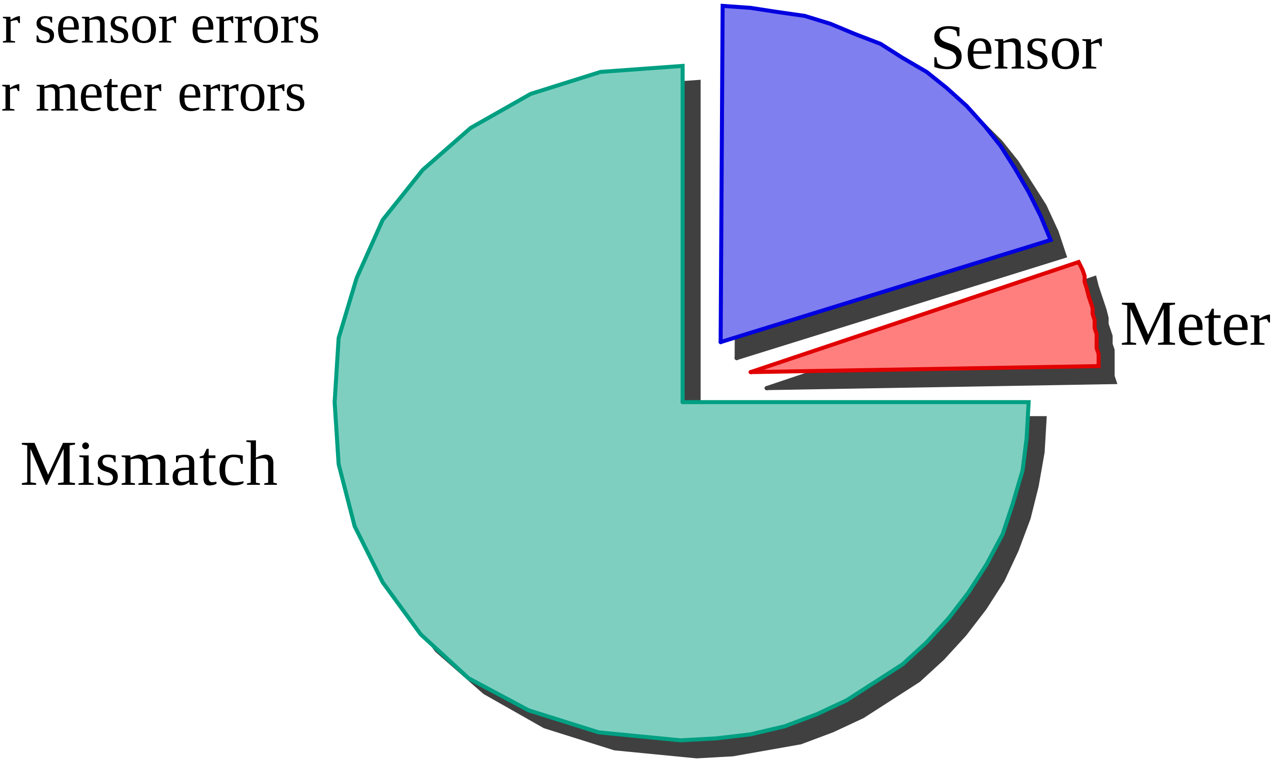


Time Gated Power Measurements

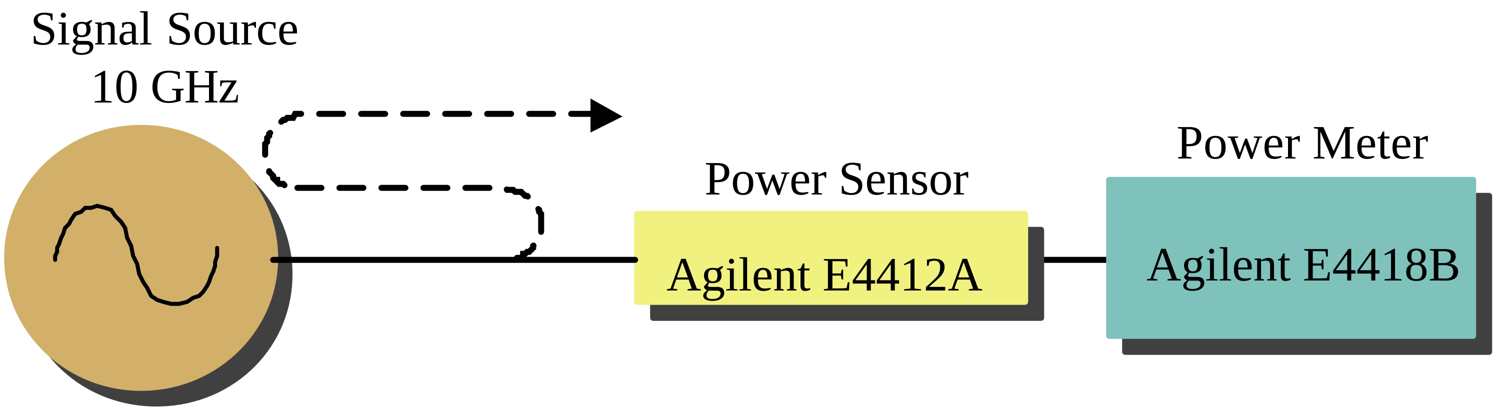


Sources of Power Measurement Uncertainty

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



Calculation of Mismatch Uncertainty



SWR = 2.0

$r_{SOURCE} = 0.33$

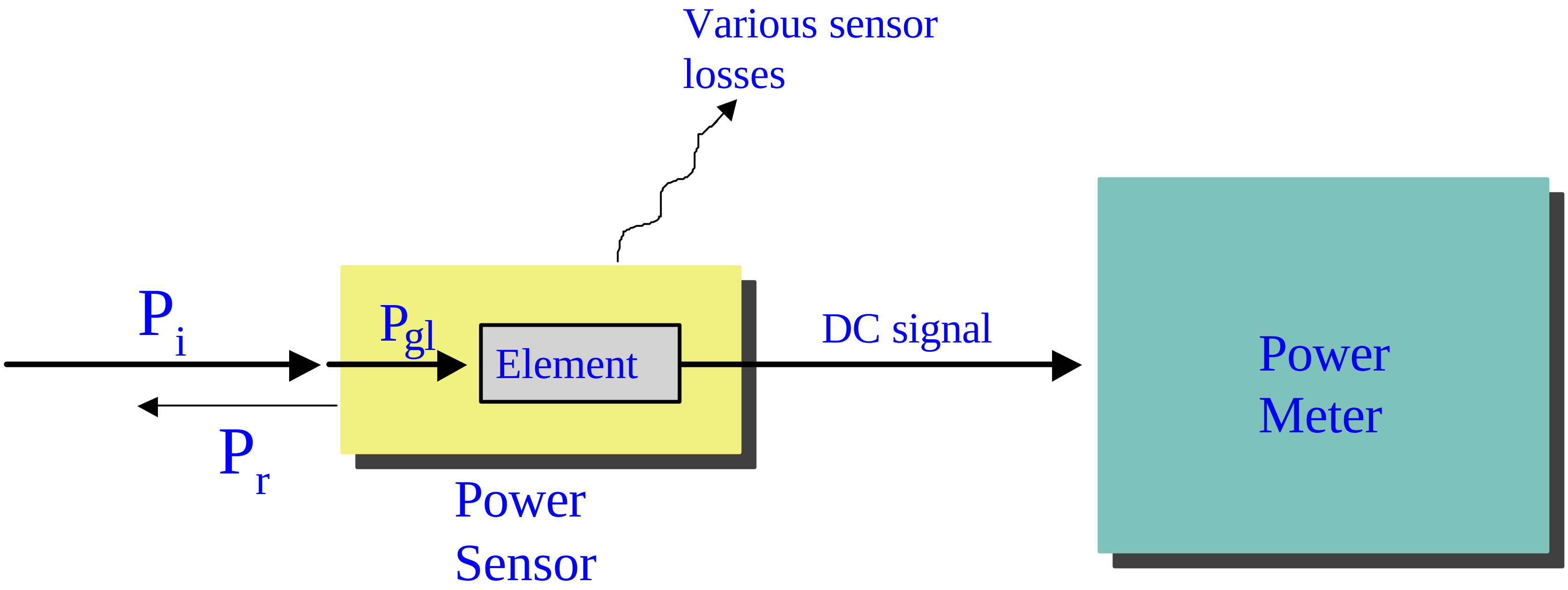
SWR = 1.22

$r_{SENSOR} = 0.10$

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

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

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% = ± 11.4%

+11.4% = 10 log (1 + 0.114) = + 0.47 dB

- 11.4% = 10 log (1 - 0.114) = - 0.53 dB

RSS Uncertainty

- In our example RSS uncertainty would be:

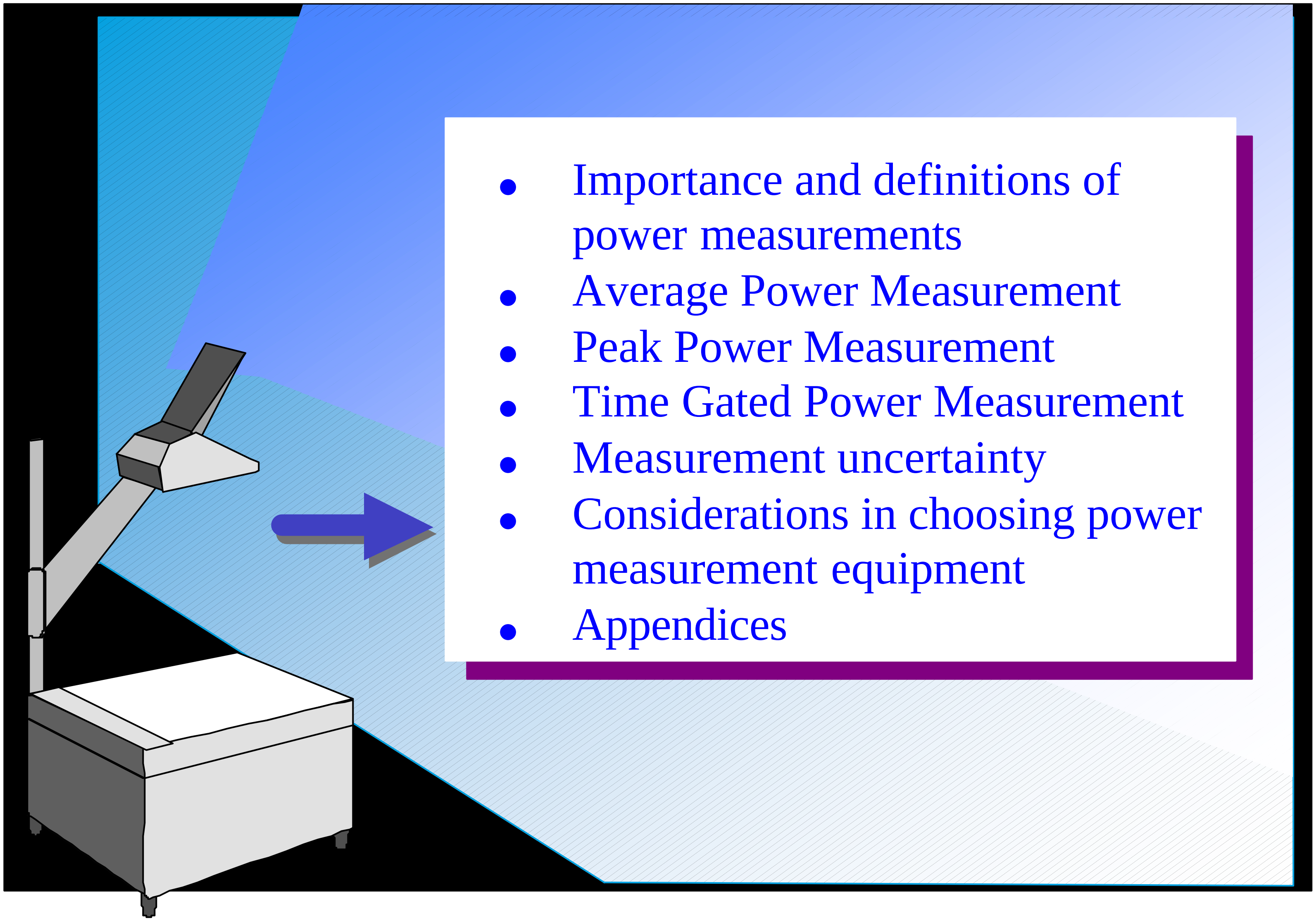
$$= \sqrt{(6.6\%)^2 + (3.1\%)^2 + (1.2\%)^2 + (0.5\%)^2}$$

$= \pm 7.4\%$

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

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

Agenda



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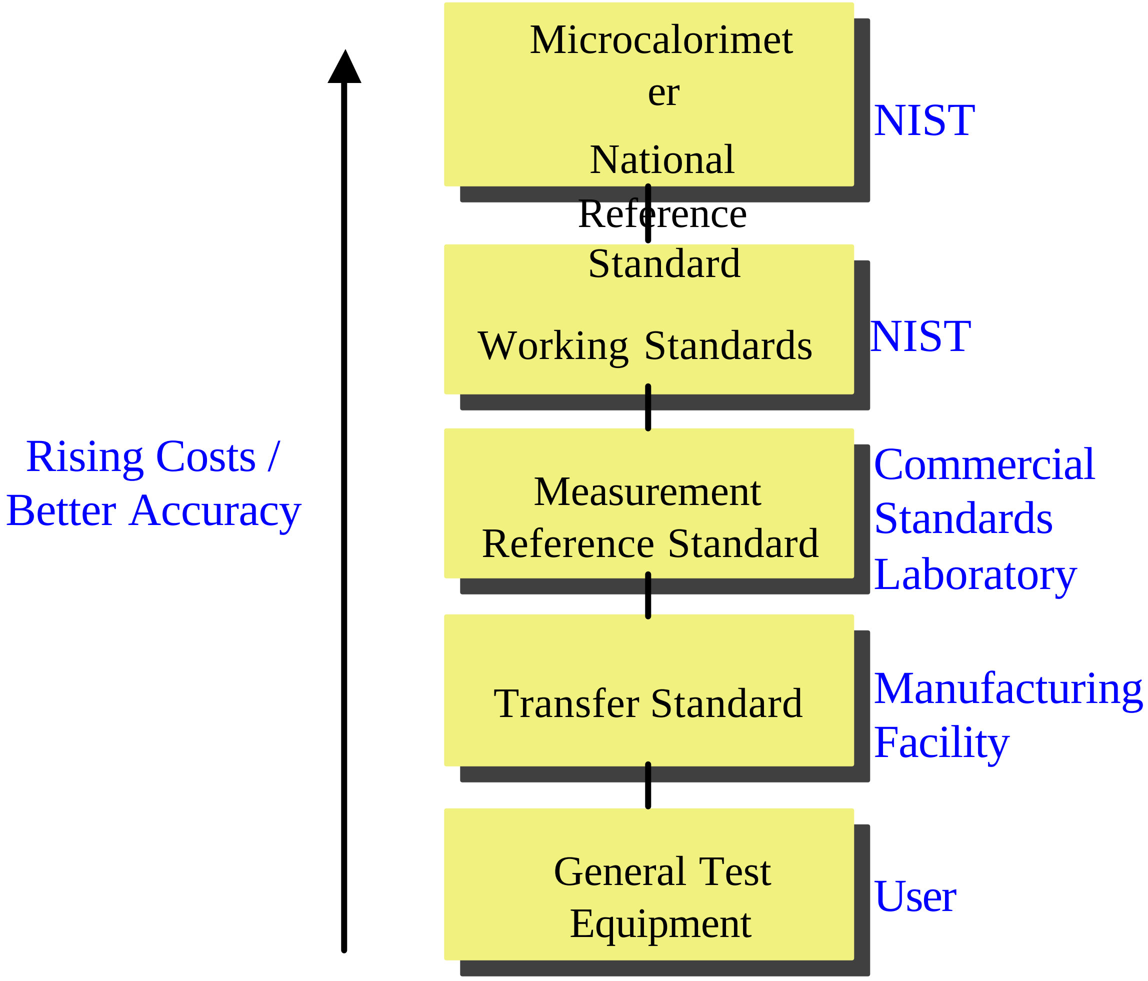
Thermistors as Transfer Standards



Microcalorimeter

National Reference Standard

NIST

Working Standards

NIST

Rising Costs /
Better Accuracy

Measurement Reference Standard

Commercial Standards Laboratory

Transfer Standard

Manufacturing Facility

General Test Equipment

User

SWR (Reflection Coefficient)

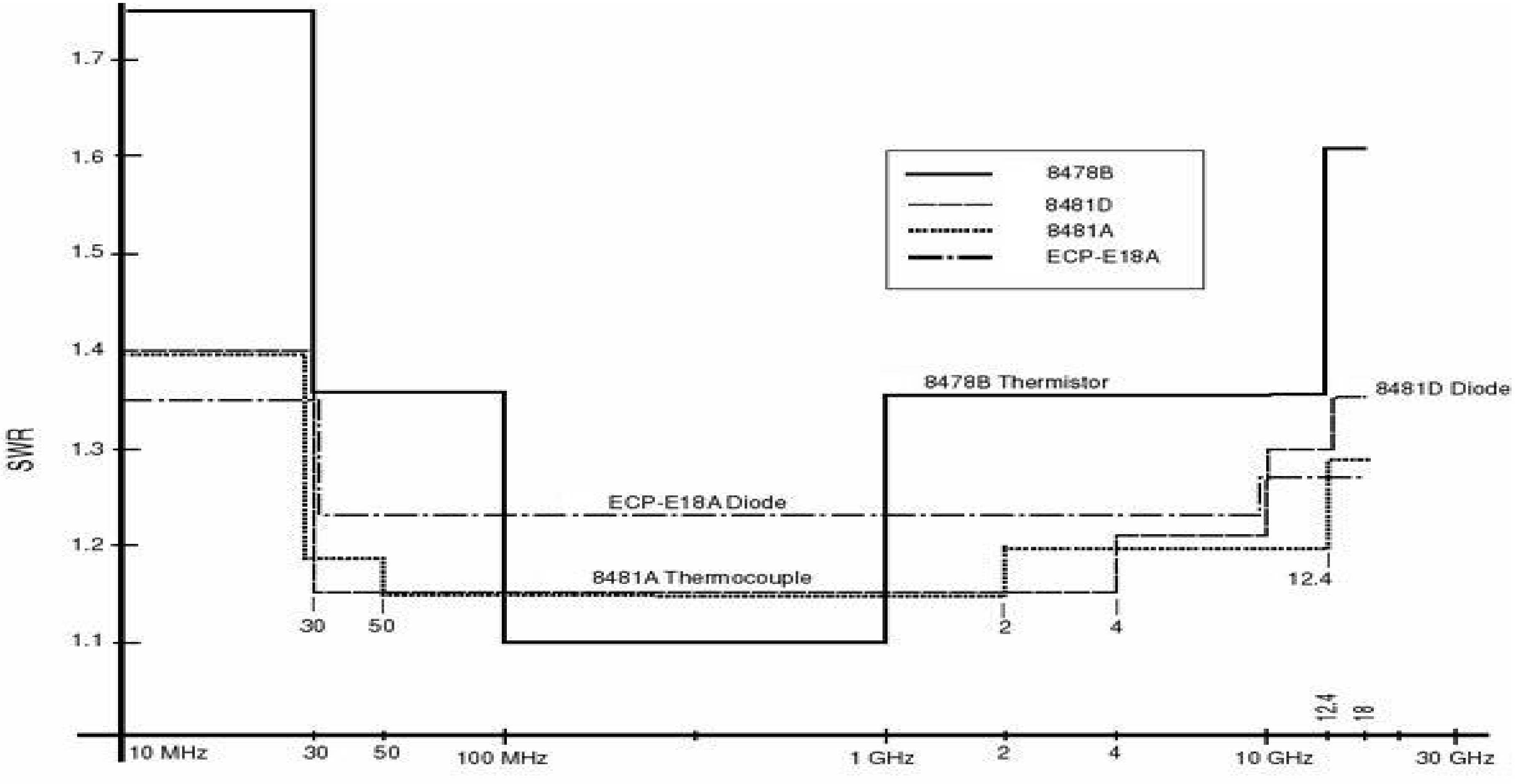


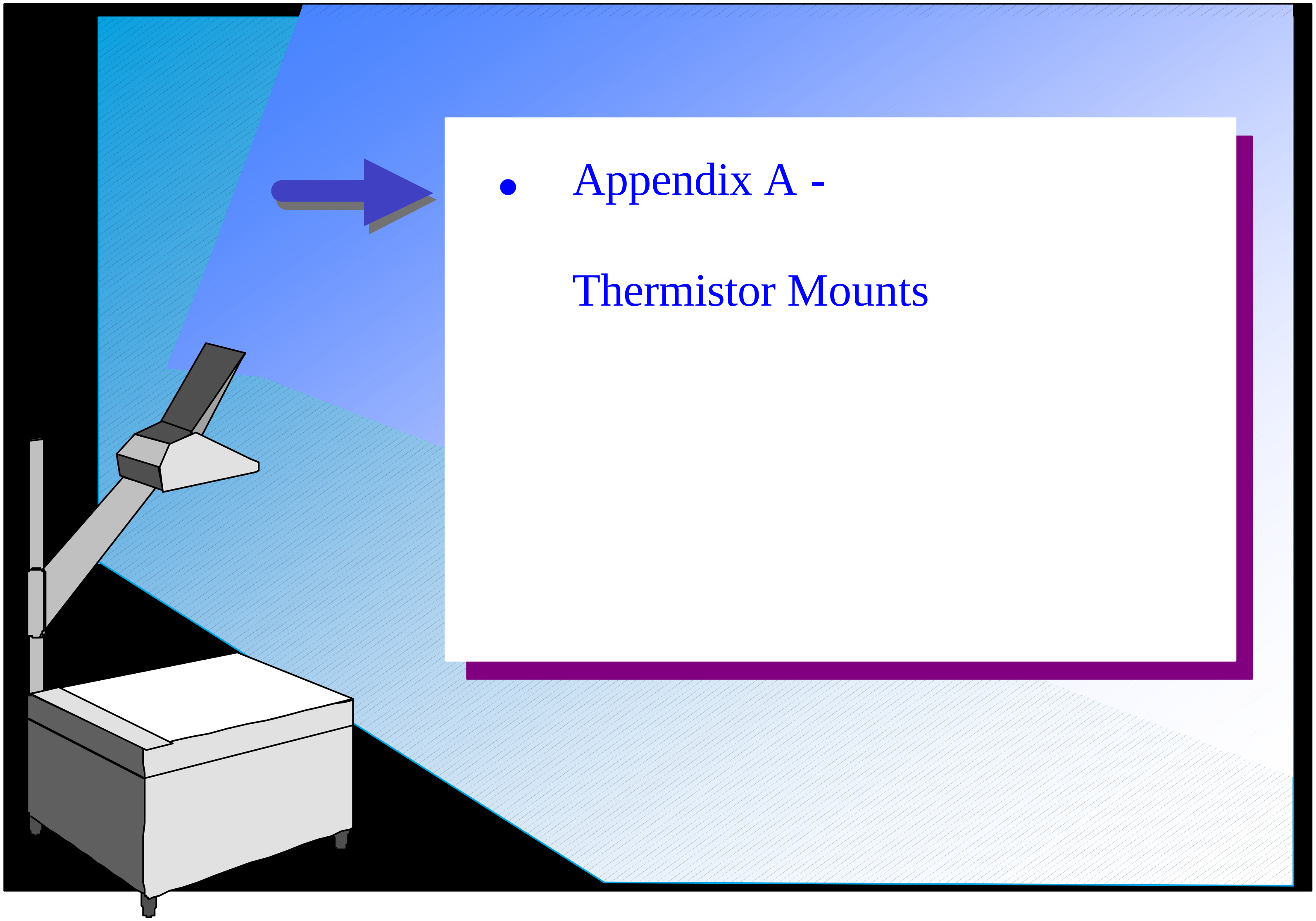
Fig 7-2

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

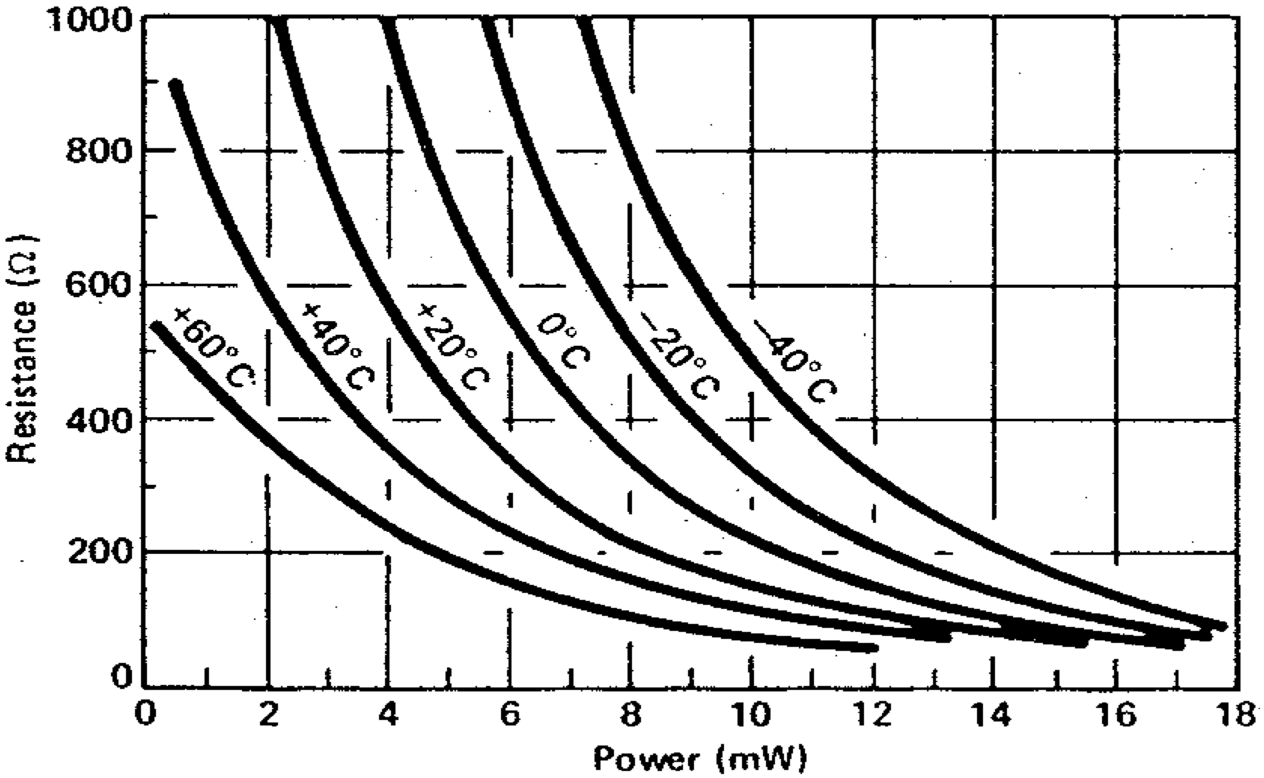
Agenda



- Appendix A - Thermistor Mounts

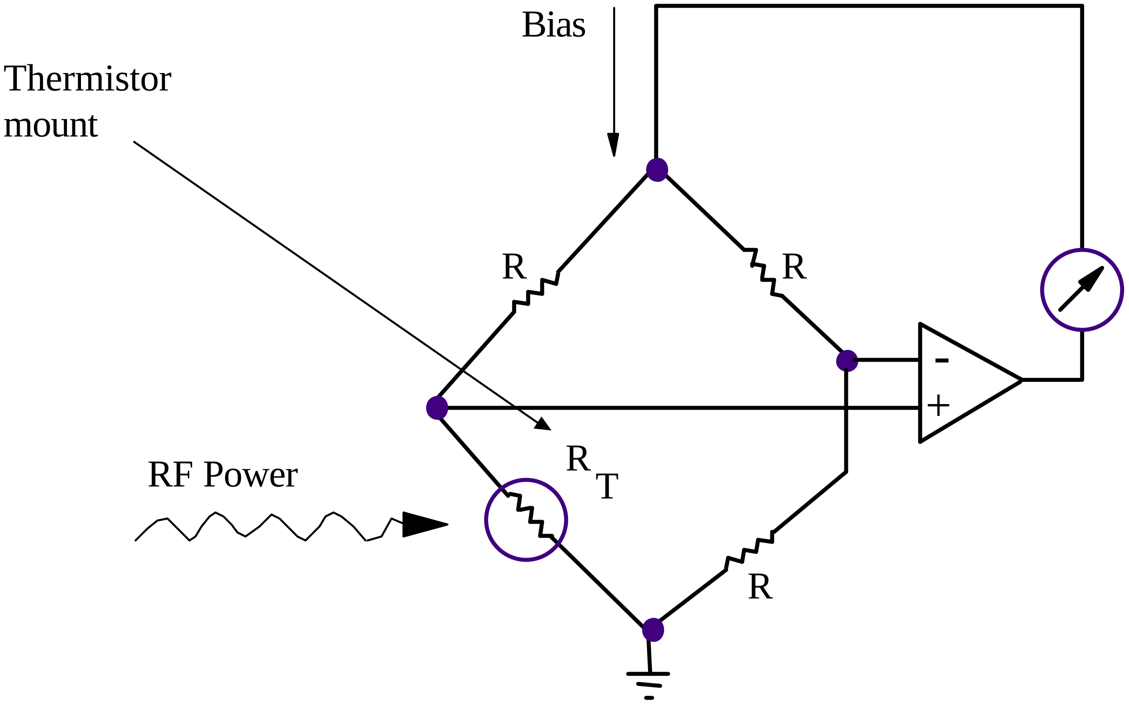
Thermistors

Characteristic curves of a typical thermistor element



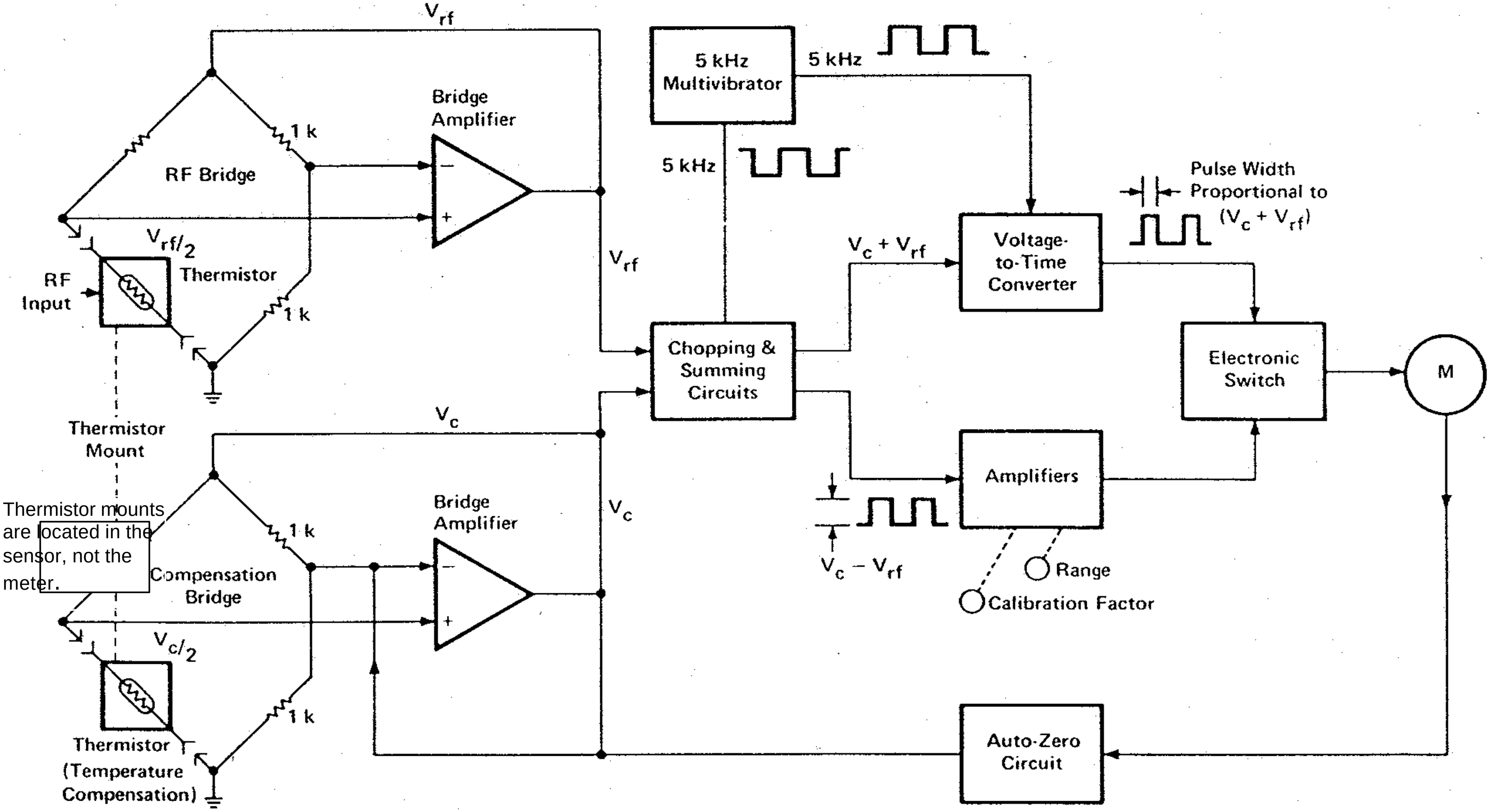
Thermistors

A self-balancing bridge containing a thermistor



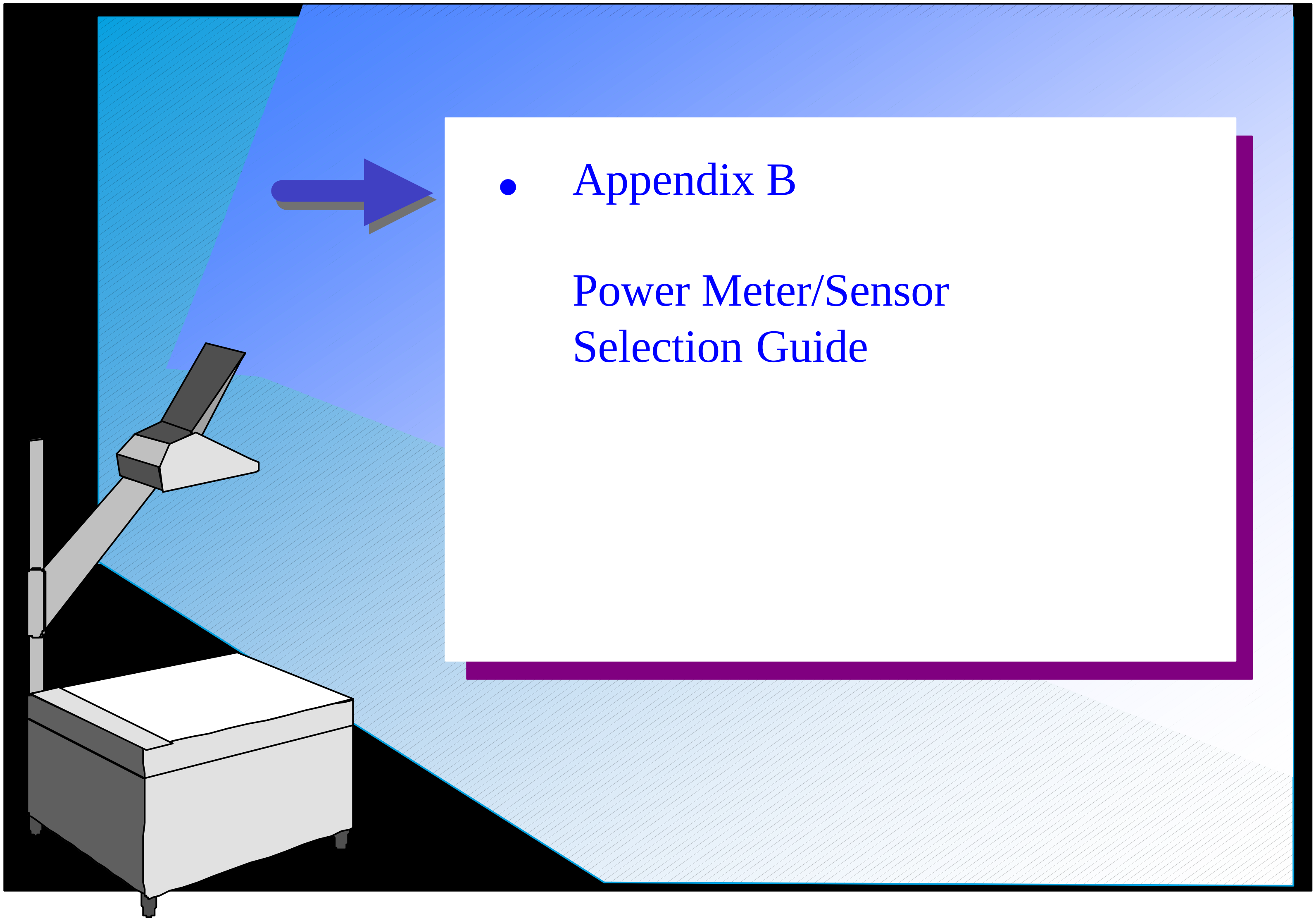
Power Meters for Thermistor Mounts

- 432A Power Meter



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

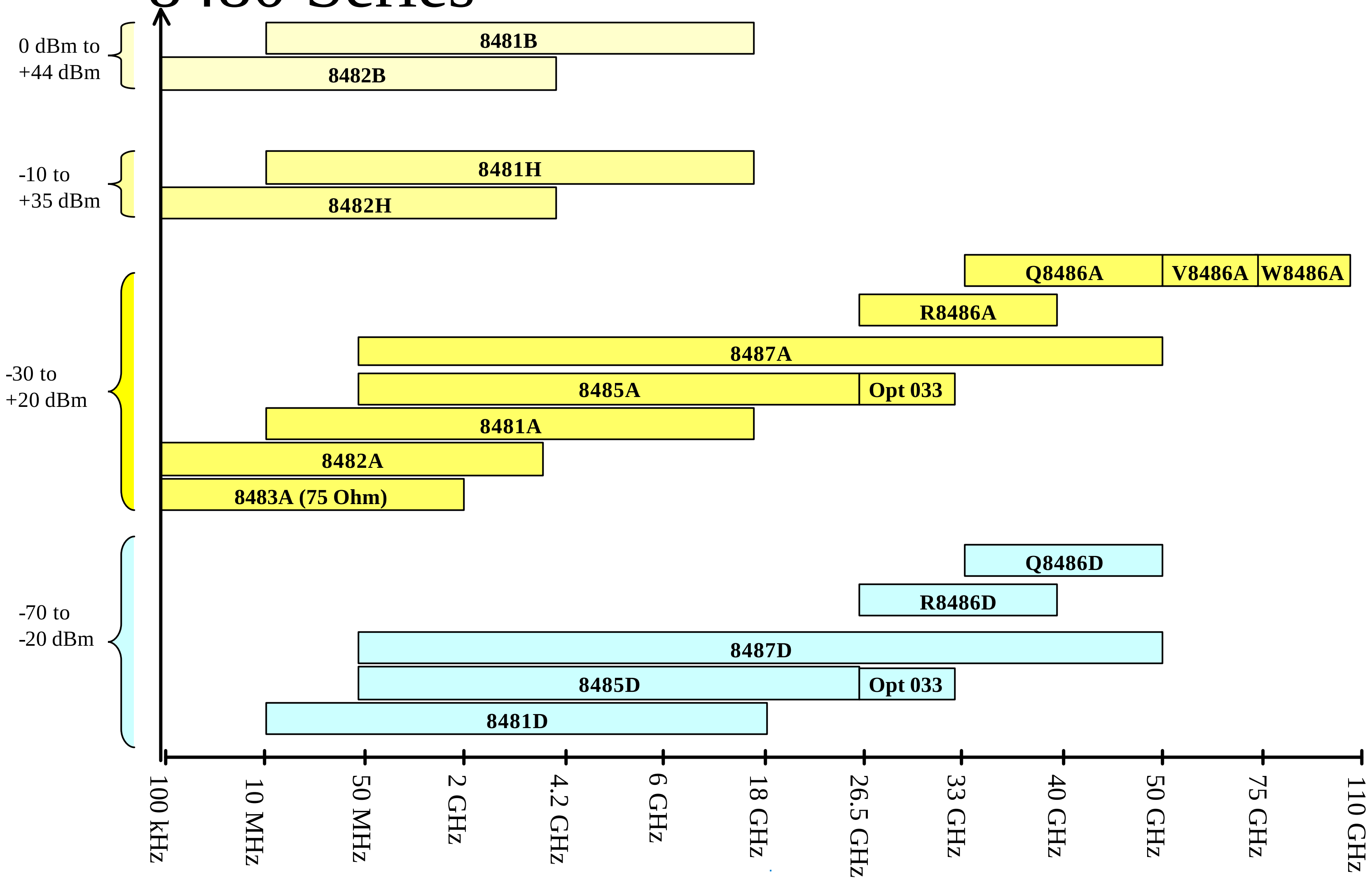
Agenda



- Appendix B

  Power Meter/Sensor Selection Guide

Agilent Power Sensor Selection Guide - 8480 Series



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