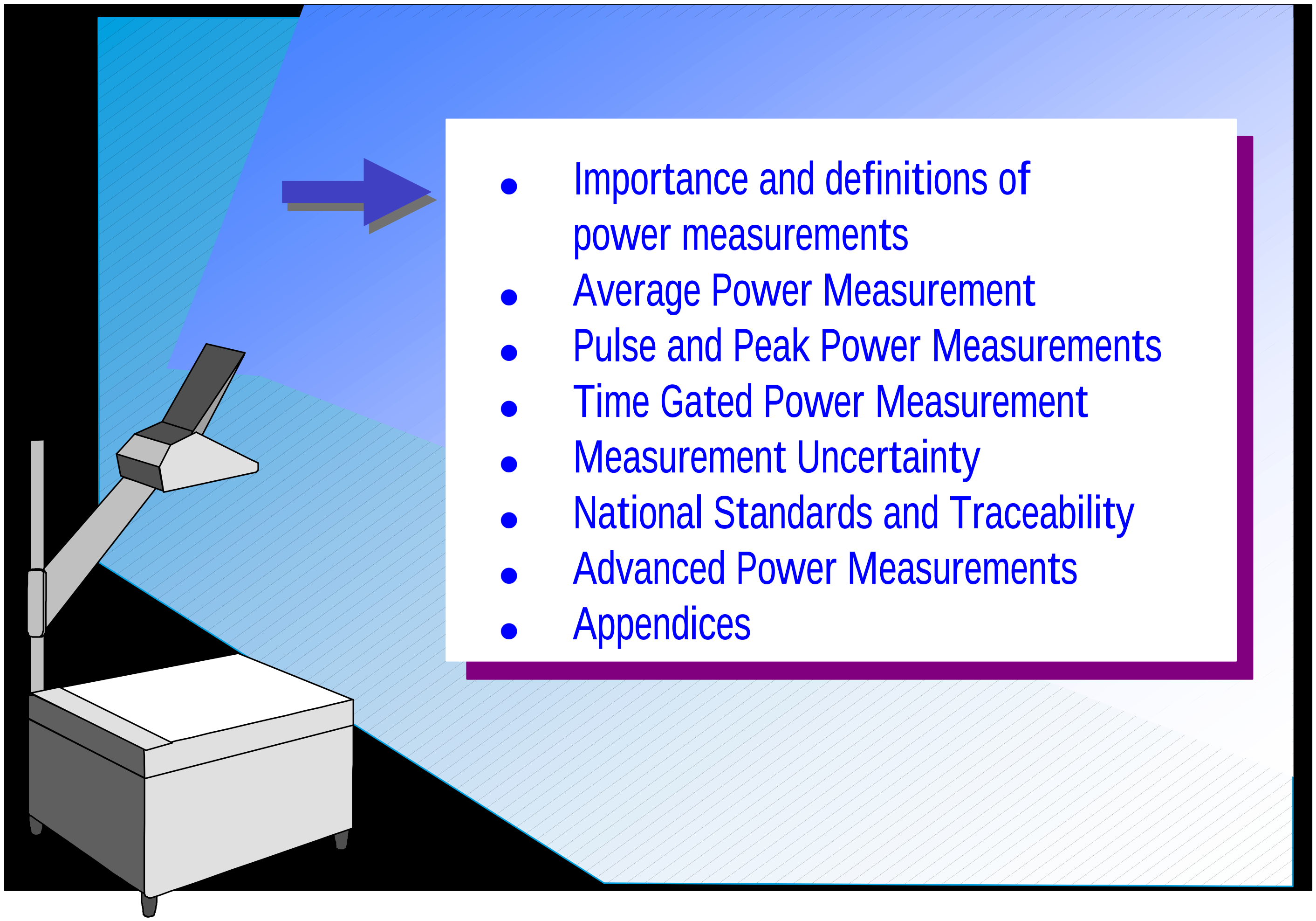
Power Measurement Basics

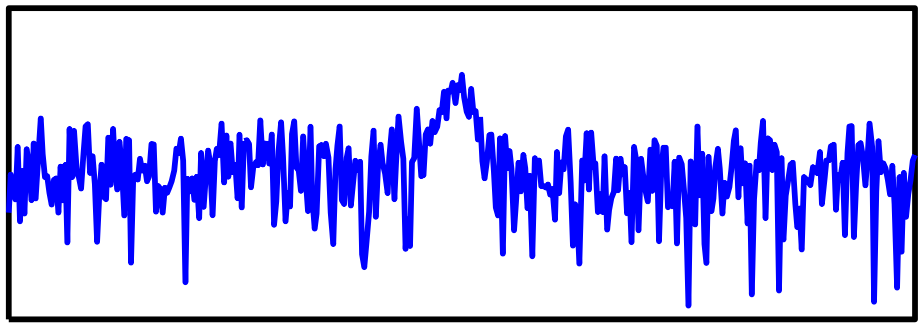
Agenda



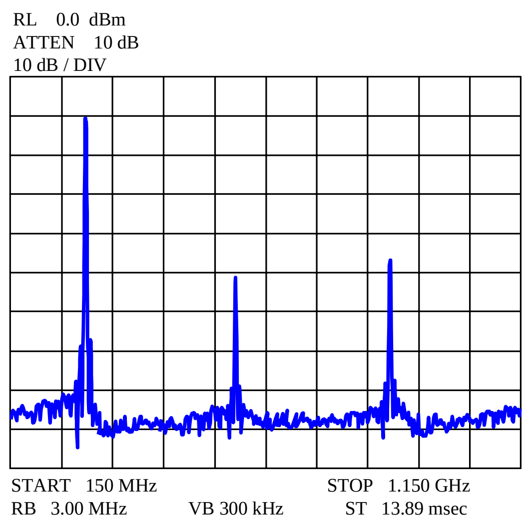
Importance and definitions of power measurements
Average Power Measurement
Pulse and Peak Power Measurements
Time Gated Power Measurement
Measurement Uncertainty
National Standards and Traceability
Advanced Power Measurements
Appendices

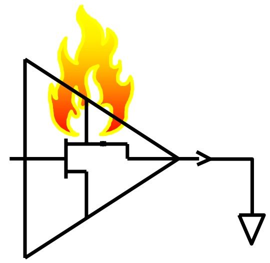
Importance of Proper Signal Levels

- Too low
  - Signal buried in noise



- Too high
  - Nonlinear distortion can occur

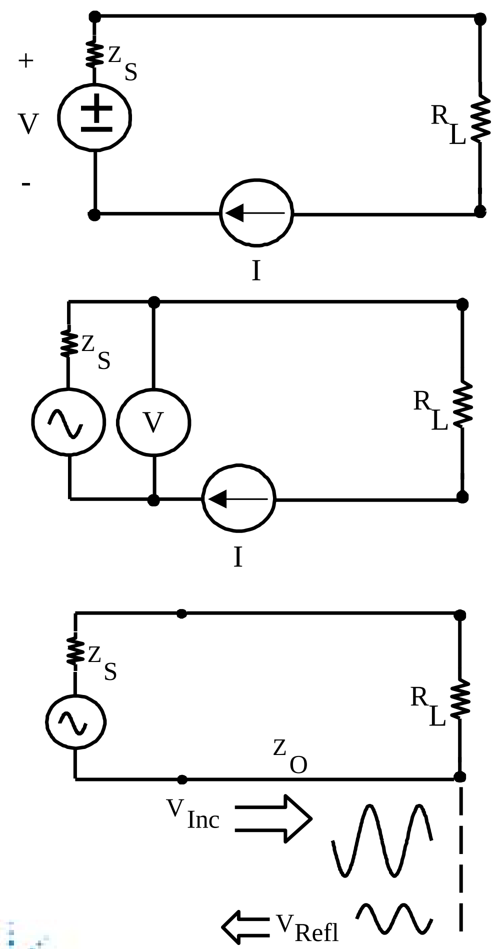




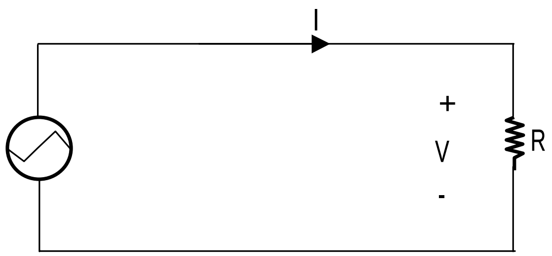
- Or even worse!

Why Not Measure Voltage?

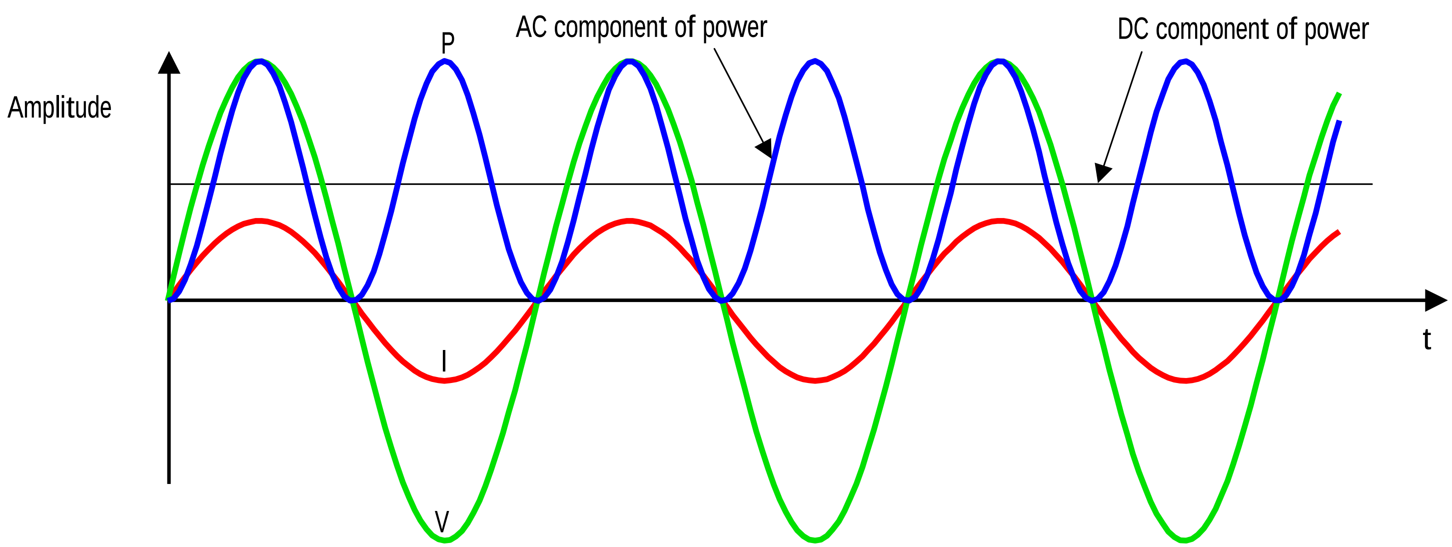
- DC
- Low Frequency
- High Frequency



Power: P = (I)(V)



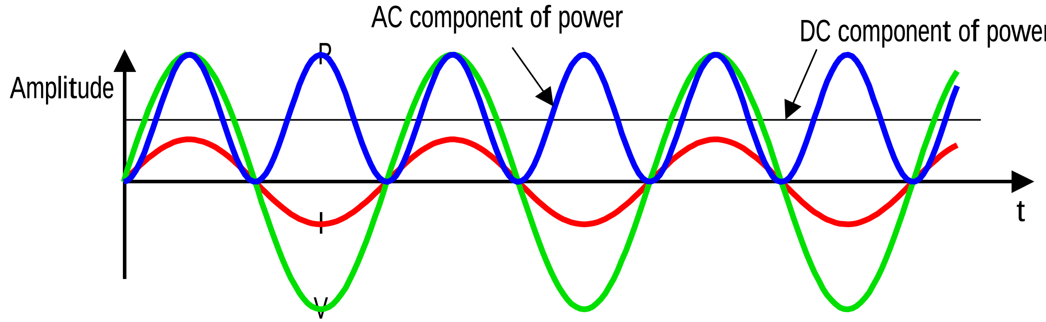
I
+
V
-
R



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

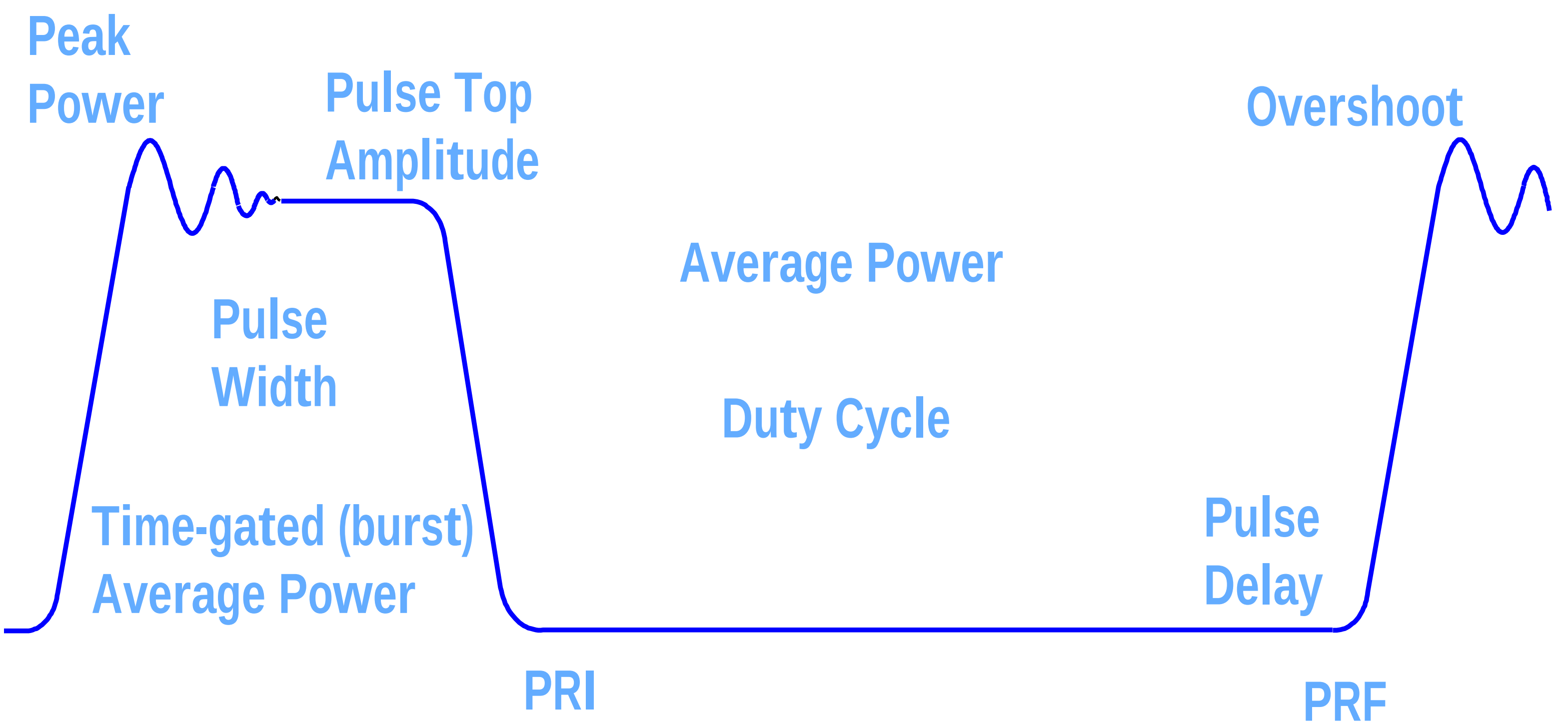
Units and Definitions

Power: $P = (I)(V)$



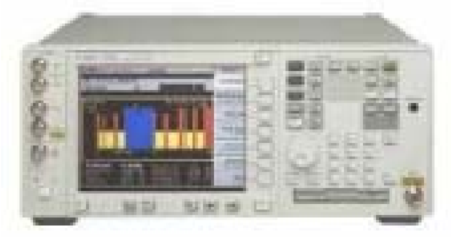
- Unit of power is the watt (W): 1W = 1 joule/sec
- Some electrical units are derived from the watt:
  1 volt = 1 watt/ampere
- Relative power measurements are expressed in dB:
  P(dB) = 10 log(P/Pref)
- Absolute power measurements are expressed in dBm:
  P(dBm) = 10 log(P/1 mW)

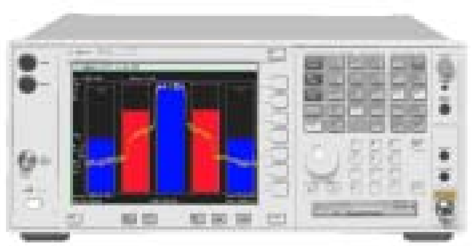
Types of Power Measurements



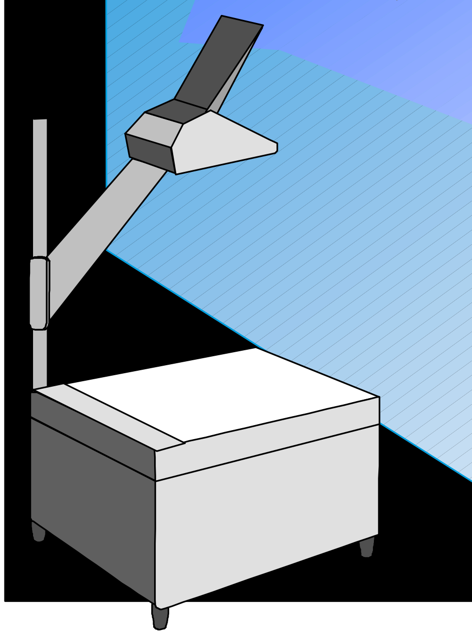
Instruments used to Measure RF and Microwave Power

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



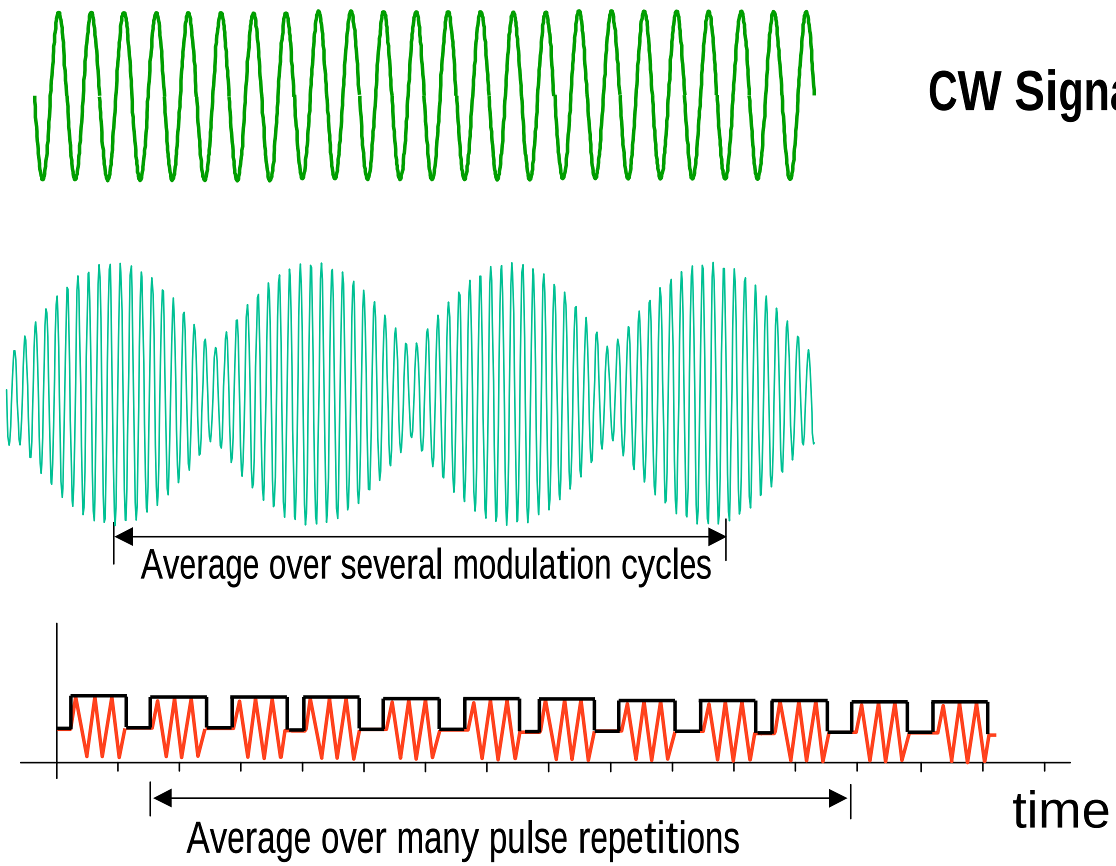


Agenda

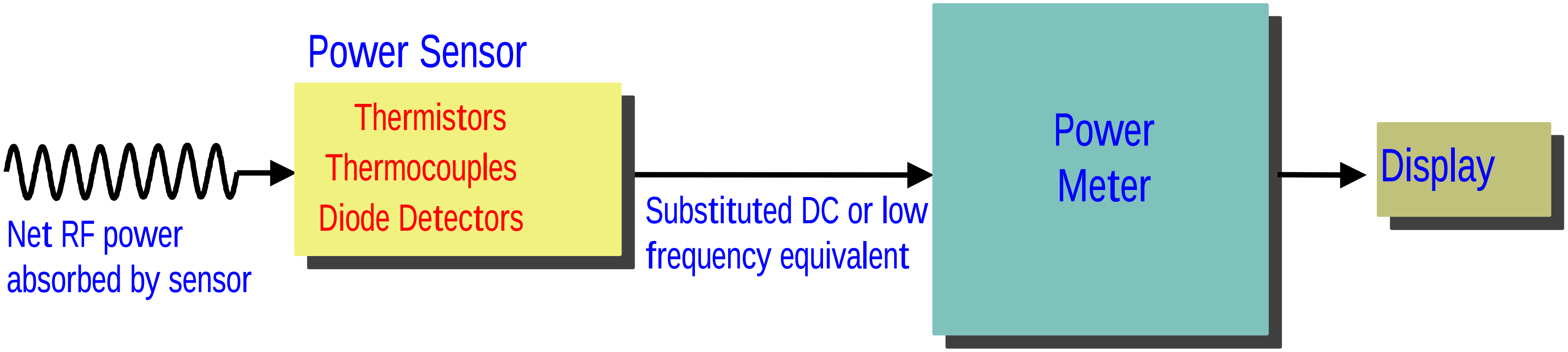


- Importance and definitions of power measurements
- Average Power Measurement
- Pulse and Peak Power Measurements
- Time Gated Power Measurement
- Measurement Uncertainty
- National Standards and Traceability
- Advanced Power Measurements
- Appendices

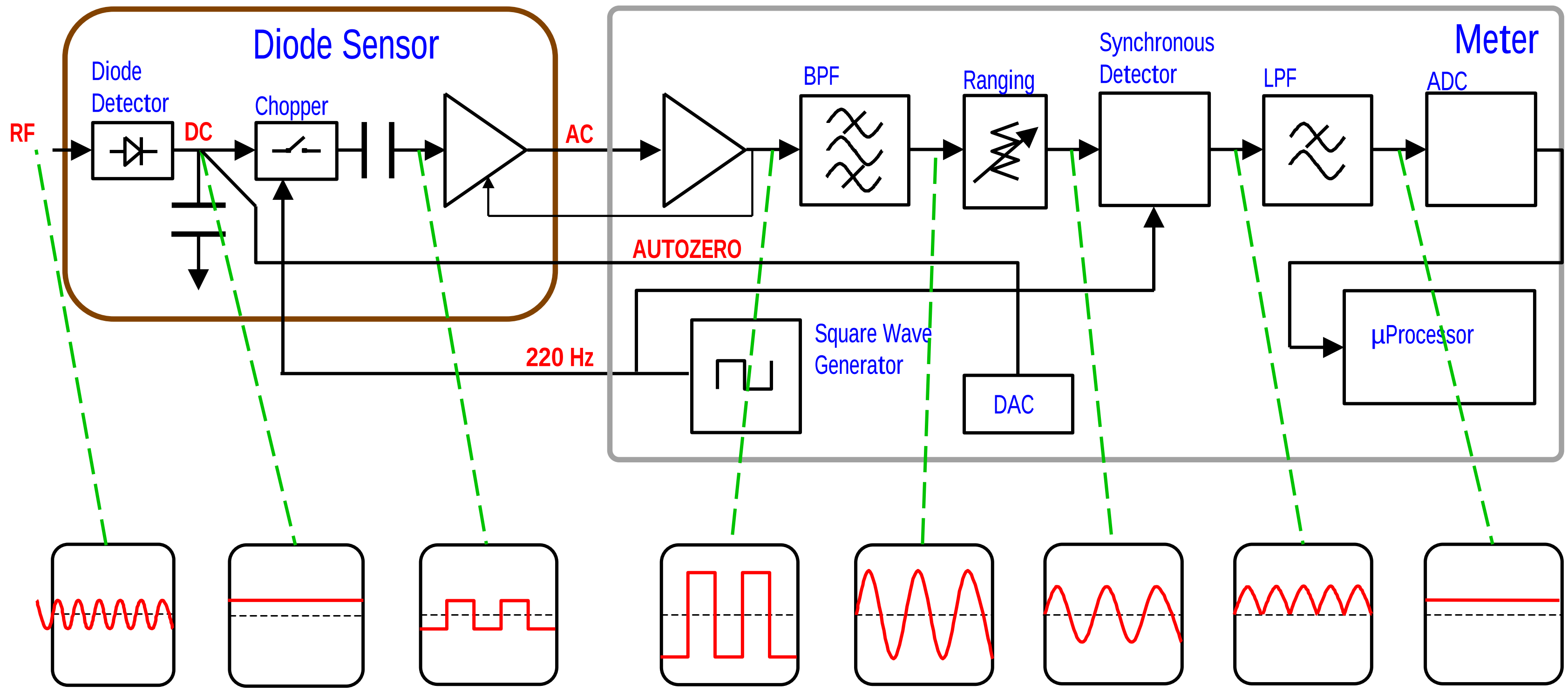
Average Power



Basic Measurement Method - Using a Power Meter

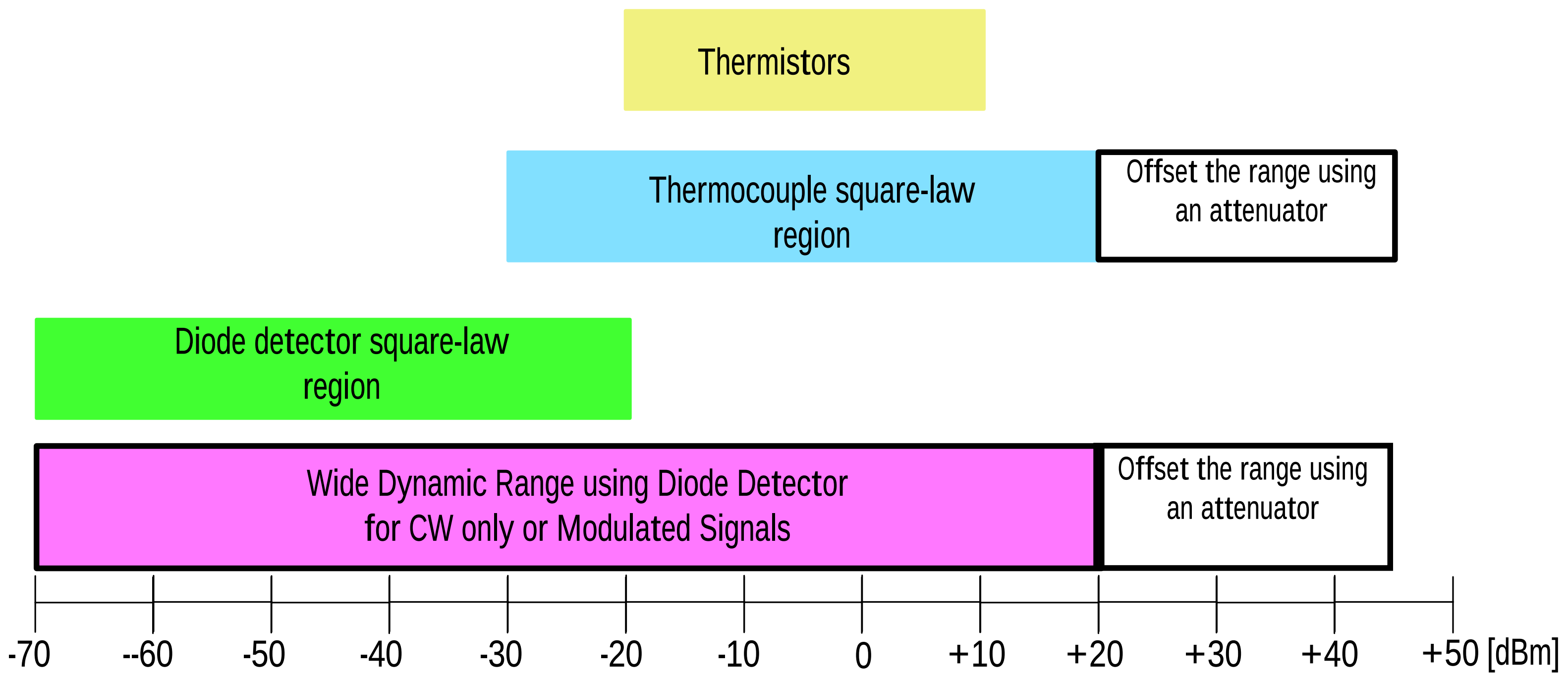


Basic Measurement Method Explained



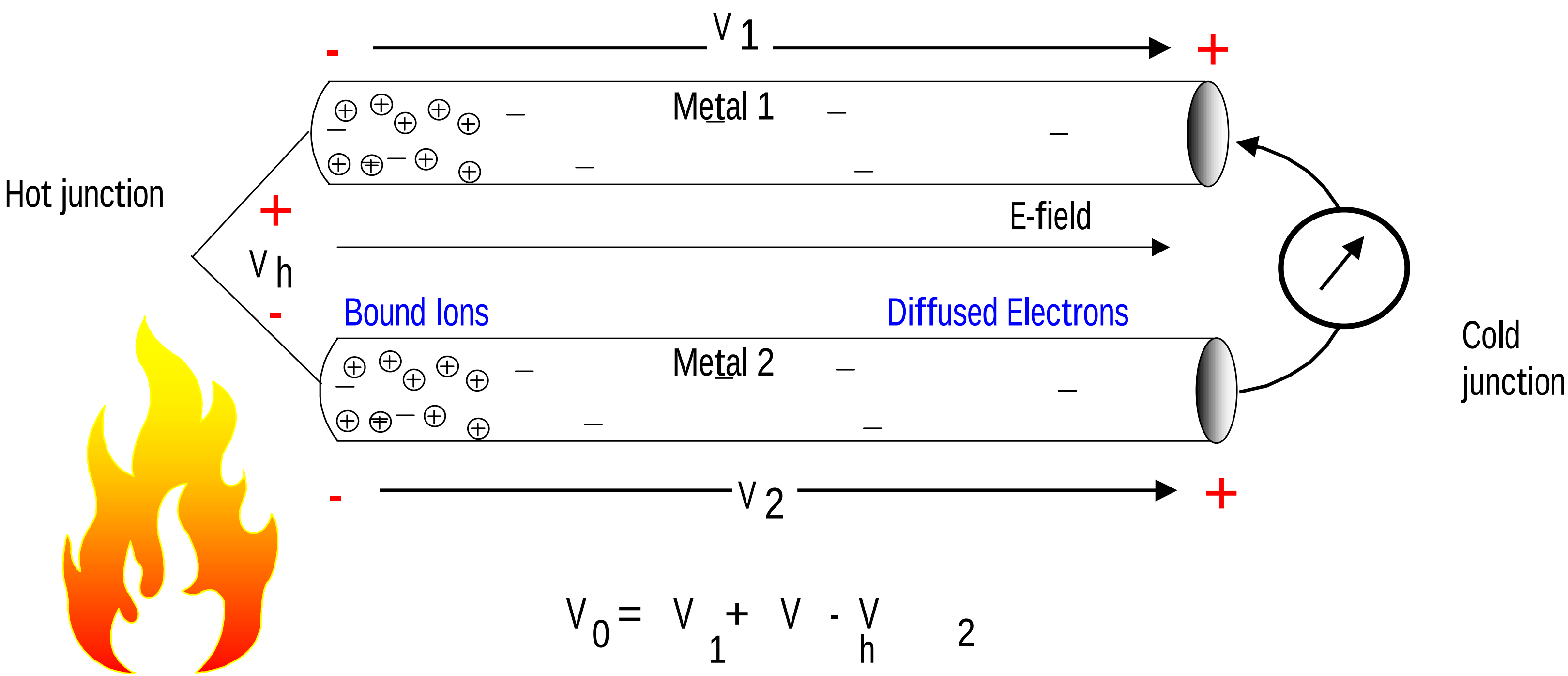
Agilent Technologies

Power Ranges of the Various Sensor Types



Thermocouples

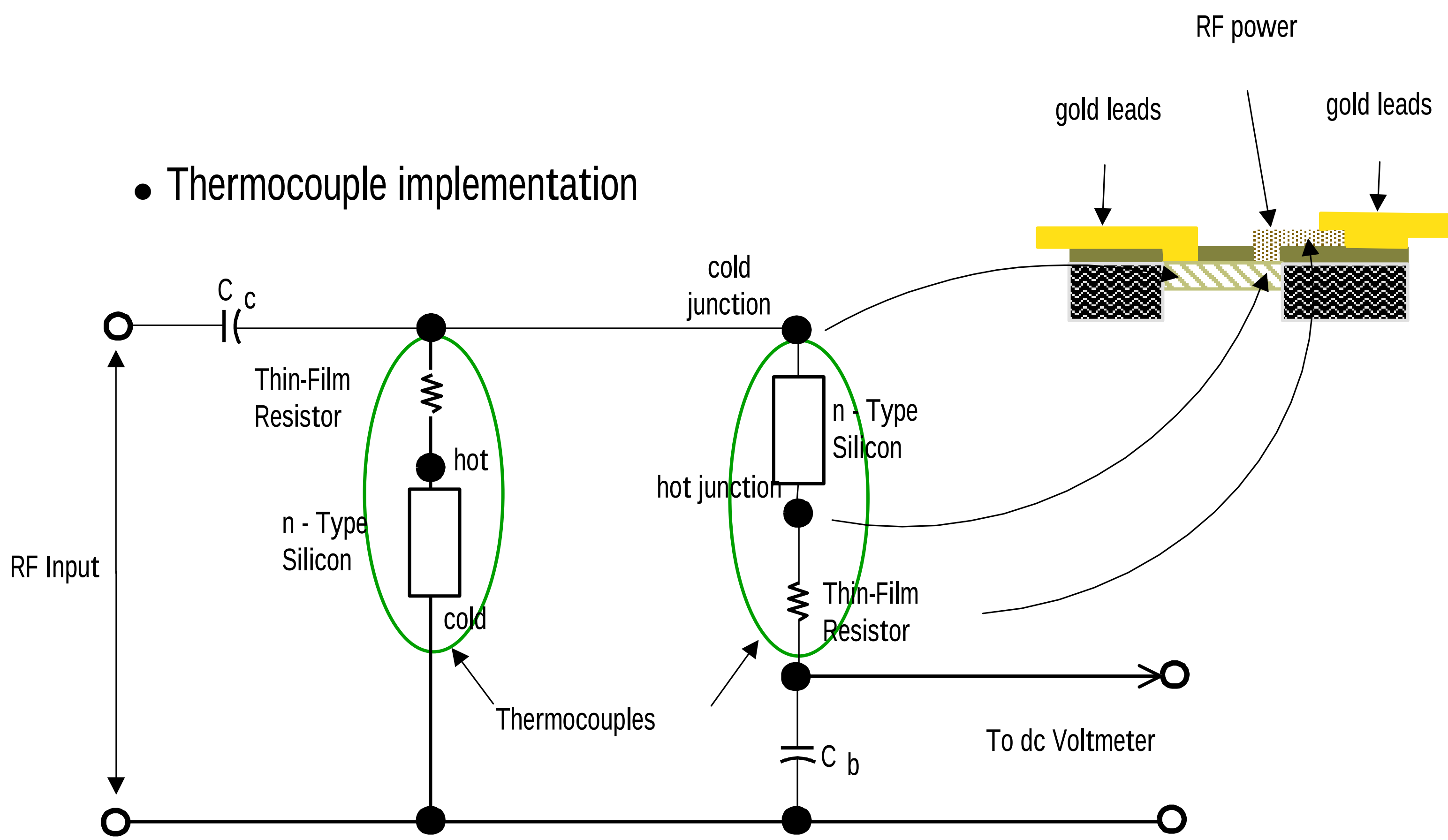
- The principles behind the thermocouple



$$V_0 = V_1 + V_h - V_2$$

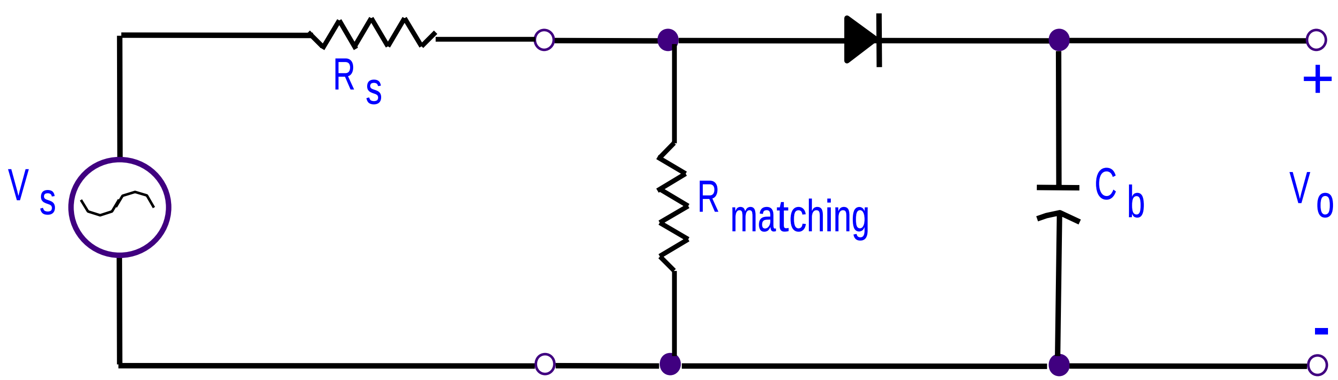
Thermocouples

- Thermocouple implementation

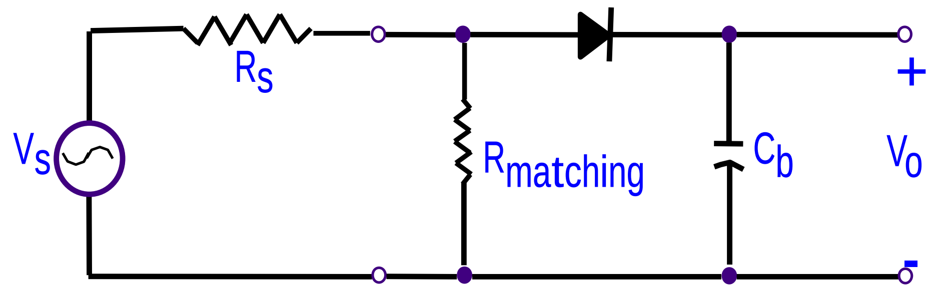


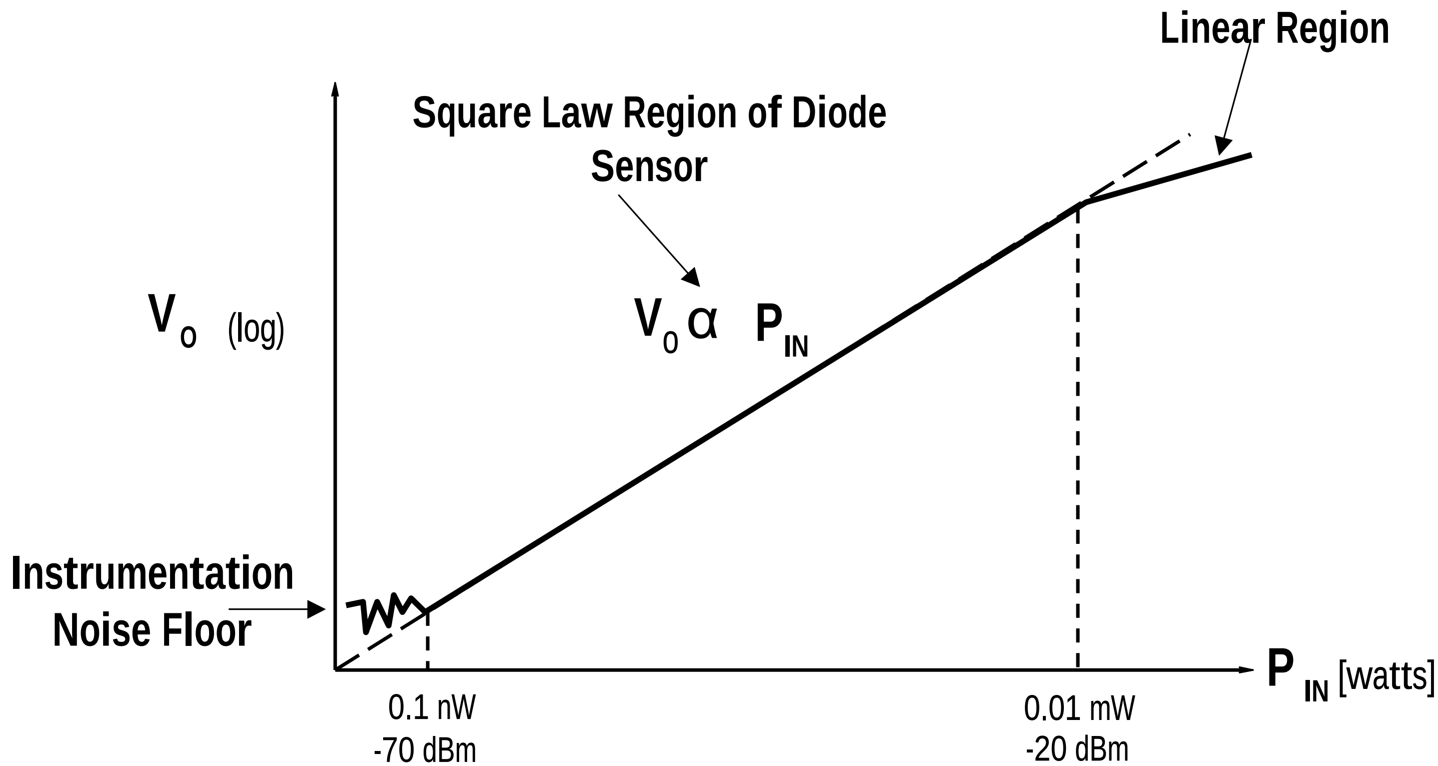
Diode Detectors

- How does a diode detector work?

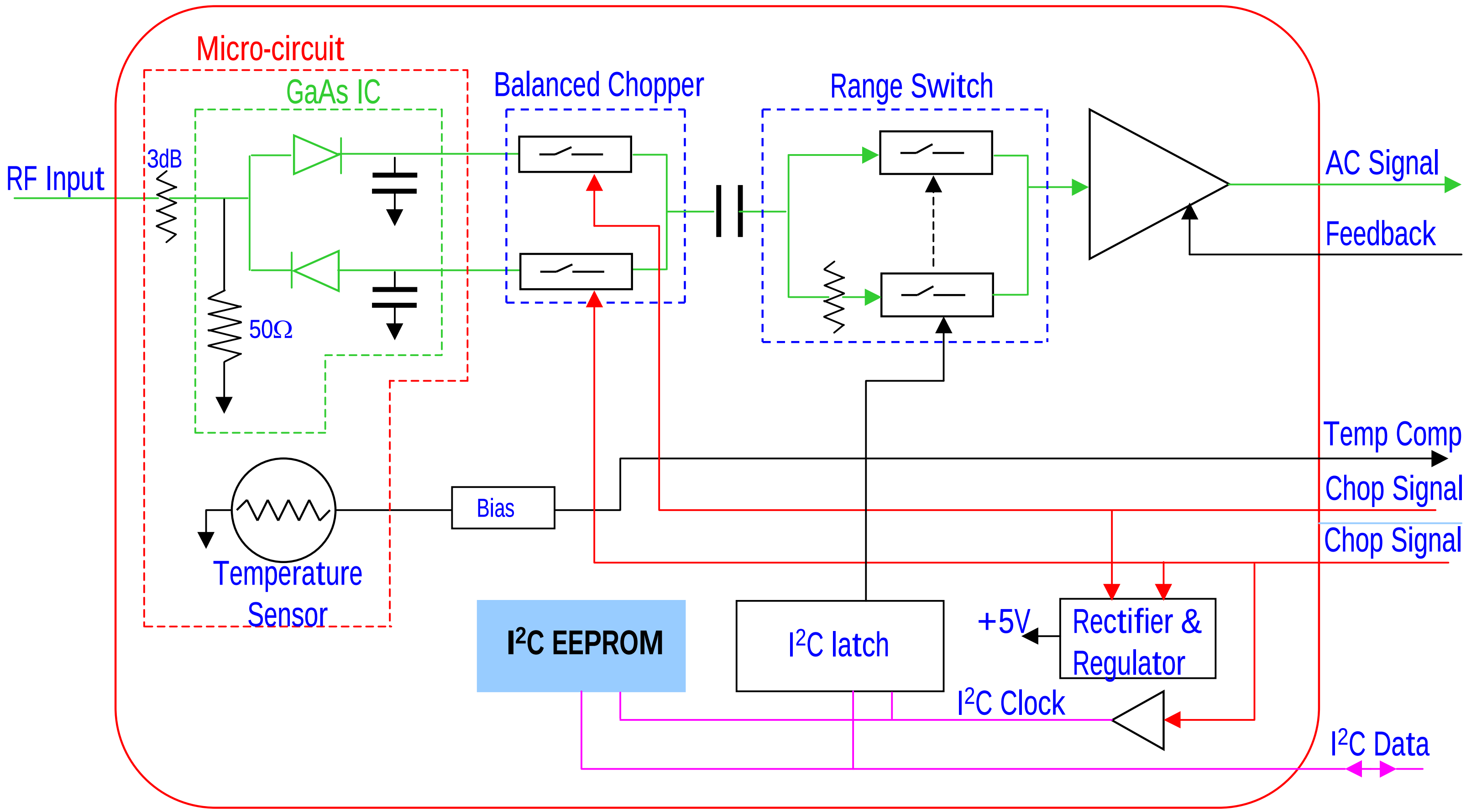


Diode Detectors



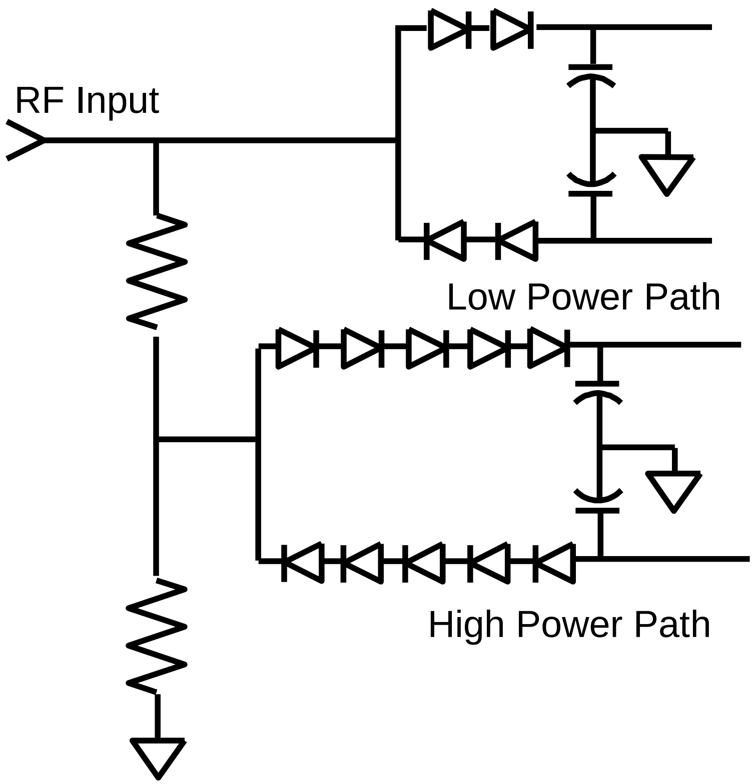


Wide-Dynamic-Range CW-only Power Sensors



Agilent Technologies

E-series E9300 Average Power Sensors Technology

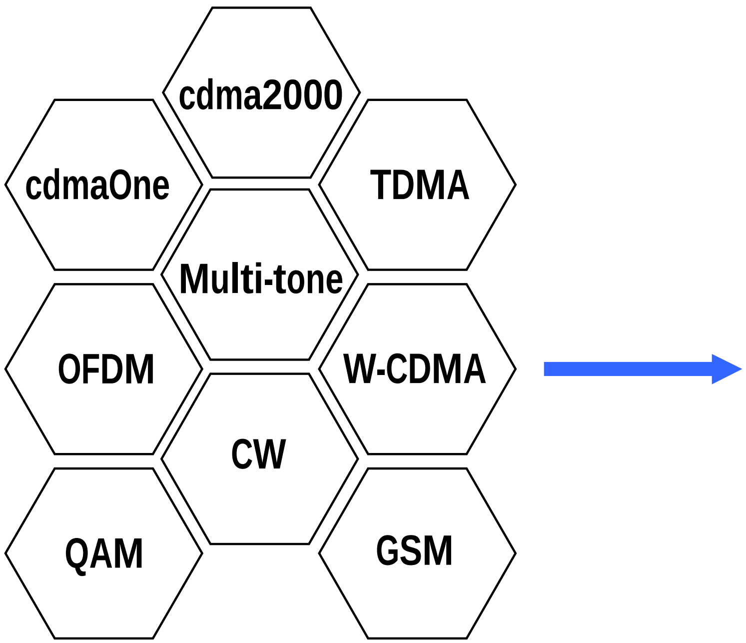


Innovative Design:

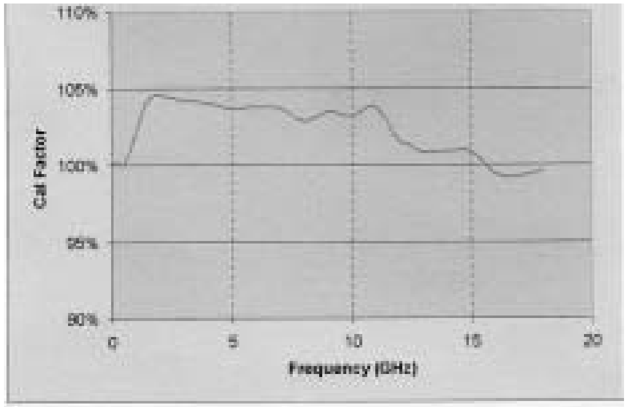
- Diode stack- attenuator-
  diode stack topology
- Two paths with an automatic
  switch point

Advantages of the E-series E9300 sensor architecture

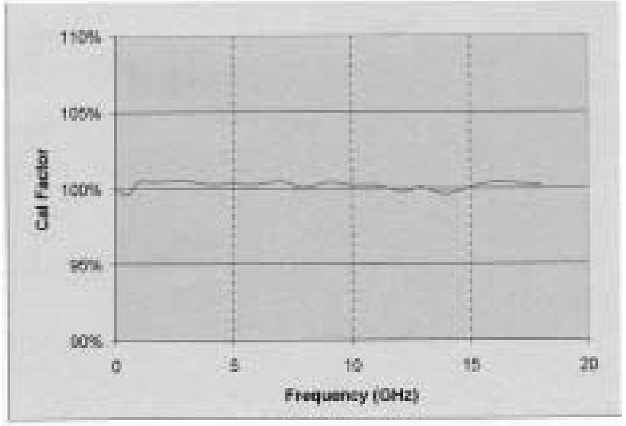
- Sensor diodes always kept in square law region:
  - means accurate measurement of signals with arbitrarily wide modulation bandwidth, and accurate measurement of signals with high peak to average ratios



Advantages of the E-series E9300 sensor architecture



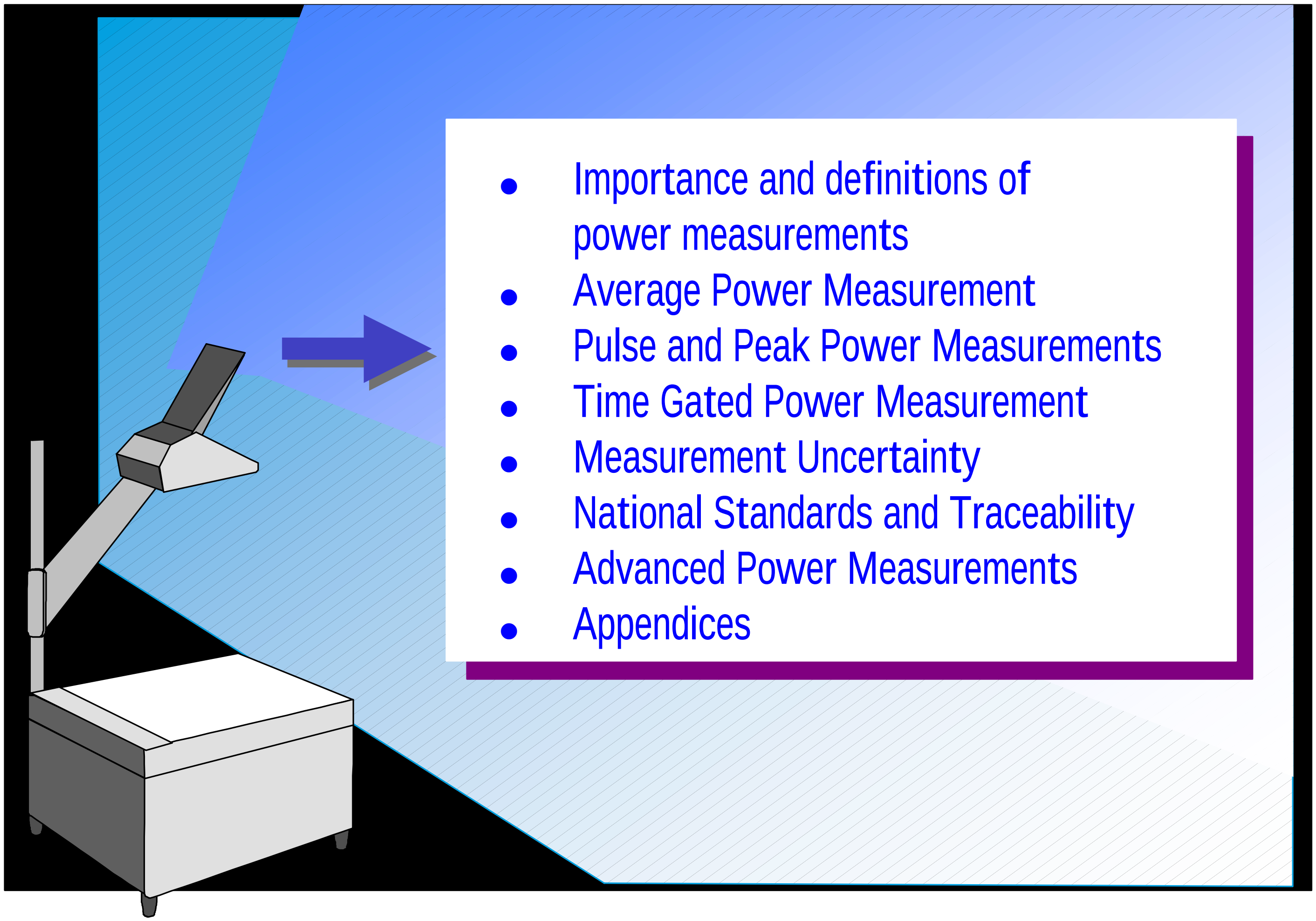
High Path Cal Factor



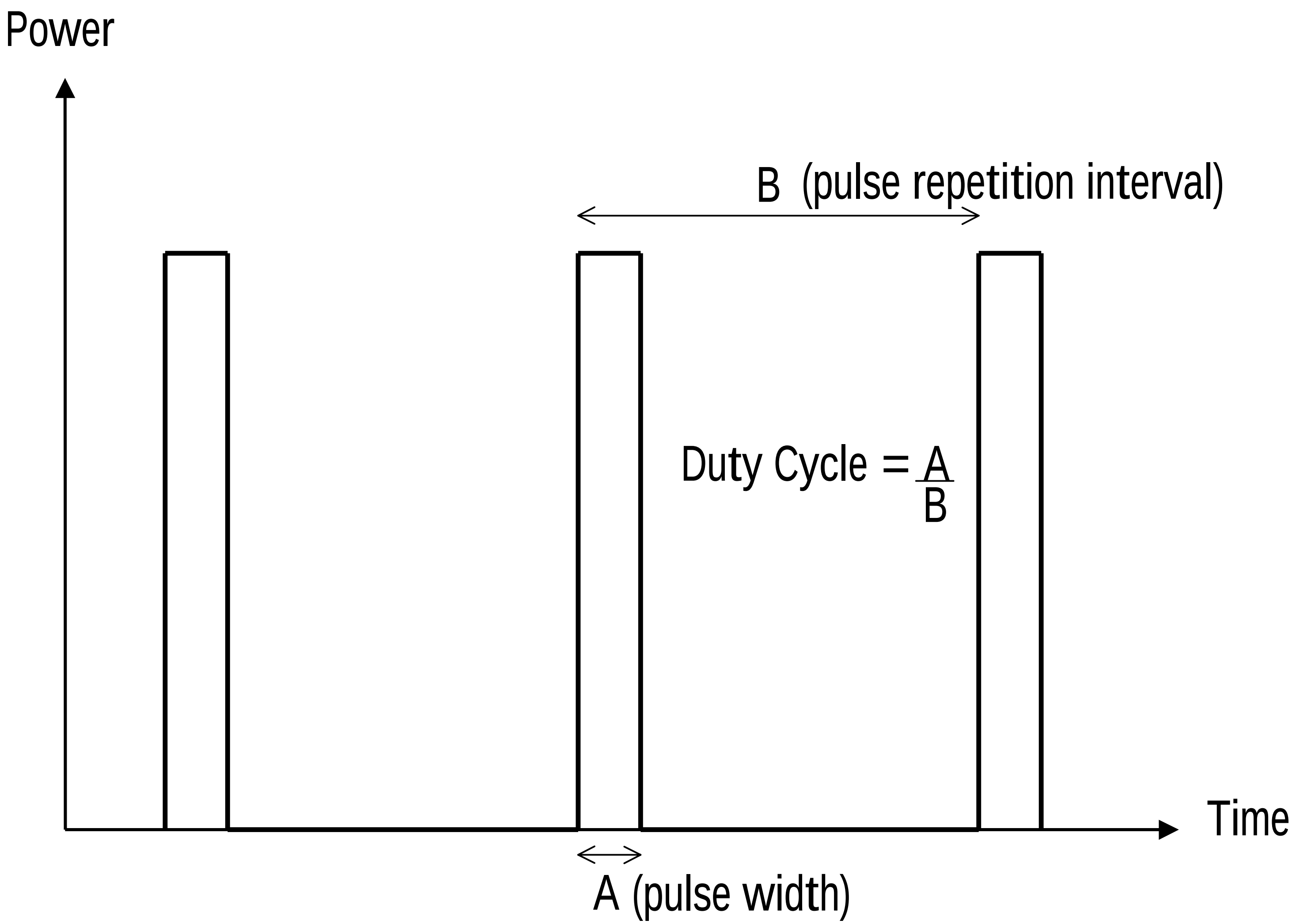
Low Path Cal Factor

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

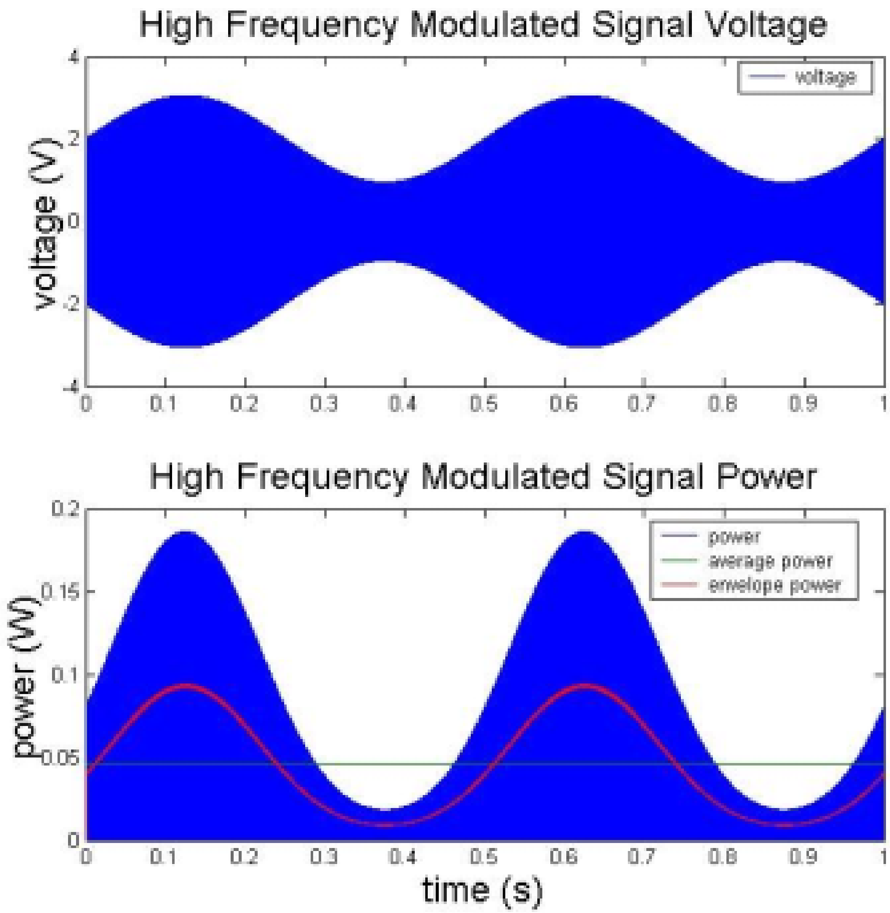
Agenda


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

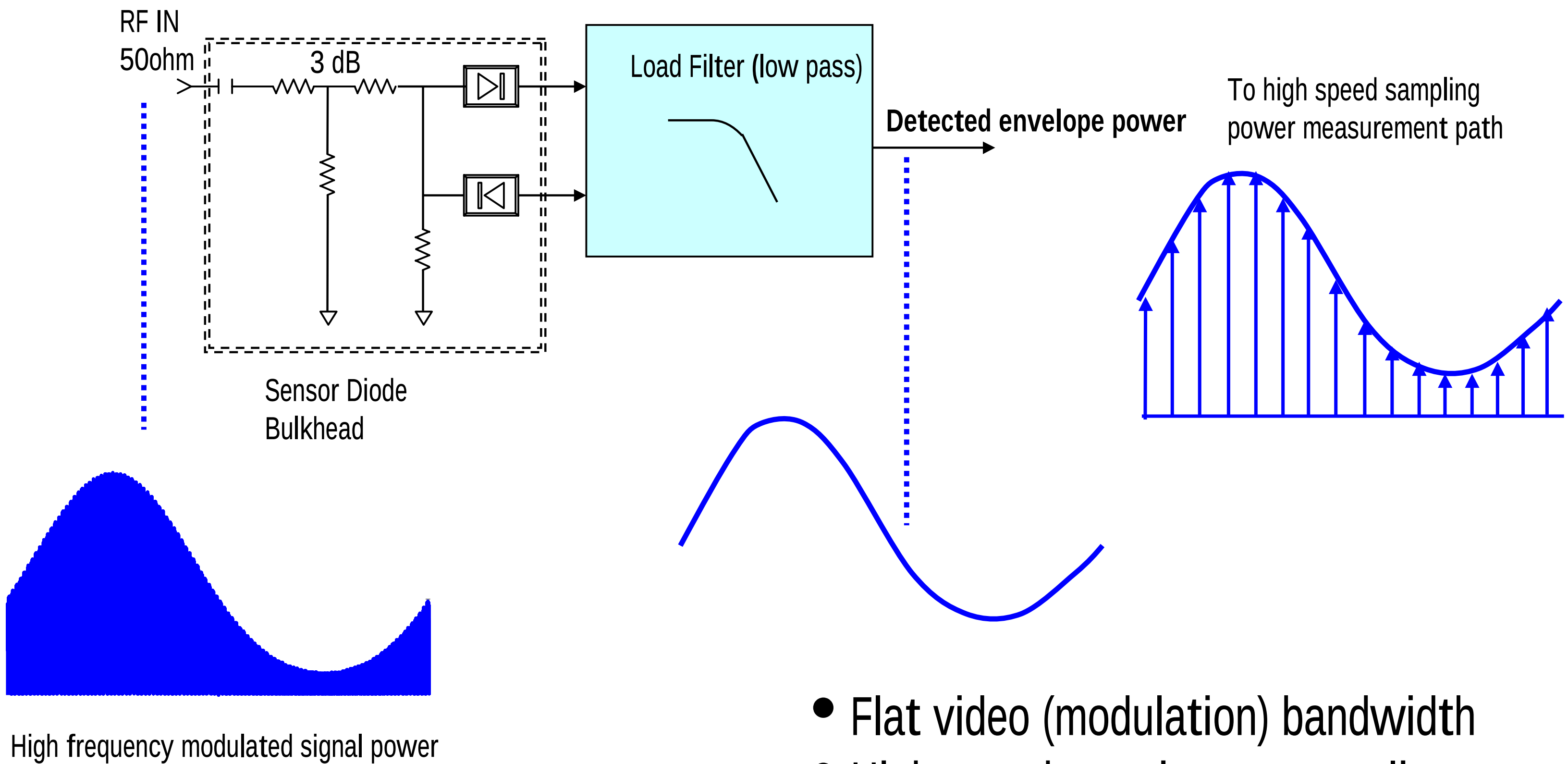
Pulse Power Measurement



Envelope Power and Peak Envelope Power



Peak Power Measurement System Characteristics



- Flat video (modulation) bandwidth
- High speed, continuous sampling
- Wide dynamic range

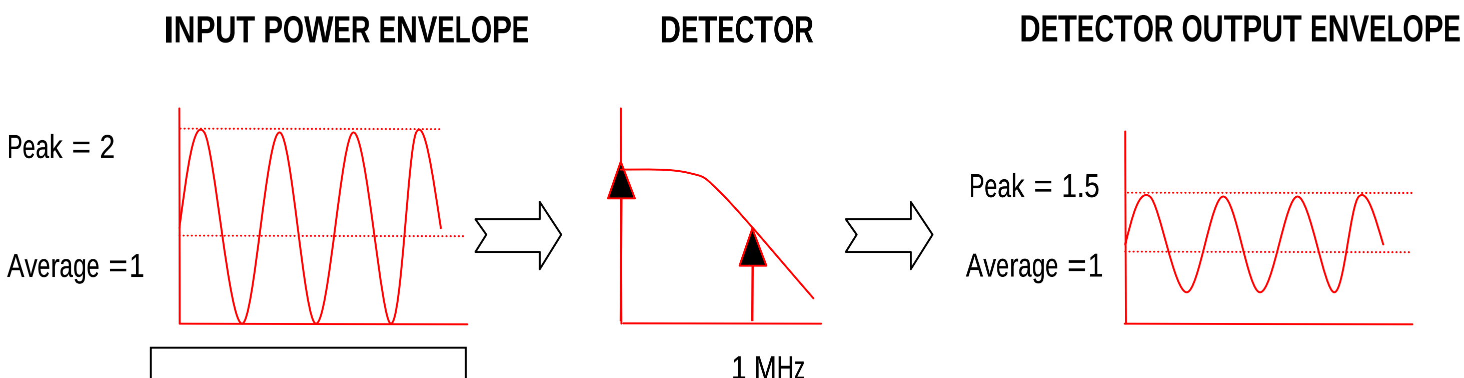
Continuous Sampling versus Random Sampling

What are the advantages of the 20Msamples/s continuous sampling compared to random sampling for power measurements?

- Continuous sampling ensures that the peak power is captured on single shot signals

- Random sampling takes longer to build up the trace display

The Effect of Insufficient Bandwidth



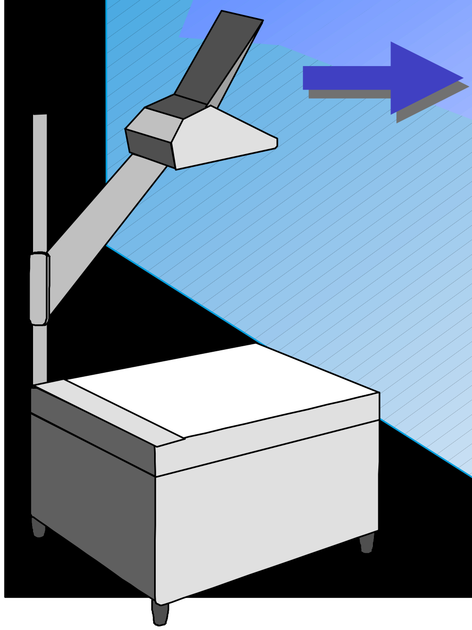
Crest Factor = 2 = 3dB

- Meter + Sensor Video Bandwidth Response

(1 MHz tone attenuated by 0.5)

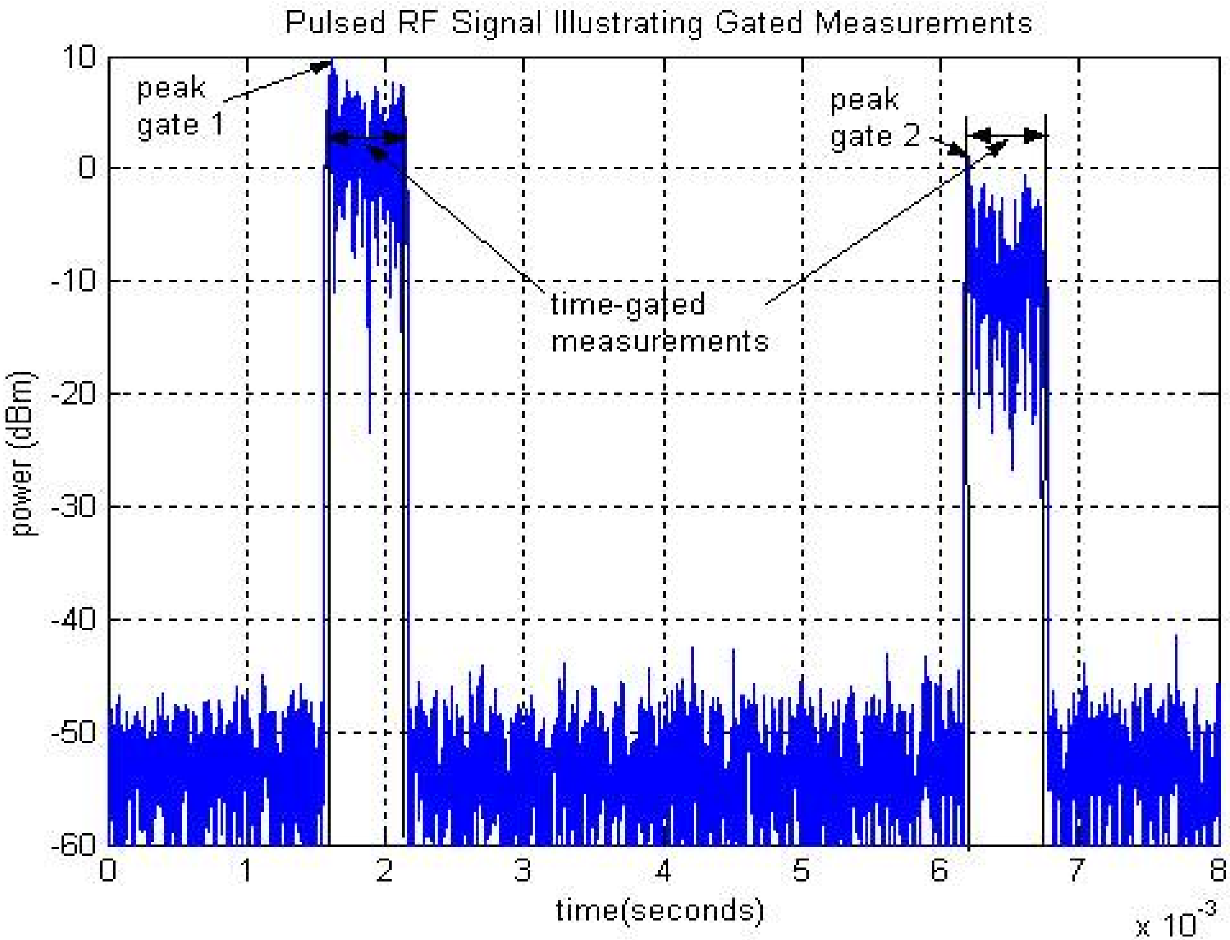
Crest Factor =1.5
= 1.76 dB
1.24 dB error

Agenda

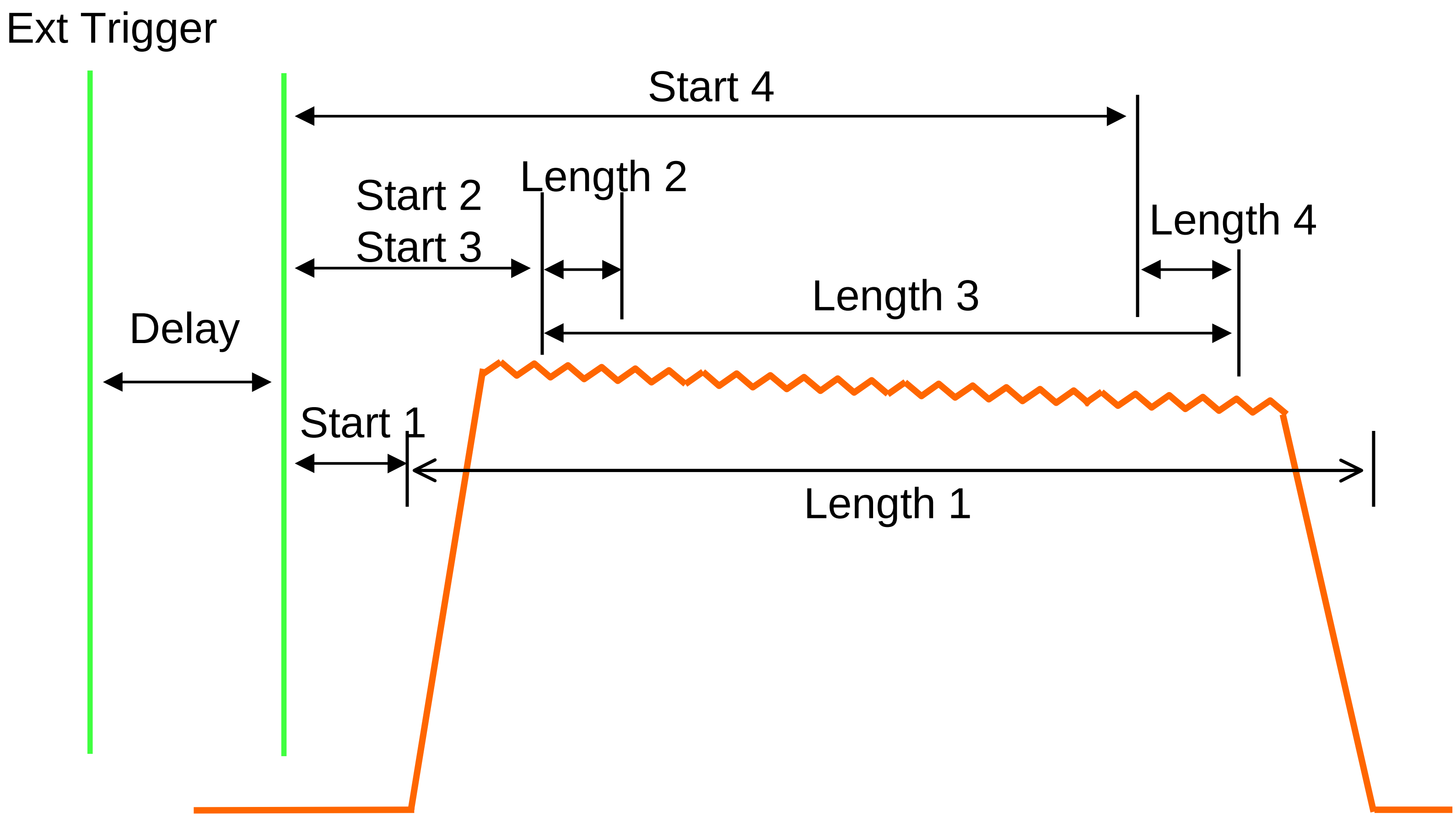


- Importance and definitions of power measurements
- Average Power Measurement
- Pulse and Peak Power Measurements
- Time Gated Power Measurement
- Measurement uncertainty
- National Standards and Traceability
- Advanced Power Measurements
- Appendices

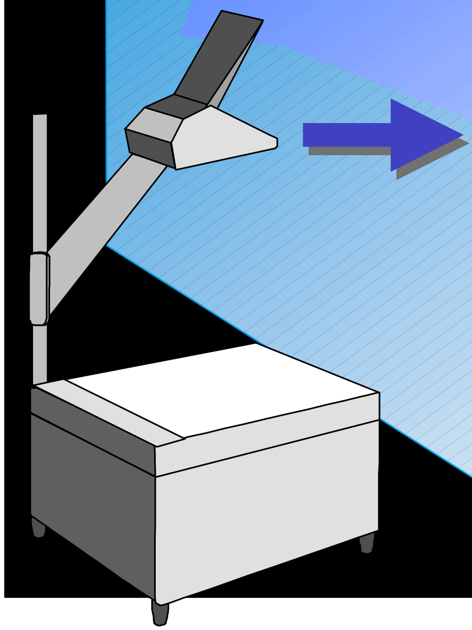
Time Gated Power Measurements



Time Gated Power Measurements



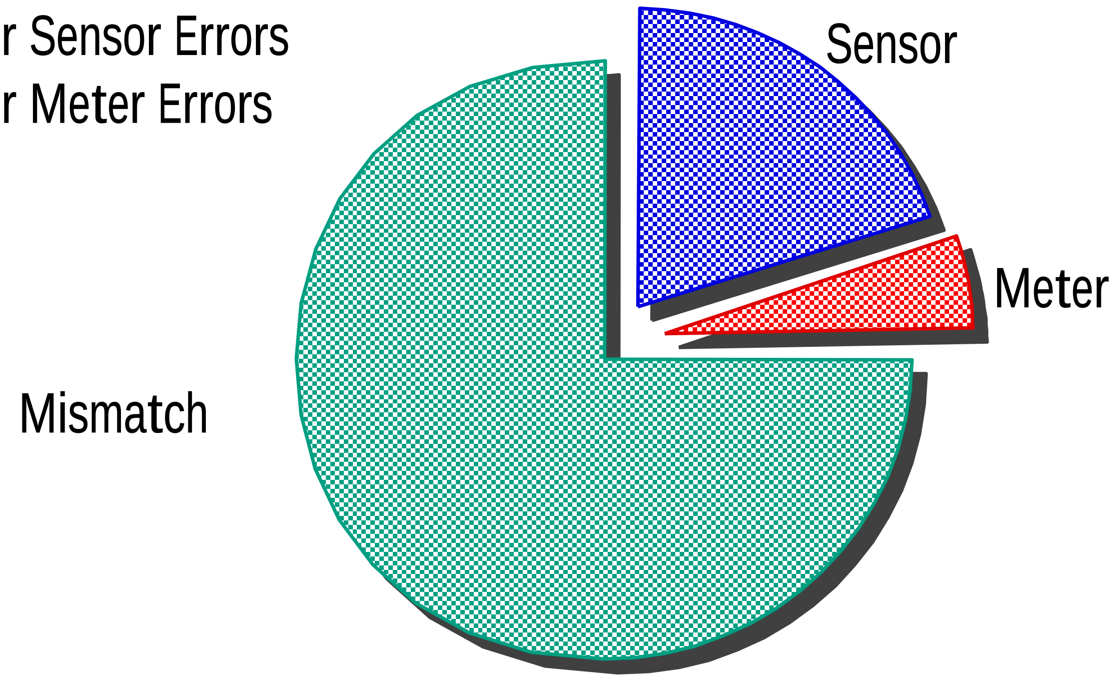
Agenda



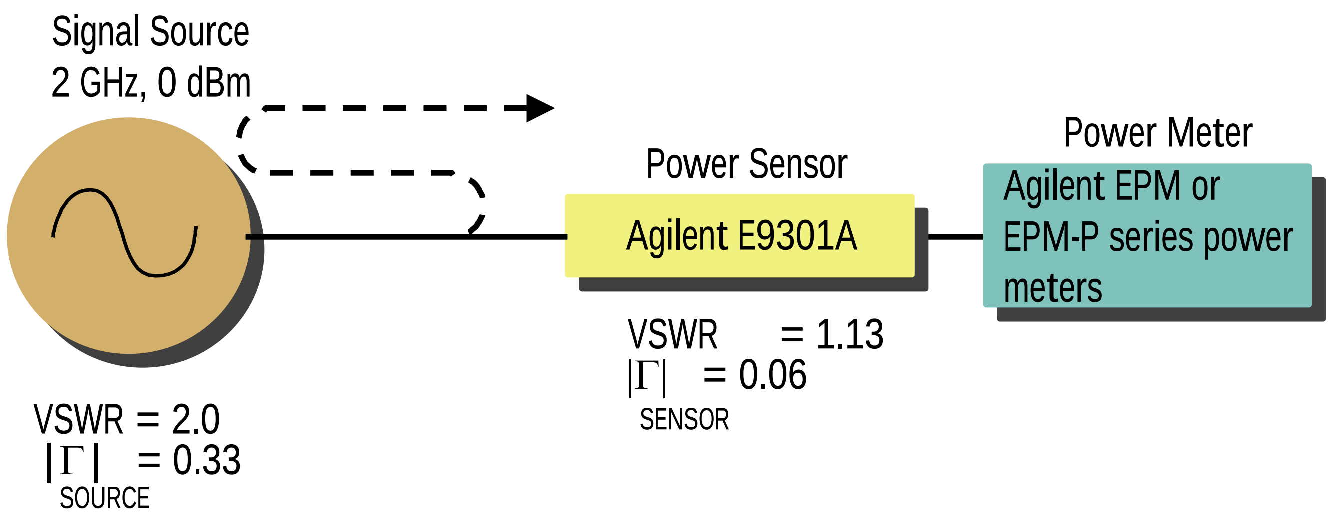
- Importance and definitions of power measurements
- Average Power Measurement
- Peak Power Measurement
- Time Gated Power Measurement
- Measurement Uncertainty
- National Standards and Traceability
- Advanced Power Measurements
- Appendices

Sources of Power Measurement Uncertainty

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



Calculation of Mismatch Uncertainty

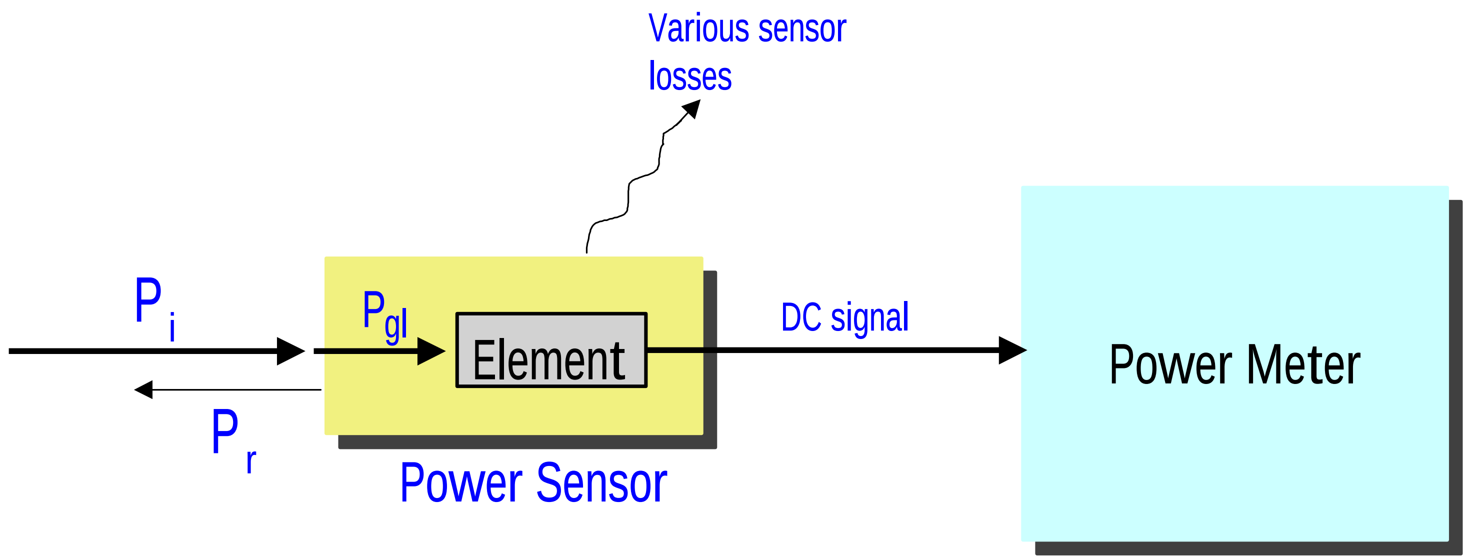


$$\text{Mismatch Uncertainty} = \pm 2 \times |\Gamma|_{SOURCE} \times |\Gamma|_{SENSOR} \times 100\%$$

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

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

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

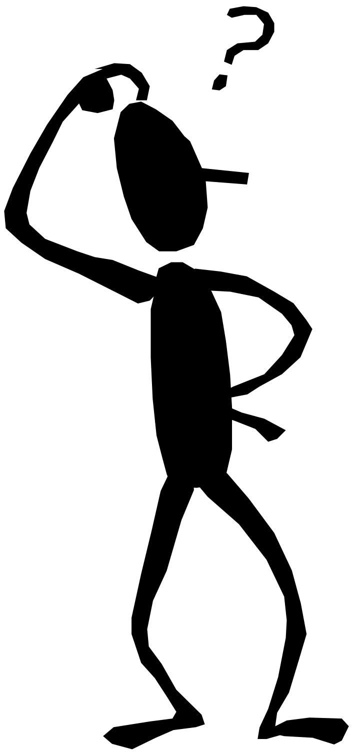
Noise

Drift

Zero Set

Instrumentation uncertainty

Judgement: What is an acceptable measurement uncertainty?



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

Which is the larger error?

Calculating Power Measurement 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

* In accordance to guidelines published in the "ISO Guide to the Expression of Uncertainty in Measurement" and the "ANSI/NCSL Z540-2-1996 US Guide to the Expression of Uncertainty in Measurement"

Combined Standard Uncertainty (u_c), using the Root Sum of the Squares (RSS)

- In our example, the u_c would be:

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

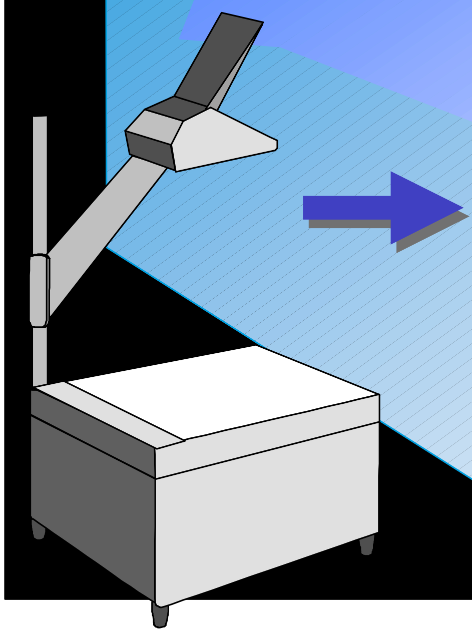
$$= \pm 3.16\%$$

- 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)*

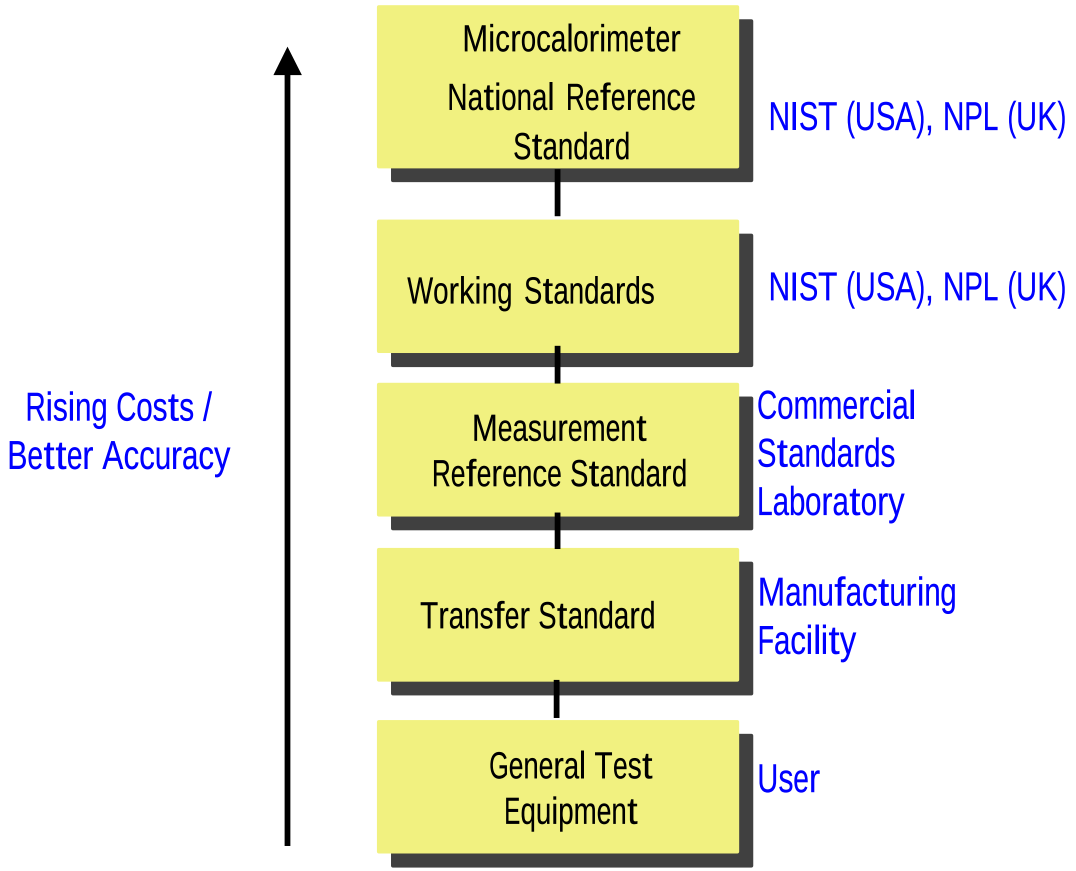
- 6.3% = 10 log (1 - 0.063) = -0.28 dB *(-0.42 dB worst case)*

Agenda

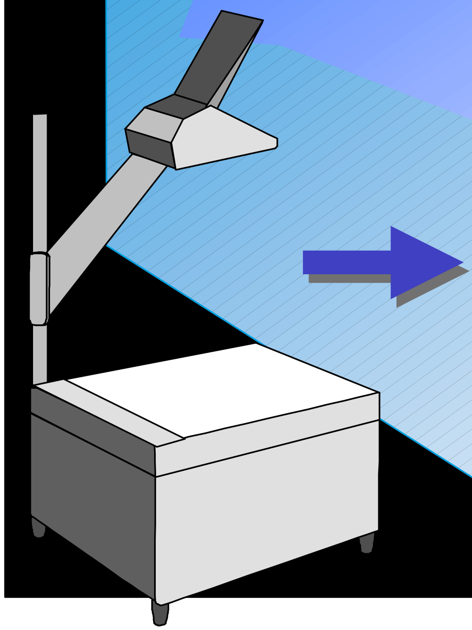


- Importance and definitions of power measurements
- Average Power Measurement
- Pulse and Peak Power Measurements
- Time Gated Power Measurement
- Measurement Uncertainty
- National Standards and Traceability
- Advanced Power Measurements
- Appendices

National Standards and Traceability



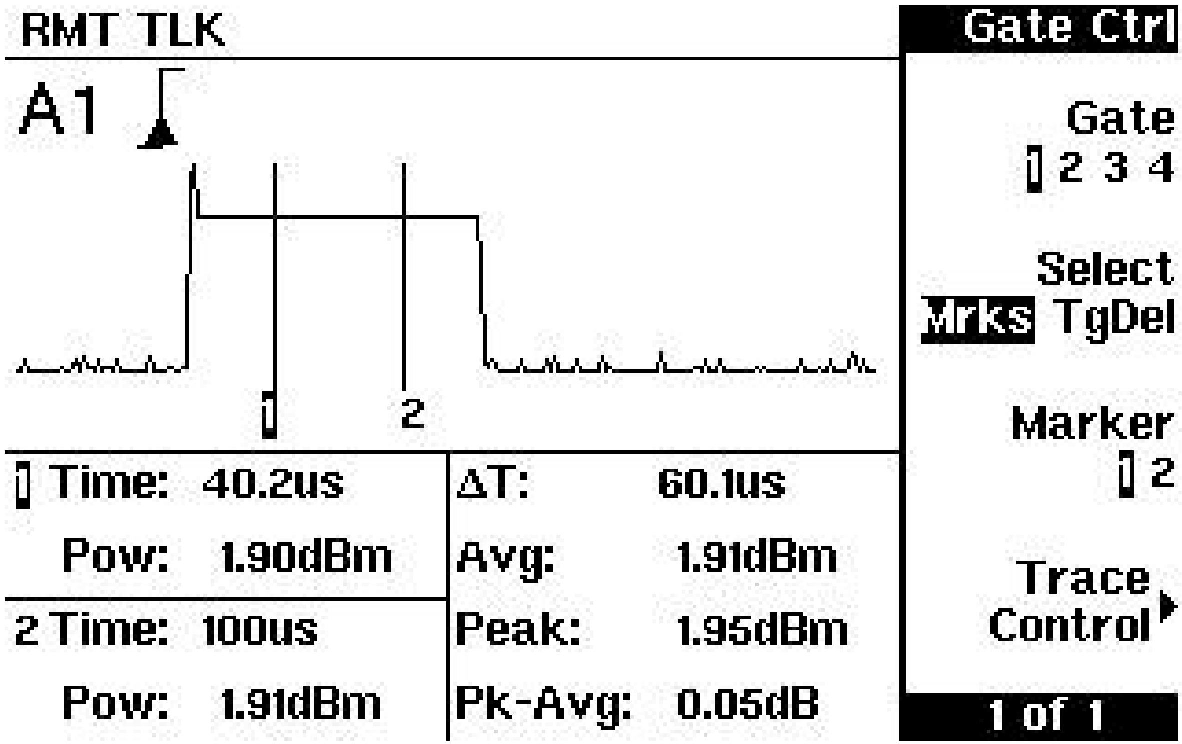
Agenda



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

Advanced Power Measurements

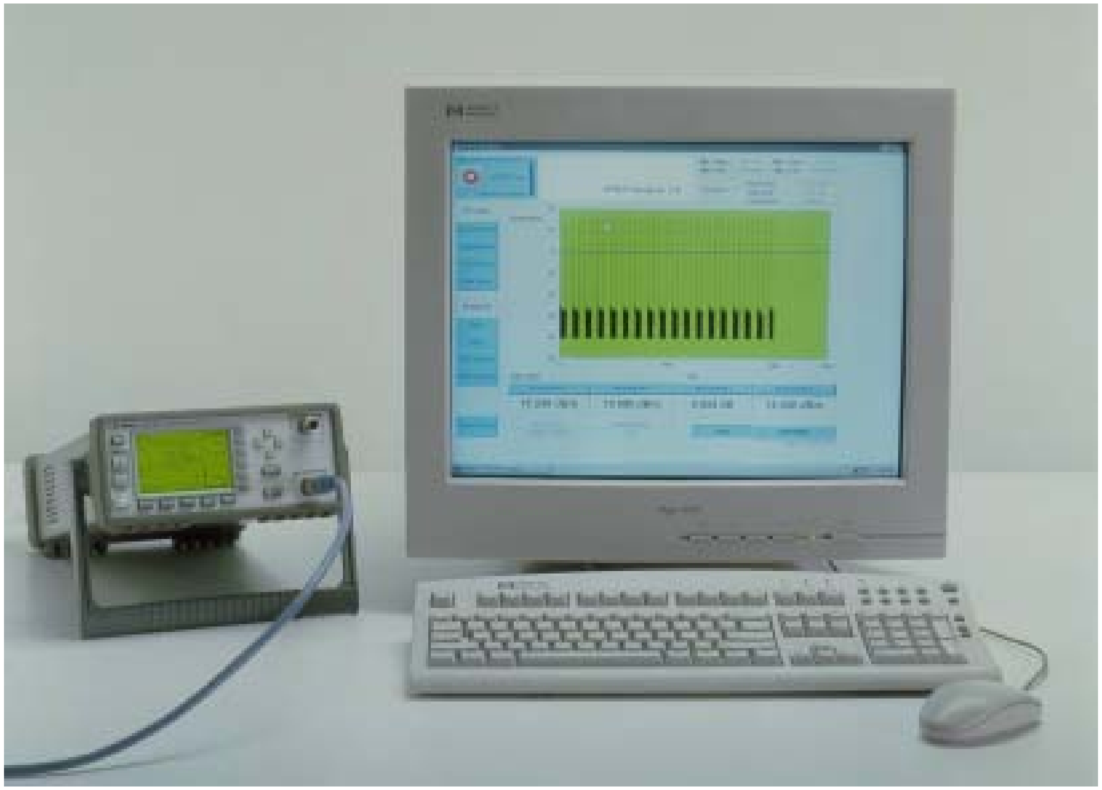
- Trace display (pulse profile)
- Marker measurements and display analysis



Agilent EPM-P power meter trace display and analysis screen

Advanced Power Measurements

- New *analyzer* features and measurements in PC or laptop environment



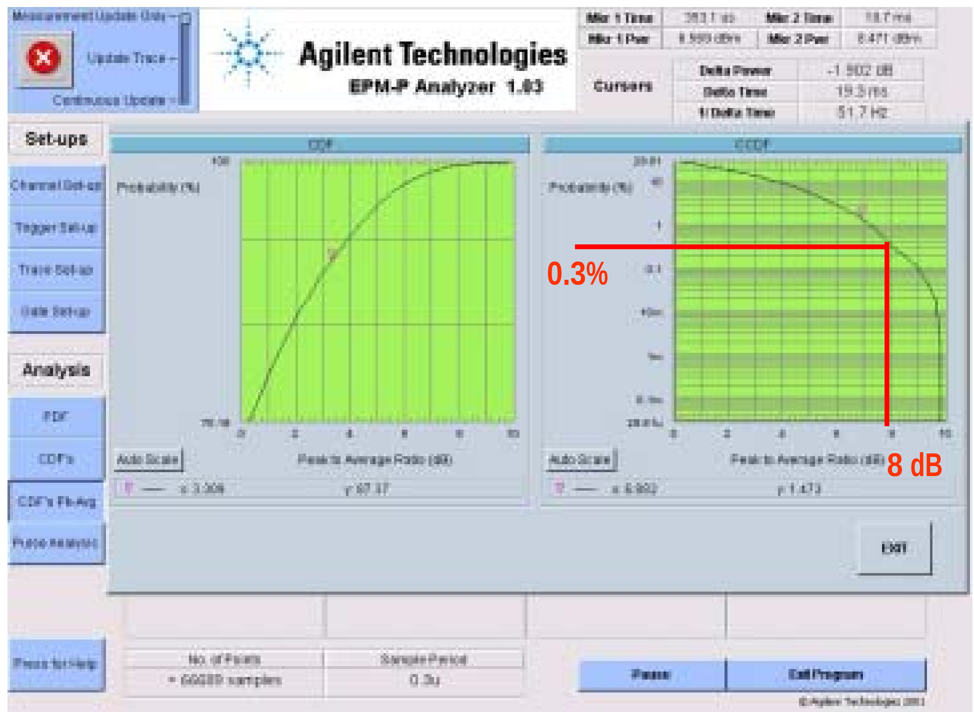
Agilent EPM-P Analyzer software

Advanced Power Measurements

- Statistical Analysis:
  - Cumulative Distribution Function (CDF)
  - Complementary Cumulative Distribution Function (CCDF or 1-CDF)
  - Probability Density Function (PDF)

Y axis is the percent time the signal power is at OR ABOVE the power specified by the X axis.

Example: For this CCDF curve, for 0.3% time the signal power is at or above 8 dB peak-to-average ratio

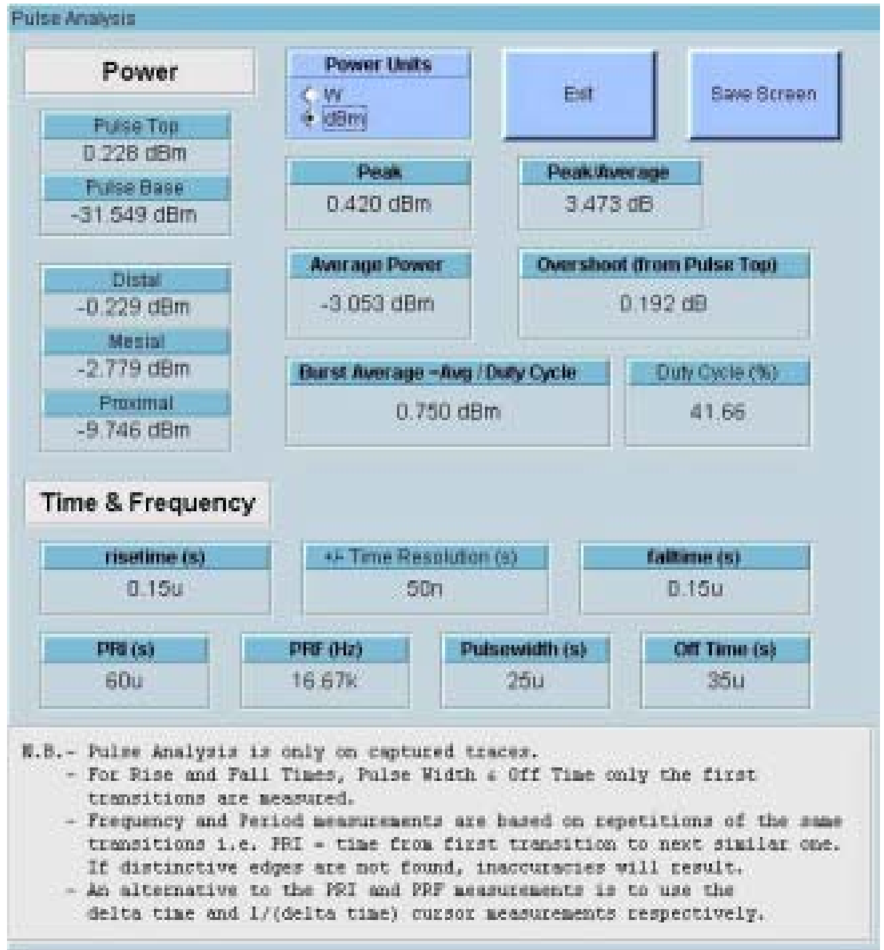


Advanced Power Measurements

- Pulse Analysis:

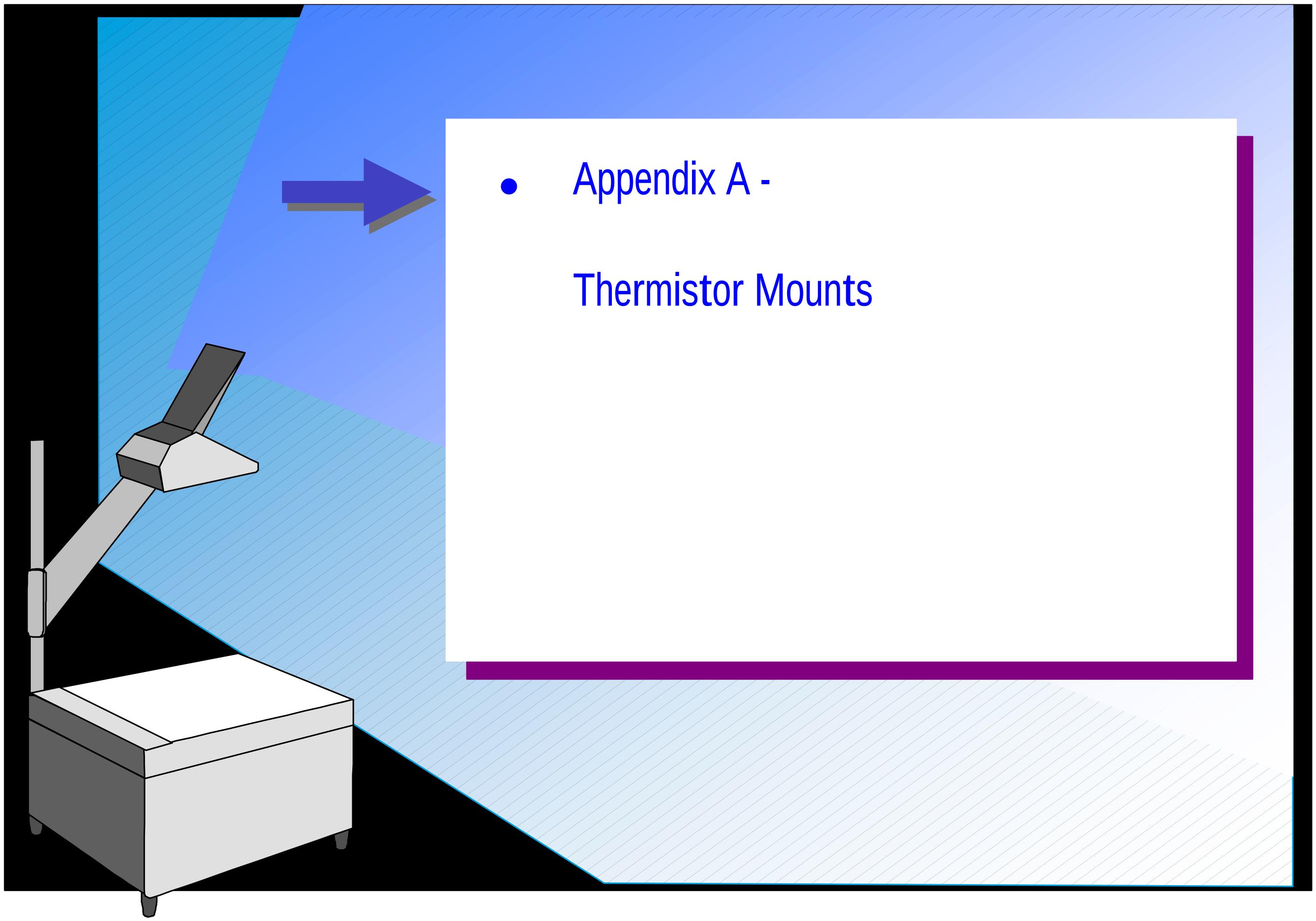
  ➢Power *:
  Pulse Top, Pulse Base, Distal, Mesial, Proximal, Peak, Average, Peak/Average Ratio, Burst Average and Duty Cycle

  ➢ Time and Frequency:
  Rise Time, Fall Time, Pulse Repetition Frequency (PRF), Pulse Repetition Interval (PRI), Pulse Width and Off Time



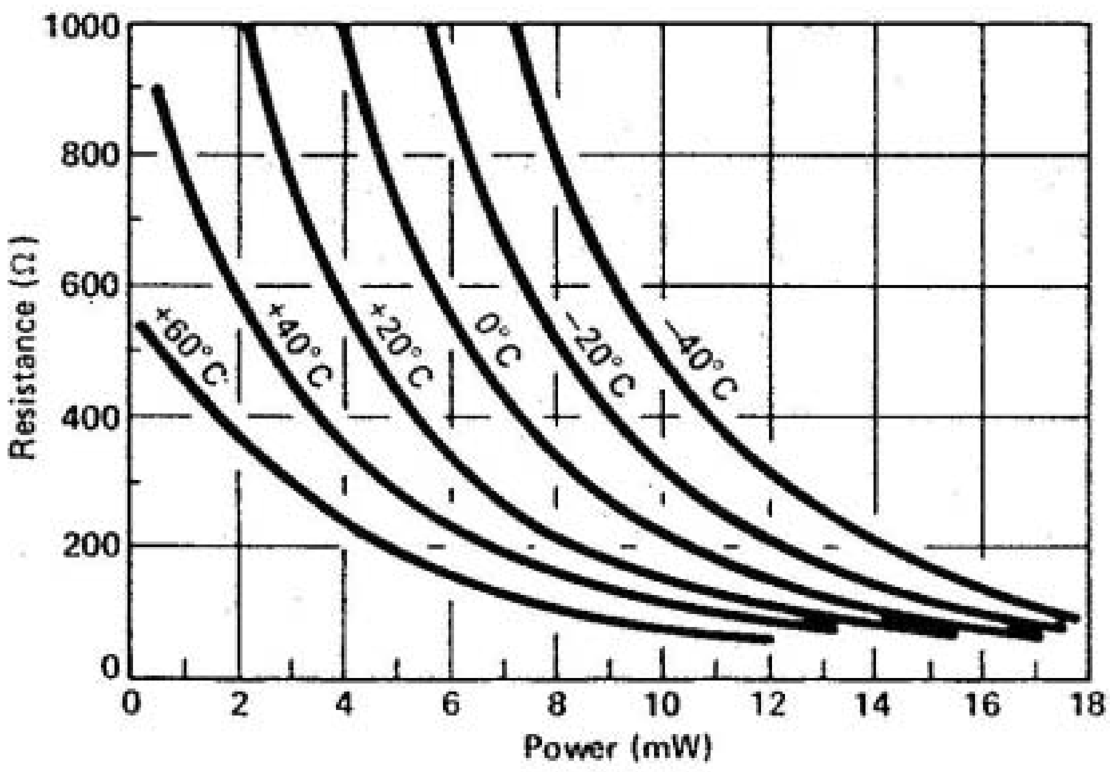
* IEEE pulse definitions and standards for video parameters applied to microwave pulse envelopes.
ANSI/IEEE Std. 194-1977

Agenda



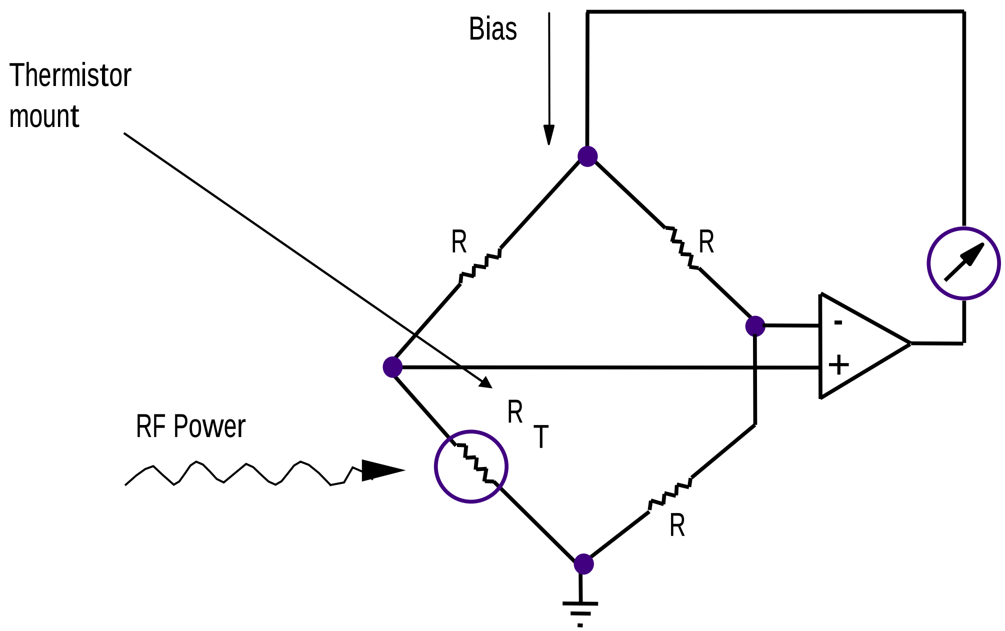
Thermistors

Characteristic curves of a typical thermistor element



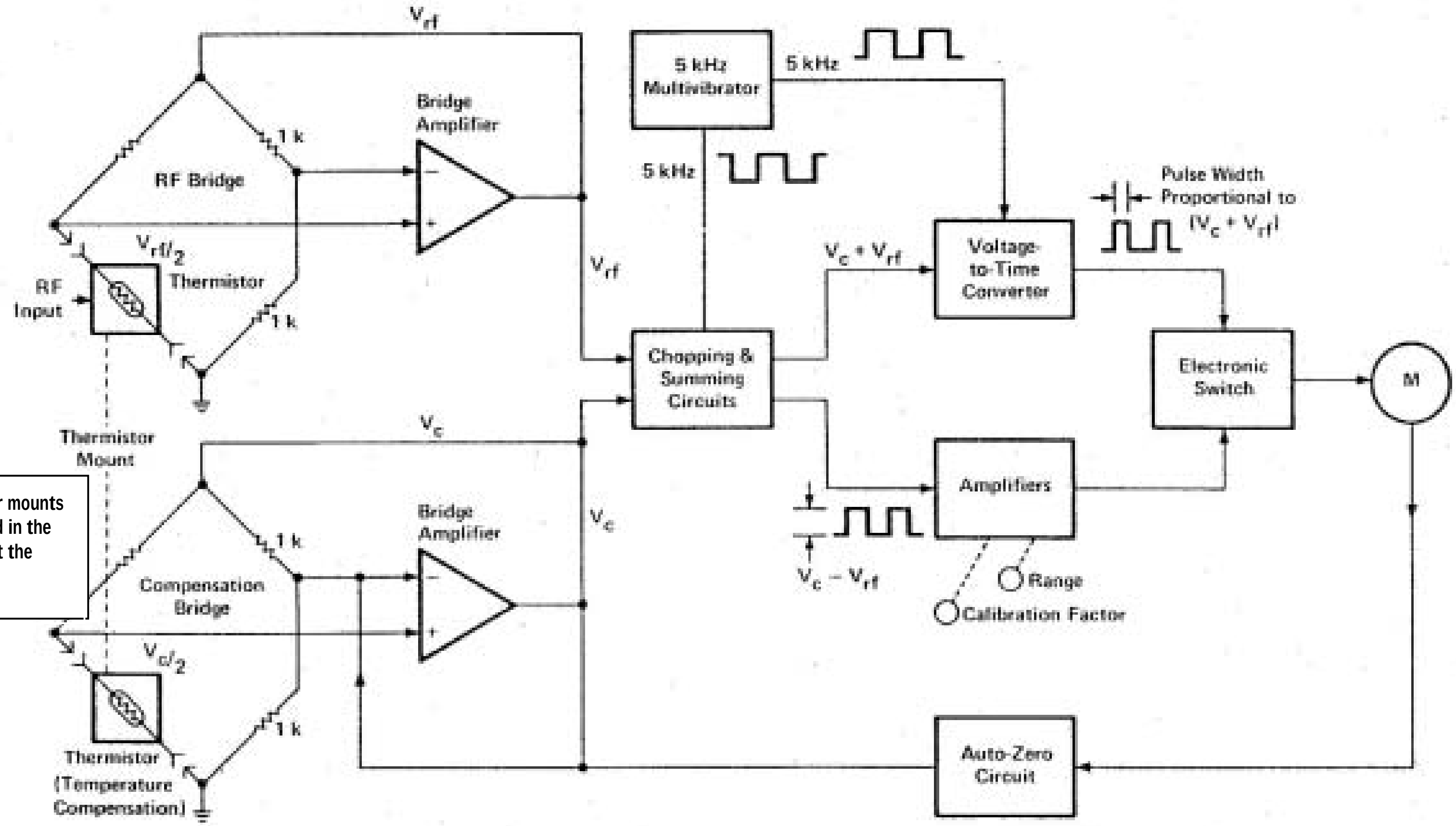
Thermistors

A self-balancing bridge containing a thermistor



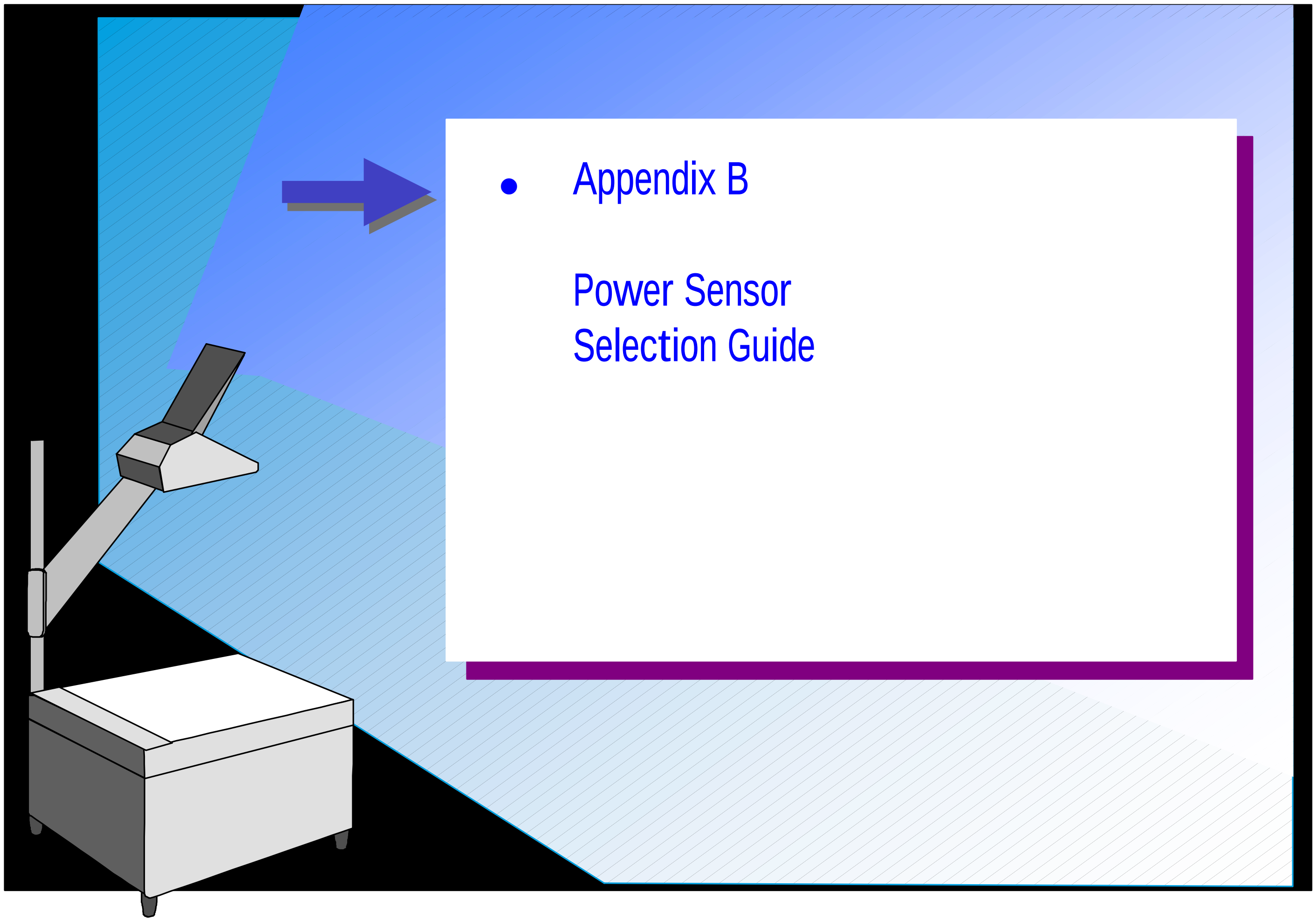
Power Meters for Thermistor Mounts

- 432A Power Meter

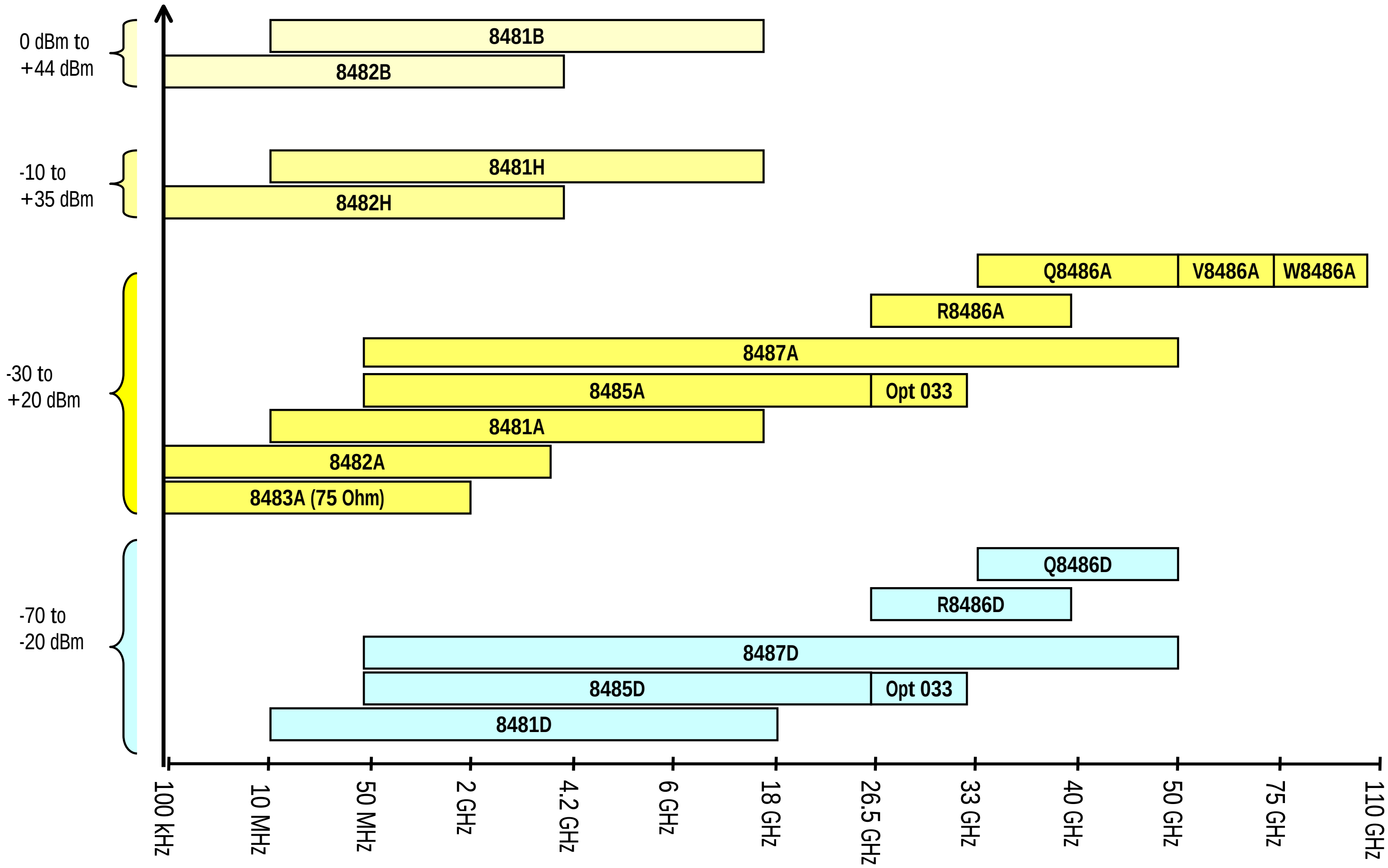


Thermistor mounts are located in the sensor, not the meter.

Agenda

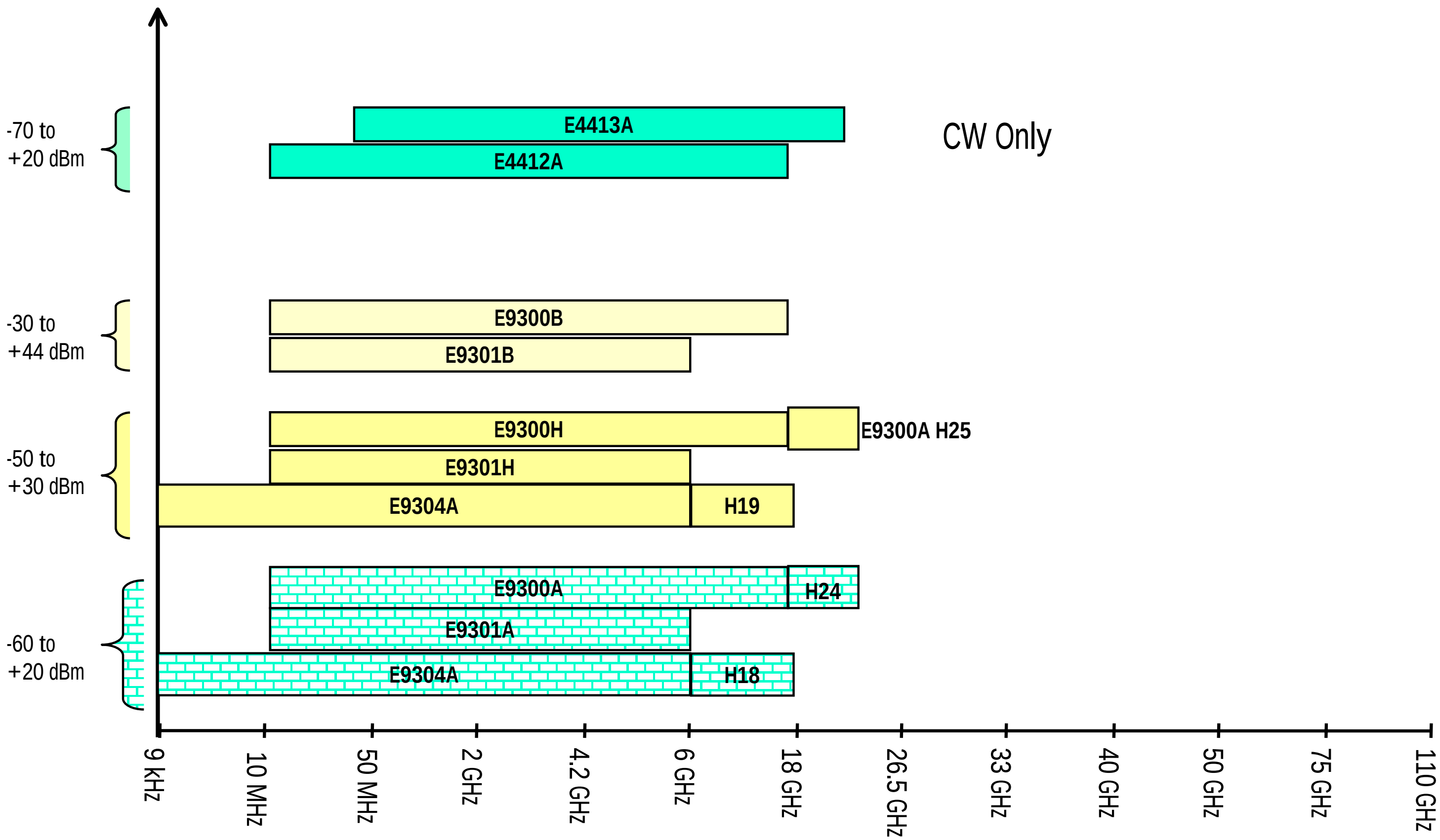


Agilent Power Sensor Selection Guide: 8480 Series

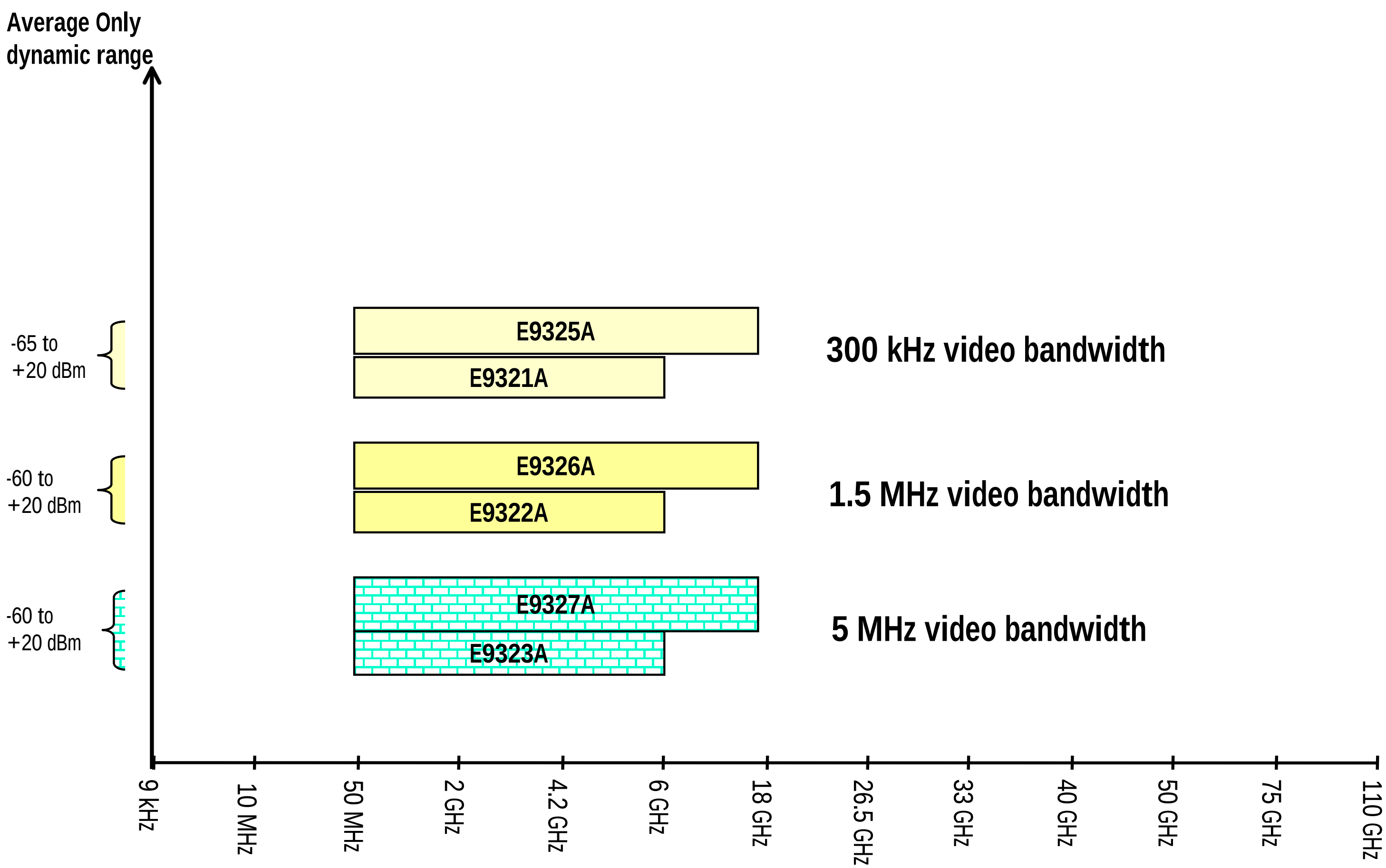


Agilent Technologies

Agilent Power Sensor Selection Guide: E-Series Wide Dynamic Range, CW and Average Sensors



Agilent Power Sensor Selection Guide: E-Series E9320 Peak and Average Sensors



Refer to the Data Sheet, 5980-1469E, for Normal mode and maximum peak power dynamic range