Power Measurement Basics

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MD1010 – Power B2B
Agenda

- Importance of Power Measurements
- Average, Peak and Pulse Power
- Power Meter & Sensor Measurement Method
- Sensor Technologies
- Agilent Power Measurement Solutions
- Time-Gated Power Measurements
- Advanced Power Measurements
- Measurement Uncertainty
Signal Power Levels are Critical

Too low:

*Signal buried in noise*

Too high:

*Nonlinear distortion...*

...Or even worse!

Power Measurement Basics
Why Not Measure Voltage?

DC

\[ P = I V = V^2 / R \]

Low Frequency

High Frequency

- \( I \) and \( V \) vary with position
- **Power is constant**

Amplitude

\[ P \]

\[ I \]

\[ V \]

AGILENT TECHNOLOGIES
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Average Power

Average over many modulation cycles

Pulsed

Average over many pulse repetitions
**Pulse Power**

Pulse Power = Average Power / Duty Cycle

- Rectangular pulse
- Constant duty cycle

\[ \text{Duty Cycle} = \frac{A}{B} \]

\( A \) (pulse width)

\( B \) (pulse repetition interval)
Envelope Power and Peak Envelope Power

![Graph showing high frequency modulated signal voltage and power](image)

- **Instantaneous Power**
- **Peak Envelope Power**
- **Envelope Power**

Power Measurement Basics

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*Image Source: Agilent Technologies*
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Instruments That Measure RF & Microwave Power

- **Power Meter and Sensor**
  - ± 0.0X dB
  - ≥ −70 dBm

- **Network Analyzer**
  - ± 0. X dB or greater
  - Frequency selective

- **Vector Signal Analyzer**

- **Spectrum Analyzer**
The Power Meter and Sensor Method

RF power → Power Sensor

Thermistor
Thermocouple
Diode Detector

DC or low-frequency equivalent → Power Meter

Display
(dBm or W)
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Thermistors

• One of the earliest types of power sensors

• Have been replaced in most applications by thermocouples and diode detectors

• Still used for power transfer standards in metrology applications
Thermocouples

• A junction of two dissimilar metals generates a voltage related to temperature
• Junction temperature is directly related to RF power
Diode Detectors

\[ V_s \rightarrow R_s \rightarrow \text{Diode} \rightarrow R_{\text{matching}} \rightarrow C_b \rightarrow V_o \]
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P-Series and EPM-P Series Power Meters

• P-Series Power Meters
  • Peak, average, peak-to-average ratio; time-gated measurements; rise time, fall time and pulse width; 30 MHz video bandwidth (N1911A/12A)

• N8262A P-Series Modular Power Meter
  • Equivalent N1912 performance with slim (1U) form factor; LXI-C compliant

• EPM-P Series Power Meters
  • Peak, average, peak-to-average ratio; time-gated measurements, 5 MHz video bandwidth (E4416A/17A)
Thermistor, HH and EPM Series Power Meters

- **N432A Thermistor Power Meter**
  - Average measurements for metrology and calibration laboratory environments; built-in calibration factor table. LXI-C compliant.

- **V3500A Handheld RF Power Meter**
  - Built-in power sensor with self calibration; powered by batteries, an AC-DC converter module, or a computer via USB interface

- **EPM Series Power Meters**
  - Average power measurements (N1913A/14A)
8480, E-Series and P-Series Power Sensors

- **8480 and N8480 Series (Therm. and Diode)**
  - Average power from –70 to +44 dBm; 100 kHz to 110 GHz; unlimited video BW
  - Typical dynamic range of 50 dB

- **E-Series (Diode)**
  - **E441X**: 90 dB dynamic range; CW only
  - **E9300**: 80 dB dynamic range; average power of any signal type; no BW limitation
  - **E9320**: peak and average power from 50 MHz to 18 GHz; 5 MHz video BW

- **P-Series (Diode)**
  - **N192XA**: peak and average from 50 MHz to 40 GHz; 30 MHz video BW
U2000 Series USB Average Power Sensors

• **U2000A/B/H**
  - 80 dB dynamic range; 10 MHz to 18 GHz

• **U2001A/B/H**
  - 80 dB dynamic range; 3 MHz to 6 GHz

• **U2002A/H**
  - 80 dB dynamic range; 50 MHz to 26.5 GHz

• **U2004A**
  - 80 dB dynamic range; 9 kHz to 6 GHz
P-Series Power Sensors Internal Zero and Cal

Internal zero and calibration within the N1921A/22A sensors - eliminates multiple connections with external calibration source.

N192XA Wideband Power Sensor Block Diagram
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Time-Gated Power Measurements

EDGE signal (GSM)

Peak, average and peak-to-average ratio of a single burst
Sensors for Time-Gated Measurements

- **Sensor rise/fall time requirements**
  - For characterizing overshoot: $\leq 1/8$ signal rise time
  - For average power: same as signal rise time

- **E9320 peak/average sensors**
  - 200 ns rise time (typical)
  - TDMA, CDMA and W-CDMA wireless formats

- **P-Series wideband power sensors**
  - $\leq 13$ ns rise time and fall time
  - Radar and pulsed component test
Triggering and Measurement Capabilities

EPM-P and P-Series Power Meters

- **Triggers**
  - Level
  - External
  - GPIB

- **Ext Trigger**
- **Delay**

- **Start 1**
- **Length 1**
  - Peak

- **Start 2**
- **Length 2**
  - Average
  - Length 3

- **Start 3**

- **Start 4**
- **Length 4**
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Technology Drivers

- Aerospace and Defence (Radar)
- Digital Wireless Communications

**GSM (0.3 GMSK)**
- TDMA system
- Time-gated average power
- Fast measurements

**EDGE (3π/8 Shifted 8PSK)**
- High-speed data transfer

**cdma2000**
- 3G technology
- Peak-to-average ratio
- CCDF
Wide Bandwidth and Fast, Continuous Sampling

- **P-Series Power Meters and Sensors**
  - 30 MHz video bandwidth up to 40 GHz
  - Continuous sampling at 100 Msample/s

0.5 μs/div = 50 samples per division
P-Series Power Meters and Sensors

• Key Measurements
  • Peak, average, peak-to-average ratio; rise time, fall time and pulse width; time-gated and free-run measurements
P-Series Measurement Display

- Graphical trace setup
- Marker measurements and analysis
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Sources of Power Measurement Uncertainty

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

Signal Source

Impedance ≠ $Z_0$

Power Sensor

Ideal impedance = $Z_0$

Power Meter

VSWR
Thank you!

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