Power Measurement Basics
Agenda

- Importance and definitions of power measurements
- Average Power Measurement
- Peak Power Measurement
- Time Gated Power Measurement
- Measurement uncertainty
- Considerations in choosing power measurement equipment
- 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: $P = (I)(V)$

Amplitude

AC component of power

DC component of power

$P$ $V$ $I$
Units and Definitions

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

- Unit of power is the watt (W): $1\text{W} = 1\ \text{joule/sec}$

- Some electrical units are derived from the watt:
  $1\ \text{volt} = 1\ \text{watt/ampere}$

- Relative power measurements are expressed in dB:
  $P(\text{dB}) = 10 \log(P/\text{Pref})$

- Absolute power measurements are expressed in dBm:
  $P(\text{dBm}) = 10 \log(P/1\ \text{mW})$
Types of Power Measurements

- Peak Power
- Pulse Top Amplitude
- Average Power
- Overshoot

- Pulse Width
- Duty Cycle
- PRI

- Pulse Delay
- PRF
Instruments used to Measure RF and Microwave Power

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

Average over several modulation cycles

Average over many pulse repetitions
Basic Measurement Method - Using a Power Meter

Net RF power absorbed by sensor → Power Sensor

- Thermistors
- Thermocouples
- Diode Detectors

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

Power Ranges:

-70 --60 --50 --40 --30 --20 --10 0 +10 +20 +30 +40 +50 [dBm]
Thermocouples

The principles behind the thermocouple

![Thermocouple diagram]

\[ V_0 = V_1 + V_h - V_2 \]
Thermocouples

- Thermocouple implementation

RF Input

n-Type Silicon

cold junction

hot junction

Thin-Film Resistor

Thermocouples

To dc Voltmeter

RF power

gold leads

gold leads

Thin-Film Resistor

n-Type Silicon

CC

CB
Diode Detectors

- How does a diode detector work?
Diode Detectors

Square Law Region of Diode Sensor

\[ V_0 = \log(\mu P_{IN}) \]

Linear Region

\[ \begin{align*}
V_0 &= 0.01 \text{ mW} \\
&= -70 \text{ dBm} \\
\end{align*} \]

\[ \begin{align*}
P_{IN} &= 0.1 \text{ nW} \\
&= -20 \text{ dBm} \\
\end{align*} \]

Noise Floor

\[ 0.1 \text{ nW} \quad -70 \text{ dBm} \]

\[ 0.01 \text{ mW} \quad -20 \text{ dBm} \]
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.
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Peak Power Measurement

Peak Power

Peak Power

Average Power
Peak Power Measurement

- **RF IN 50ohm**
- **Load Filter**: 3 dB, (300 kHz, 1.5 MHz, 5 MHz low pass)
- **Chopper**
- **Variable Gain Differential Amplifier**: (300 kHz, 1.5 MHz, 5 MHz)
- **Thermistor Bias**
- **Gain / Mode Control**
- **Sensor ID**
- **E²PROM**
- **GAIN SELECT**
- **SERIAL BUS**
- **PEAK AUTO-ZERO**
- **CW PATH ISOLATE**
- **AVERAGE ONLY PATH**
- **Switched Gain Preamp**
- **CW PATH**
- **NORMAL PATH**
- **NORMAL PATH**
- **Peak Power Measurement**
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Time Gated Power Measurements

Gate Start

Gate Length

\( t \)
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

**Signal Source**
10 GHz

**Power Sensor**
Agilent E4412A

**Power Meter**
Agilent E4418B

\[
\text{Mismatch Uncertainty} = \pm 2 \cdot r_{\text{source}} \cdot r_{\text{sensor}} \cdot 100\%
\]

\[
\begin{align*}
\text{SWR}_\text{source} &= 2.0 \\
 r_{\text{source}} &= 0.33 \\
\text{SWR}_\text{sensor} &= 1.22 \\
 r_{\text{sensor}} &= 0.10
\end{align*}
\]

Mismatch Uncertainty = \(\pm 2 \cdot 0.33 \cdot 0.10 \cdot 100\% = \pm 6.6\%\)
Power Sensor Uncertainties
(Effective Efficiency)

Various sensor losses

Cal Factor: \( K_b = \eta_e \frac{P_{gl}}{P_i} \)
Power Meter Instrumentation Uncertainties

- **Power reference uncertainty**: +/- 1 count
- **Zero Set**
- **Zero Carryover**
- **Drift**
- **Noise**
- **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:

\[ = 6.6\% + 3.1\% + 1.2\% + 0.5\% = \pm 11.4\% \]

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

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

- 7.4\% = 10 \log (1 - 0.074) = -0.33 dB
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Thermistors as Transfer Standards

Rising Costs / Better Accuracy

- Microcalorimeter
  - National Reference Standard
  - Working Standards
  - Measurement Reference Standard
  - Transfer Standard
  - General Test Equipment

NIST
Commercial Standards Laboratory
Manufacturing Facility
User
SWR (Reflection Coefficient)
# Susceptibility to Overload

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<tr>
<td>Maximum Average Power</td>
<td>30 mW</td>
<td>300 mW</td>
<td>3.5 W</td>
<td>100 mW</td>
<td>200 mW</td>
<td>315 mW</td>
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<tr>
<td>Maximum Energy per Pulse</td>
<td>10 W·µs</td>
<td>30 W·µs</td>
<td>100 W·µs</td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
</tr>
<tr>
<td>Peak Envelope Power</td>
<td>200 W</td>
<td>15 W</td>
<td>100 W</td>
<td>100 mW</td>
<td>200 mW</td>
<td>2W</td>
</tr>
</tbody>
</table>

(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

-0 dBm to +44 dBm
-10 to +35 dBm
-30 to +20 dBm
-70 to -20 dBm

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

-70 to +20 dBm
- E4413A
- E4412A

-30 to +44 dBm
- E9300B
- E9301B

-50 to +30 dBm
- E9300H
- E9301H

-60 to +20 dBm
- E9300A
- E9301A
- E9304A
- H18

CW Only

9 kHz
10 MHz
50 MHz
2 GHz
4.2 GHz
6 GHz
18 GHz
26.5 GHz
33 GHz
40 GHz
50 GHz
75 GHz
110 GHz