SNIA Power Meter Workshop
SNIA Hands-On Power Meter Workshop

presented by Chroma System Solutions, Inc.
Work Shop Overview

- Power Meter Basic’s
- Manual Operation of Power Meter
- Remote Interface and Software operation of Power Meter
- External Current Sensors (Shunts & Current Transformers)
- AC Source requirements for consistent and compatible measurements.
- Q & A
Power Meter Basic’s

[Image of a Chroma Digital Power Meter Model 66202 with readings 117.12, 0.1501, and 17.585 displayed]
Power Meter Workshop

Power Meter Types:

• **Analog Power Meter**
  - Measured only Voltage, Current, Frequency, Power, Energy
  - Good for a Sine wave voltage and current
  - Limited to a specific power, voltage and freq. range.

• **Digital Power Meter**
  - Extended measurements to include, Voltage, Current, Frequency, Power (W, VA, VAR), Surge Current, Energy (Joules, Whr), Harmonic Distortion, Power Factor, Crest Factor.
  - Improved accuracy for Non Sine wave voltage and current.

• **Power Analyzer**
  - Includes DPM plus high speed waveform analysis for Phase Angle and distortion and higher frequency measurements.
Power Meter Workshop

Power Meter applications:

- Power Measurements for Energy Consumption (Joules, Whr)
  - Accurate measurements for manufacturers products to meet various energy standards. Note: a printer left on in standby mode can consume 408Kwr per year. A refrigerator 20CF can consume as much as 1700Kwhr per year. (1Whr = 3600 Joules)

- Power Measurements to determine Efficiency
  - New Standards and Guidelines have increased the need for Power Meters, due to power conservation
  - Energy Guidelines for improved efficiency, from NREL, DOE, IEC, ISO, CEC, Energy Star

- Measurements for Harmonic Distortion (THDv & THDi)
  - Utilities concern that distortion causing stress on the grid’s hardware.
  - Concerns of Consumers equipment affected by Noise and Harmonics generated by devices connected to the grid including EMI.
Power Meter Measurements:

Power Meters should have the ability to measure or extract the following:

- Voltage RMS, Voltage Peak + and – (continuous)
- Current RMS, Current Peak + and -- (continuous), Surge Current (Instantaneous)
- Power Factor
- Crest Factor
- Watts, VA, VAR
- Energy (Whrs, Joules)
- THDi, THDv

And all measurements should have Accuracy better than 1%
With Sample rates greater than 100Khz
Power Meter Requirements
per Energy Star 6.0 for Computers

**Power Meter:** Power meters shall have the following attributes:

1. **Current Crest Factor:**
   a.) An available crest factor of 3 or more at its rated range value; and
   b.) A current range of 10 milliamperes or less

2. **Minimum Frequency Response:** 3.0Khz

3. **Minimum Resolution:**
   a.) 0.01W for measurement values less than 10W;
   b.) 0.1W for measurement values from 10W to 100W; and
   c.) 1.0W for measurement values greater than 100W

4. **Measurement Accuracy:**
   a.) Power measurements with a value greater than or equal to 0.5W shall be made with an accuracy of less than 2%
   b.) Power measurements with a value of less than 0.5W shall be made with an accuracy of less than +/- 0.01W (2% at 0.5W)
## Power Source Requirements per Energy Star 6.0 for Computers

### Table 1: Input Power Requirements for Products with Nameplate Rated Power Less Than or Equal to 1500 watts (W)

<table>
<thead>
<tr>
<th>Market</th>
<th>Voltage</th>
<th>Voltage Tolerance</th>
<th>Maximum Total Harmonic Distortion</th>
<th>Frequency</th>
<th>Frequency Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America, Taiwan</td>
<td>115 volts (V) ac</td>
<td>+/- 1.0 %</td>
<td>2.0 %</td>
<td>60 hertz (Hz)</td>
<td>+/- 1.0 %</td>
</tr>
<tr>
<td>Europe, Australia, New Zealand</td>
<td>230 V ac</td>
<td>+/- 1.0 %</td>
<td>2.0 %</td>
<td>50 Hz</td>
<td>+/- 1.0 %</td>
</tr>
<tr>
<td>Japan</td>
<td>100 V ac</td>
<td>+/- 1.0 %</td>
<td>2.0 %</td>
<td>50 Hz or 60 Hz</td>
<td>+/- 1.0 %</td>
</tr>
</tbody>
</table>

### Table 2: Input Power Requirements for Products with Nameplate Rated Power Greater Than 1500 W

<table>
<thead>
<tr>
<th>Market</th>
<th>Voltage</th>
<th>Voltage Tolerance</th>
<th>Maximum Total Harmonic Distortion</th>
<th>Frequency</th>
<th>Frequency Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America, Taiwan</td>
<td>115 V ac</td>
<td>+/- 4.0 %</td>
<td>5.0 %</td>
<td>60 Hz</td>
<td>+/- 1.0 %</td>
</tr>
<tr>
<td>Europe, Australia, New Zealand</td>
<td>230 V ac</td>
<td>+/- 4.0 %</td>
<td>5.0 %</td>
<td>50 Hz</td>
<td>+/- 1.0 %</td>
</tr>
<tr>
<td>Japan</td>
<td>100 V ac</td>
<td>+/- 4.0 %</td>
<td>5.0 %</td>
<td>50 Hz or 60 Hz</td>
<td>+/- 1.0 %</td>
</tr>
</tbody>
</table>
Power Meter Workshop

Digital Power Meter:

- Zero Crossing Detector
- Voltage Sense
  - Analog to Digital Converter (ADC)
- Current Sense
  - Analog to Digital Converter (ADC)
- Digital Signal Processor (DSP)
- Memory
- Embedded Firmware with Algorithms
Analog to Digital Converter (ADC) Bit resolution:

- The Higher the Bit count the greater the Voltage and Current measurement resolution.
- 8 Bit ADC = 256 increments at 300V range = 1.172V resolution
- 10 Bit ADC = 1024 increments at 300V range = 0.293V resolution
- 12 Bit ADC = 4096 increments at 300V range = 0.073V resolution
- 16 Bit ADC = 65536 increments at 300V range = 0.00458V resolution
Power Meter Basics

If Voltage and Current Waveforms were pure sinewaves and loads were pure resistive the power measurements could be simply taking the Peak voltage and peak current $\times 0.707$ to create the $V_{rms}$ and $I_{rms}$ and the multiply the 2 together.

$$\text{True Power or Watts} = V_{rms} \times I_{rms} \times \cos \theta$$

$V_{rms} = V_{pk} \times 0.707$ \hspace{1cm} $I_{rms} = I_{pk} \times 0.707$

$\cos \theta$ or $PF = \frac{W}{(V_{rms} \times I_{rms})}$

Ex. $120V_{rms} \times 10A_{rms} \times 0.9PF = 1080W$
Power Meter Basics (Sample Rates)

Real world voltage and current waveforms are seldom sinusoidal. Digital Power Meters Sample Rates are critical to accuracy.

Sample rate of approx 1024 samples per second equates to approx one measurement every millisecond and only 20 measurements per cycle at 50Hz. At 800Hz it equates to 1.25 measurements per cycle. In the example waveform the Peak current would be missed.

Chroma 66202 Sample rate is 240K Samples/Sec

\[ V_{\text{RMS}} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + V_4^2 + \ldots + V_{11}^2 + V_n^2}{n}} \]
Power Meter Basics

Harmonic Distortion Measurements for a specific harmonic:
Digital Power Meters use DSP’s for a digital equivalent of a Digital Bandpass Filter to extract the voltage and current at a specific harmonic. Then measured using the RMS measurement algorithms for RMS Voltage and RMS Current at each Harmonic.

BandPass Filter Graph
Power Meter Basics

Cosine $\theta$ or Power Factor Measurements

Power Factor = the Cosine of the Phase angle of the current versus voltage waveforms.

$PF \text{ or } \cos \theta = \text{Cosine of } \left(\frac{t1}{t2} \times 360^\circ\right)$

Ex. $\cosine \left(\frac{0.002\text{Sec}}{0.0166\text{Sec}}\right) \times 360 = 0.726$
Harmonic Distortion

Current distortion affects the power system and distribution equipment. It may directly or indirectly cause the destruction of loads or loss of product. From the direct perspective, current distortion may cause transformers to overheat and fail even if they are not fully loaded. Conductors and conduit systems can also overheat leading to open circuits and downtime.
Power Meter Basic’s

With Digital Signal Processors many other parameters can be calculated using internal embedded Firmware and Algorithms based on Voltage, Current and time measurements.

<table>
<thead>
<tr>
<th>Single Phase Measurement Parameter</th>
<th>Computing Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>True rms value</strong></td>
<td></td>
</tr>
<tr>
<td>$V_{rms}$</td>
<td>$\sqrt{\frac{1}{T} \int_{0}^{T} v^2(t) dt}$</td>
</tr>
<tr>
<td>$I_{rms}$</td>
<td>$\sqrt{\frac{1}{T} \int_{0}^{T} i^2(t) dt}$</td>
</tr>
<tr>
<td>$W$</td>
<td>$\frac{1}{T} \int_{0}^{T} v(t) i(t) dt$</td>
</tr>
<tr>
<td>$VAR$</td>
<td>$\sqrt{VA^2 - W^2}$</td>
</tr>
<tr>
<td>$VA$</td>
<td>$V_{rms} \times I_{rms}$</td>
</tr>
<tr>
<td>$PF$</td>
<td>$\frac{W}{VA}$</td>
</tr>
</tbody>
</table>
# Power Meter Basic's

Algorithms like these use the Voltage, Current and Time measurements to determine more complex values

<table>
<thead>
<tr>
<th>Mean value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{dc}$</td>
<td>$\frac{1}{T} \int_{0}^{T} v(t) dt$</td>
</tr>
<tr>
<td>$I_{dc}$</td>
<td>$\frac{1}{T} \int_{0}^{T} i(t) dt$</td>
</tr>
<tr>
<td>$W_{dc}$</td>
<td>$V_{dc} \times I_{dc}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integration</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (Wh or Joule)</td>
<td>$\frac{1}{T} \int_{0}^{T} v(t) i(t) dt$</td>
</tr>
<tr>
<td>T is a setting integration time by user.</td>
<td></td>
</tr>
<tr>
<td>Integration (W)</td>
<td>$\int_{0}^{T} v(t) i(t) dt$</td>
</tr>
<tr>
<td>T is a setting integration time by user.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Zero crossing detection</td>
</tr>
</tbody>
</table>
Power Meter Basic’s

Algorithms like these use the Voltage, Current and Time measurements to determine more complex values

<table>
<thead>
<tr>
<th>Peak value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{PK+}$</td>
<td>The maximum sampling value of the positive half wave of $v(t)$ during two continuous cycles.</td>
</tr>
<tr>
<td>$V_{PK-}$</td>
<td>Absolute value of the maximum sampling value of the negative half wave of $v(t)$ during two continuous cycles.</td>
</tr>
<tr>
<td>$I_{PK+}$</td>
<td>The maximum sampling value of the positive half wave of $i(t)$ during two continuous cycles.</td>
</tr>
<tr>
<td>$I_{PK-}$</td>
<td>Absolute value of the maximum value of the negative half wave of $i(t)$ during two continuous cycles.</td>
</tr>
</tbody>
</table>
Power Meter Basic’s

Algorithms like these use the Voltage, Current and Time measurements to determine more complex values

<table>
<thead>
<tr>
<th>Crest Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CF_i$</td>
</tr>
<tr>
<td>$\frac{\text{maximum of } (I_{pk+}, I_{pk-})}{I_{rms}}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THD &amp; Harmonic value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$THD_v$</td>
</tr>
<tr>
<td>$\frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + \cdots + V_n^2}}{V_1} \times 100%$</td>
</tr>
<tr>
<td>$I_n^2$ the subscript $n$ indicates the range of harmonic which is 2, 3, 4, ..., 100.</td>
</tr>
</tbody>
</table>

| $THD_i$          |
| $\frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \cdots + I_n^2}}{I_1} \times 100\%$ |
| $V_n^2$ the subscript $n$ indicates the range of harmonic which is 2, 3, 4, ..., 100. |
Typical use of a Power Meter for Power Supply Efficiency testing
Typical use of a Power Meter for Power Supply Efficiency testing

\[
\text{Efficiency} \% = \left( \frac{\text{Pout}}{\text{Pin}} \right) \times 100
\]

\[
\text{Pin} = V_{\text{rms}} \times I_{\text{rms}} \times \cos\theta
\]

\[
\text{Pout} = V_{\text{dc}} \times I_{\text{dc}}
\]

Ex.

Output Power (Pout) = 100W
V_{\text{rms}} = 115V, I_{\text{rms}} = 1A, PF = 0.87
Input Power (Pin) = 120W
Eff\% = \left( \frac{100}{120} \right) \times 100 = 83\%
SNIA Emerald test Block Diagram

- AC Source 6400, 6500, 61500, 61600, 61700
- Digital Power Meter 66203, 66204 for 3 phase, 66202 for 1 phase
- Storage Network
- SNIA Emerald Work load
- Computer for test data collection
Manual Operation of Power Meter (Chroma 66202)
Manual Operation of Power Meter (Chroma 66202)
Manual Operation of Power Meter (Chroma 66202)

1. Display 1 for Vrms, Vpk+, Vpk- measurements
2. Display 2 for Current, Irms, Ipkn+, Ipkn-
3. Function Key for Display 1, 2, and 3
4. Indicators for GO/NG, Pass, Fail, Rmt, Shunt, Limit, Meas, IS-trg
5. Display 4 for PF, Cfi, THDv, THDi, Freq, Energy
6. Indicators for Key for Display 4, PF, Cfi, THDv, THDi, F, E, KJ.
7. Display 3 for Watts, PF, VA, and VAR
8. Voltage Range selection button
9. Current Range selection button
10. Setup Button
11. Trig Enter
12. Power ON/OFF
Manual Operation of Power Meter (Chroma 66202)
Manual Operation of Power Meter (Chroma 66202)

1. Current Sense Connections
2. Control Signals Connector
3. USB Connector
4. GPIB Address Select switch
5. GPIB
6. Voltage Sense Connectors
7. Input Voltage Select Switch 120/240
8. Input Power connection (IEC 60320-1)
9. Input Power Fuse
# Chroma 66202 Power Meter

## Control Signal Connector

<table>
<thead>
<tr>
<th>Pin</th>
<th>Definition</th>
<th>Pin</th>
<th>Definition</th>
<th>Pin</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+5V</td>
<td>6</td>
<td>GND</td>
<td>11</td>
<td>Fail -</td>
</tr>
<tr>
<td>2</td>
<td>Is Trigger</td>
<td>7</td>
<td>Reserve TTL3</td>
<td>12</td>
<td>Fail +</td>
</tr>
<tr>
<td>3</td>
<td>Reserve TTL1</td>
<td>8</td>
<td>Limit Trigger</td>
<td>13</td>
<td>Reserve TTL5</td>
</tr>
<tr>
<td>4</td>
<td>GND</td>
<td>9</td>
<td>GND</td>
<td>14</td>
<td>Pass -</td>
</tr>
<tr>
<td>5</td>
<td>Reserve TTL2</td>
<td>10</td>
<td>Reserve TTL4</td>
<td>15</td>
<td>Pass +</td>
</tr>
</tbody>
</table>
Limit Trigger Connection

Figure A-1 shows the connection of Limit Trigger. **66201/66202** Power Meter defines the Limit Trigger as falling edge trigger. Ground the 8\textsuperscript{th} pin can trigger it. The trigger is same as pressing **Trig/Enter** on the front panel.

![Diagram of Limit Trigger Connection](image)
Three Phase Wye Connections
External Current Transformer & Current Shunt

* Hi indicates primary current direction

Power Line

Current Direction

Output
Red (+) (-) Black

Test Circuit

I₀ →
1-Turn Primary

0.5VA
R_L
Switch to Live WebCam focused on 66202
For Manual Operating Instructions and Reference User Manual
Software for Power Meter
(Chroma 66202)
Software for Power Meter (Chroma 66202)
Chroma Digital Power Meters

**Digital Power Meter Multi-Channel**

- Voltage Range: 15/30/60/150/300/600 Vrms
- Current Range: 0.005/0.02/0.05/0.2/0.5/2/5/20 Arms
- Frequency Range: DC, 15Hz~10kHz
- Support different wiring configuration power measurement (1P2W/1P3W/3P3W/3P4W)
- Support external shunt and CT for higher current measurement application
- 5 mA minimum current range & 0.1mW power resolution
- Meets ENERGY STAR / IEC 62301 measurement requirements
- Inrush current and energy measurement
- Voltage/Current harmonics measurement up to 50 orders
AC Power Supply or Source
AC Source Power Stages

Linear type, a transformer on output, high impedance

A transformer on input, weight is heavy
Chroma’s AC Source Advantages

1. No low-frequency transformer, lighter than others
2. Standard PFC input, save power and less interference to main
3. No transformer on output, low impedance
61500/61600 Softpanel Function

Report Function: Data Recording stored in a File
61500 AC Source Functions for Transient Output

**LIST Mode:** Program output waveform sequence by sequence.
61500 AC Source Functions for Transient Output

**PULSE Mode**: Insert a waveform into normal voltage
61500 AC Source Functions for Transient Output

**STEP Mode**: Change from an initial voltage to destination step by step
Transient Output with High Voltage

2 units of AC Source with synchronizing signal:
Use 3-phase Mode, 61500/61600 as the Master, 61500 as the Slave.

Master: Fixed Mode 220V
Slave: List Mode 180V/0.5 sec

220V with 400V/0.5s transient

UUT
Distorted Waveform

Different kind of distorted waveform:

Harmonic Distortion

Interharmonic Distortion

Clipped Sine Waveform

Low frequency drift
Regulation for Distorted Waveform

**IEC 61000-4-13**: Harmonics, Interharmonics including mains signaling at AC power port immunity tests
61500's Functions for Distorted Waveform

**SYNTHESIS**: Edit harmonic components (Amplitude & Phase) of 40 orders to synthesize a new waveform.

(50/60Hz)
61500’s Functions for Distorted Waveform

INTERHARMONICS: Add a sweeping frequency component (0.01Hz – 2400 Hz) on a normal voltage. It helps to find the resonance point, or the weak point of the UUT.
61500’s Functions for Distorted Waveform

WAVEFORM EDITOR: Edit waveform by harmonic orders on softpanel, send the data and save to User Waveform of AC Source.
DC Component of AC Power

It contains DC component on some AC power sources, like UPS.

1. Current unbalance. Input rectifier may be damaged.
2. Input transformer saturation (DC current)

Using AC Source AC+DC mode to simulate.

Without DC component

With DC component
Thank You,
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