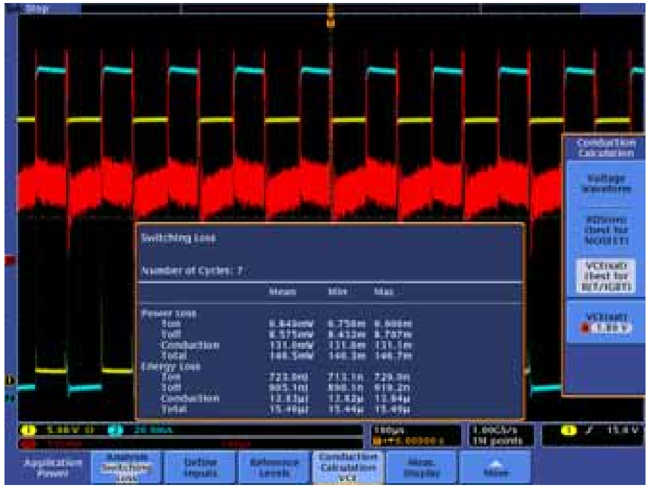
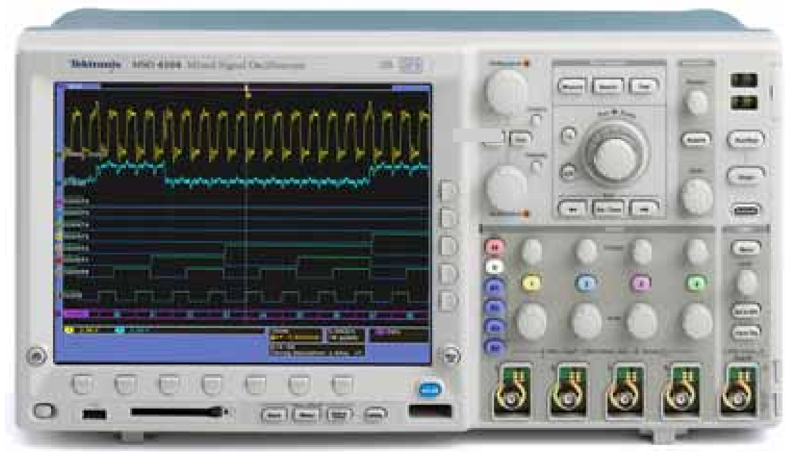
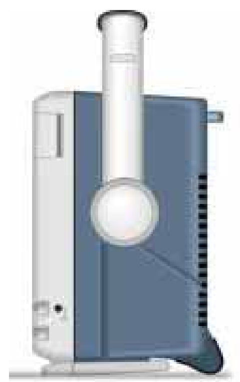
Power Supply Measurement and Analysis

With Tektronix Oscilloscopes







Stephen Wu

Tektronix
Innovation Forum

Agenda

- Today's Power Supplies
- Switching Device Measurements
- Magnetic Component Measurements
- Power Line Measurements
- Choosing the Right Solution

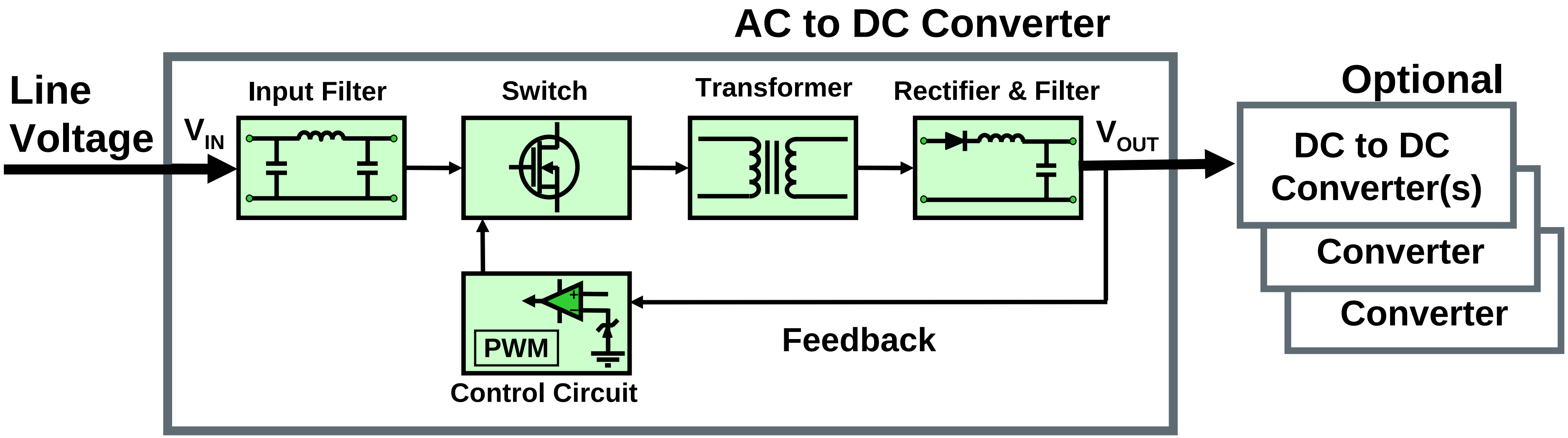
Today's Power Supplies

- Convert power from one form to another
- Found in a wide range of applications
- Many different kinds and sizes
- Must be efficient
- Face complex, dynamic operating environment





The Basic Switch-Mode Power Supply



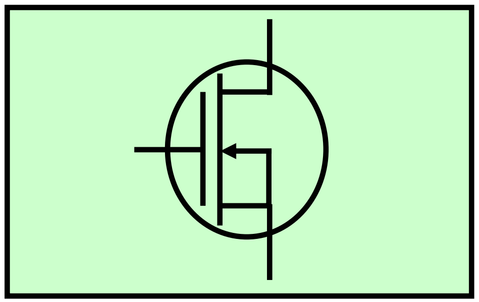
- Active Components (Switch)
  - Switching Loss
  - Safe Operating Area
- Passive Components (Transformer)
  - Magnetic Power Loss
  - B-H Characteristics
- Power Line
  - Harmonics
  - Power Quality

Agenda

- Today's Power Supplies
- ***Switching Device Measurements***
- Magnetic Component Measurements
- Power Line Measurements
- Choosing the Right Solution

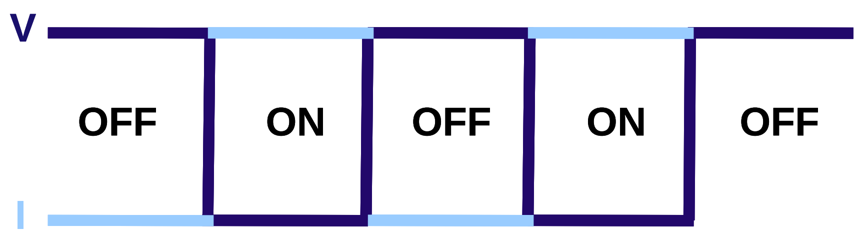
Active Component Measurements: Switching Devices

- Transistor switch circuits dissipate the most energy during transitions
- Common measurements:
  - –Turn Off Loss
  - –Turn On Loss
  - –Power Loss
  - –Slew Rate
  - –Dynamic On Resistance
  - –Safe Operating Area

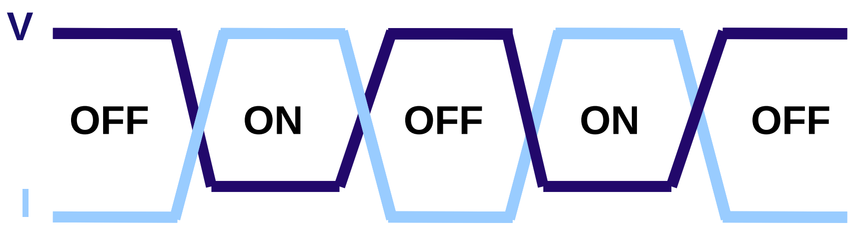


Switch

Ideal Switch



"Real" Switch

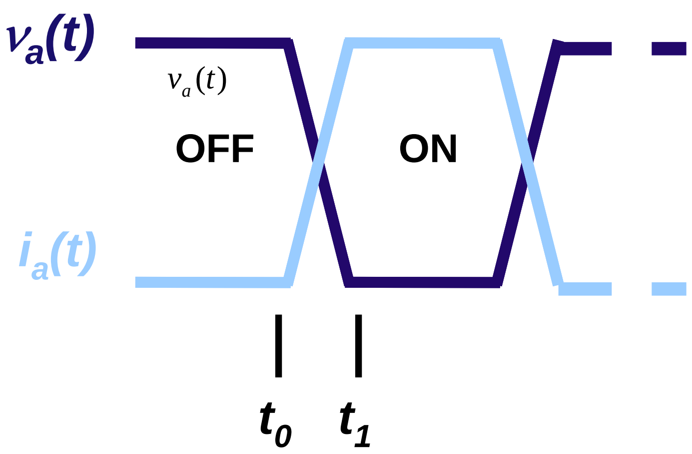


Switching Loss Basics

- Energy loss during the transition can be estimated by:

$$E_{on} = \int_{t_o}^{t_1} v_a(t) \cdot i_a(t) \cdot dt$$

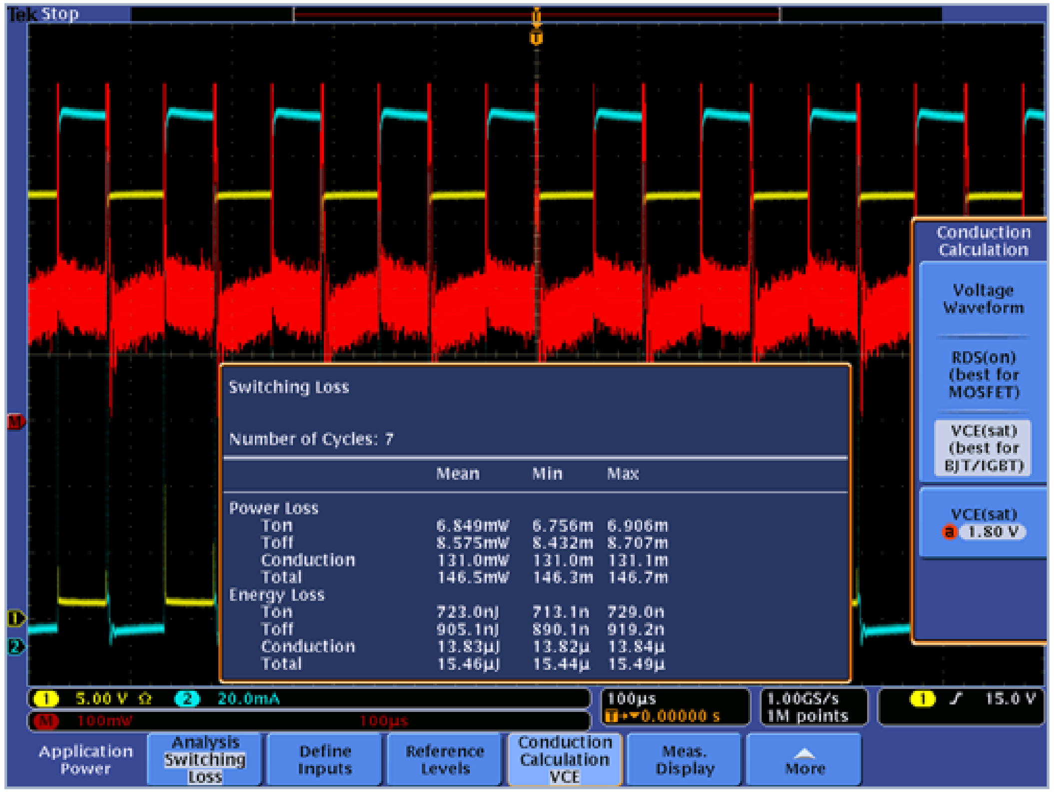
- Where:
  - E_{on} is the energy loss in the switch during the transition.
  - $v_a(t)$ is the instantaneous voltage across the switch.
  - $i_a(t)$ is the instantaneous current through the switch.
  - t_1 is when the transition is complete.
  - t_0 is when the transition begins.

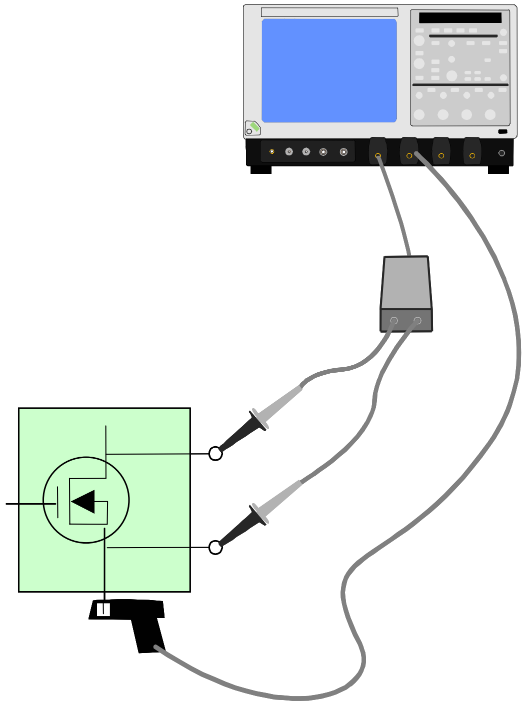


- The equation for E_{off} is similar

Switching Loss Measurements

- As simple as measuring voltage across and current through the switch device.
- Power analysis software will calculate Turn-On, Turn-Off and Conduction Losses.
- Caution: timing between voltage and current waveforms must be precise.





Tektronix MSO/DPO4000 Oscilloscope with DPO4PWR

Safe Operating Area Measurements

- Characterizes the operating region of the device
- Instantaneous Power is calculated by:

$$P_n = V_n I_n$$

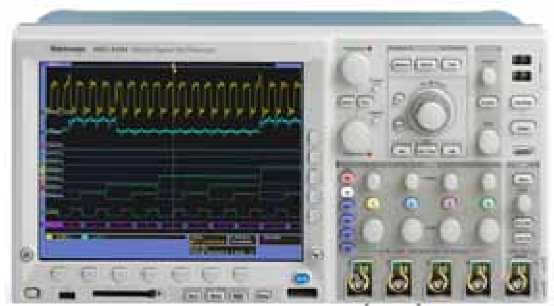
- Where:
  - P_n is the instantaneous power.
  - V_n is the voltage.
  - I_n is the current.
  - n is the sample point.

- Test variables may include different loads, operating temperatures, high and low line input voltages, and more.

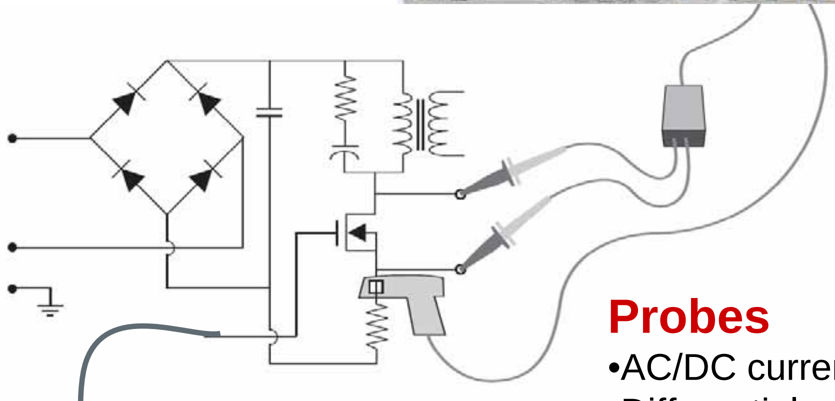
Tektronix MSO/DPO4000 Oscilloscope with DPO4PWR

Active Component Measurements: Choosing the Right Measurement Solution

Oscilloscope

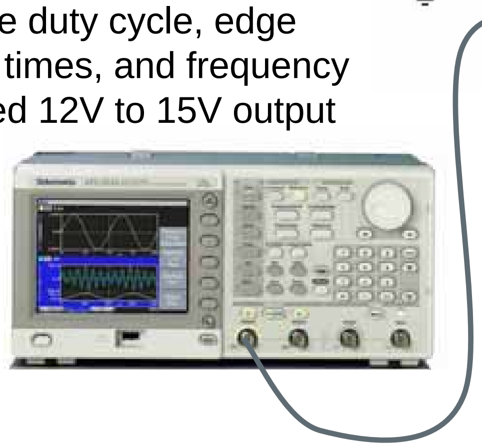


- Enough bandwidth and rise time to handle switching signal frequency components
- Fast sample rate to capture transitions
- Deep record length for long acquisitions



Signal Source

- Simulate gate drive signal
- Adjustable duty cycle, edge transition times, and frequency
- Many need 12V to 15V output



Probes

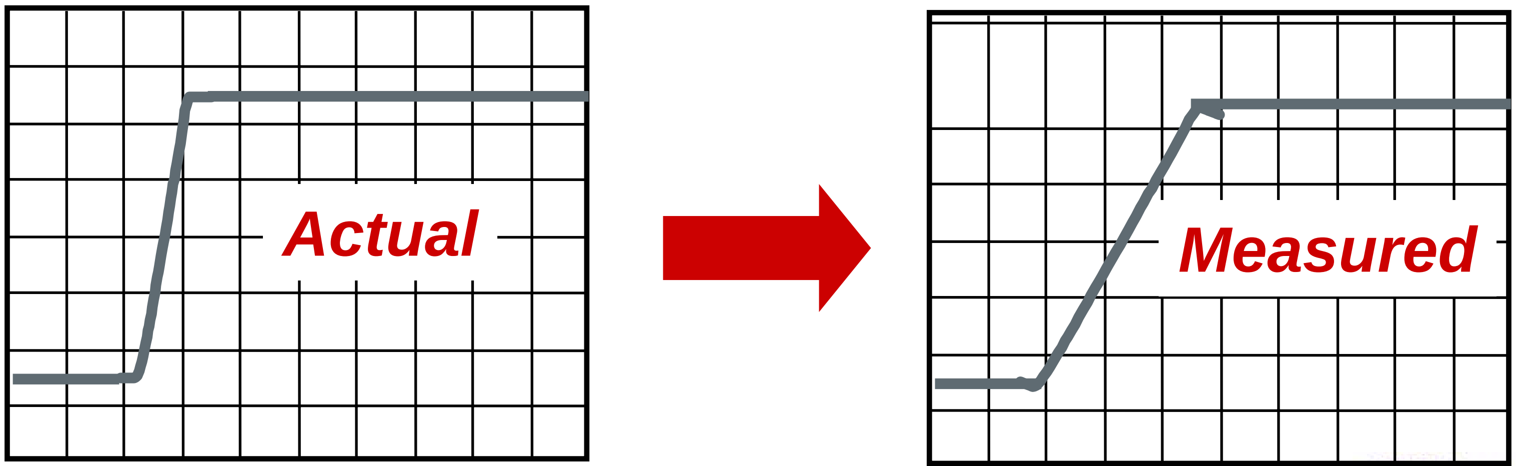
- AC/DC current probes
- Differential probes to make floating measurements

Oscilloscope Performance Considerations

- Rise Time
  - Switching signal rise time may be quite fast
  - For accurate measurements, measurement system (oscilloscope + probe) rise time should be ***5X faster***

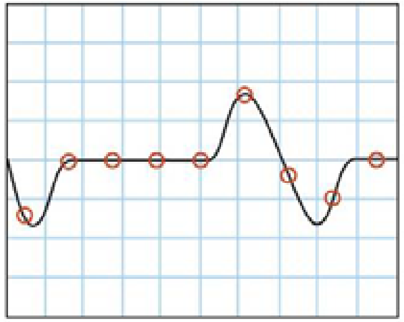
$$\text{Meas. Sys. Rise Time} = \frac{\text{Signal Rise Time}}{5}$$

$$\text{Measured Rise Time} = \sqrt{\left[\text{Meas. Sys. Rise Time}\right]^2 + \left[\text{Signal Rise Time}\right]^2}$$

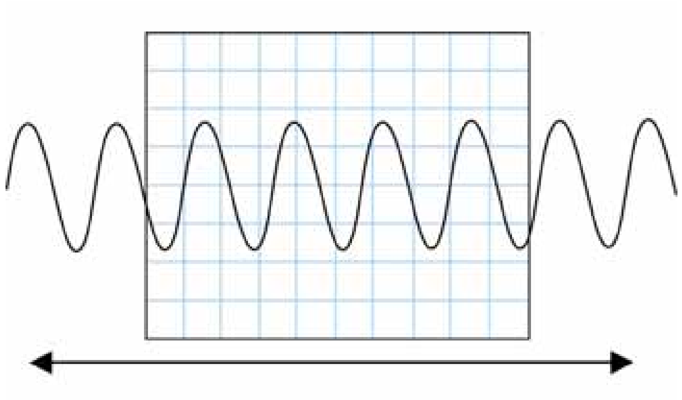


Oscilloscope Performance Considerations

- Sample Rate
  - Faster sample rate provides greater resolution and detail of the waveform



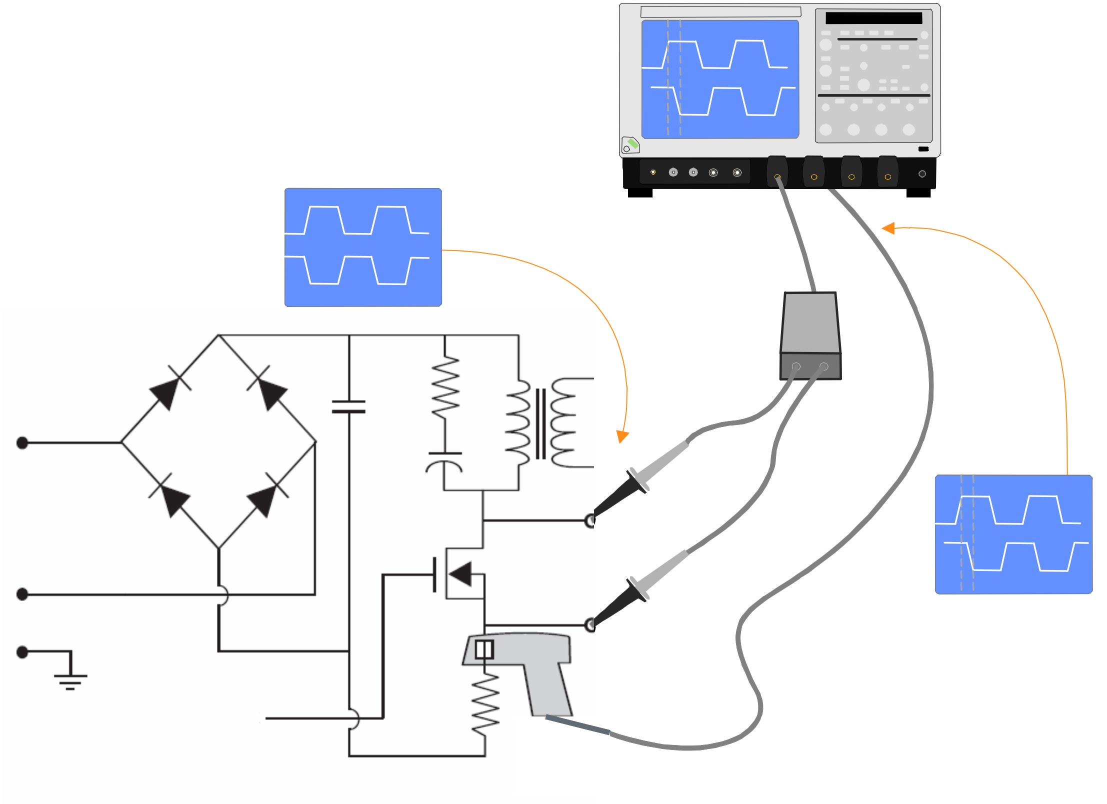
- Record Length
  - Determines how much “time” is captured for given sample rate
  - An example:
    - A half-cycle of 60 Hz is over 8 ms
    - With sample rate of 1 GS/s, need 8 Mpoint record length



$$\textbf{Time} = \frac{\textbf{Record Length}}{\textbf{Sample Rate}}$$

Measurement Challenge: Skew Between Probes

- To make a power measurement, must measure voltage across and current through the switching device
  - Requires two separate probes: voltage and current
  - Each probe has its own characteristic propagation delay
  - Difference between two delays is skew



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An Example of Skew

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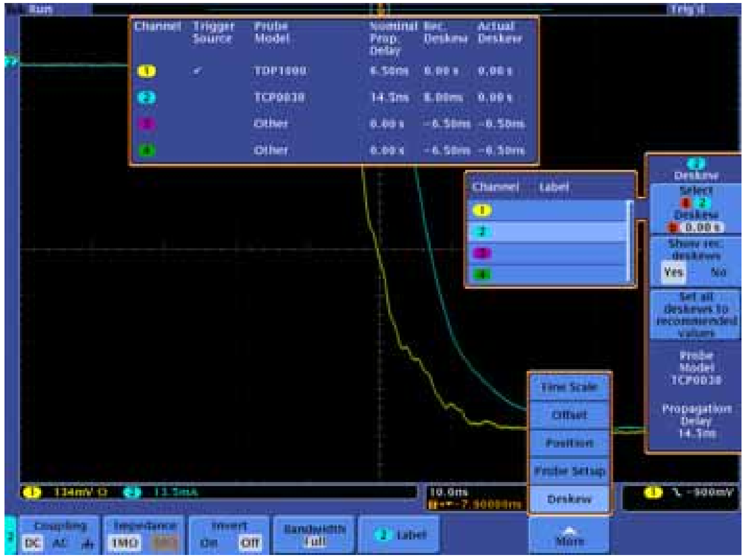
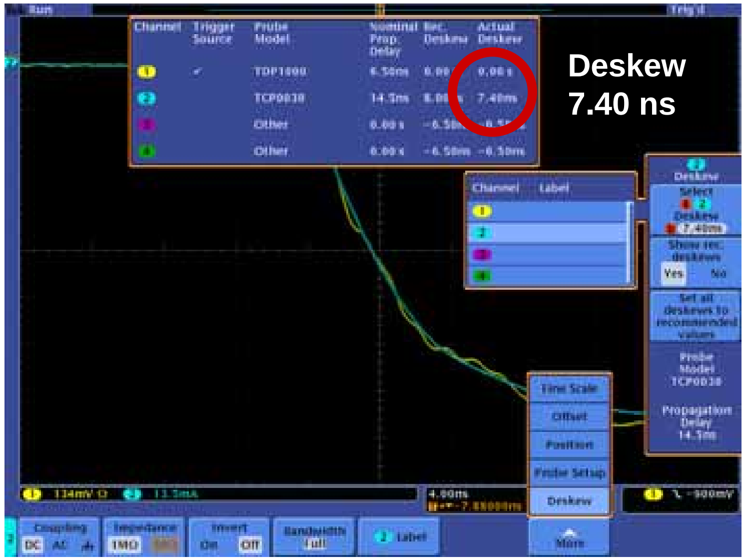
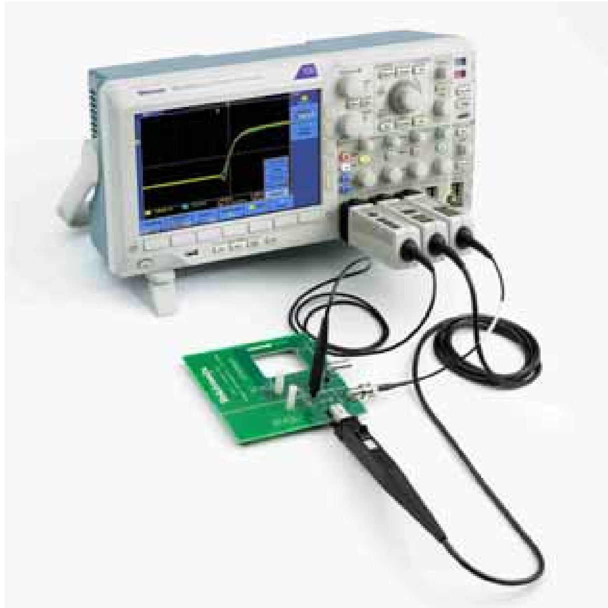
Solution:
Eliminating Skew Between Voltage and Current Probes







Tektronix DPO3000 Oscilloscope with TekVPI® probes and deskew kit

Measurement Challenge: Probe Offset

- Differential and current probes may have a slight DC offset
- Need to remove before taking measurements for highest accuracy

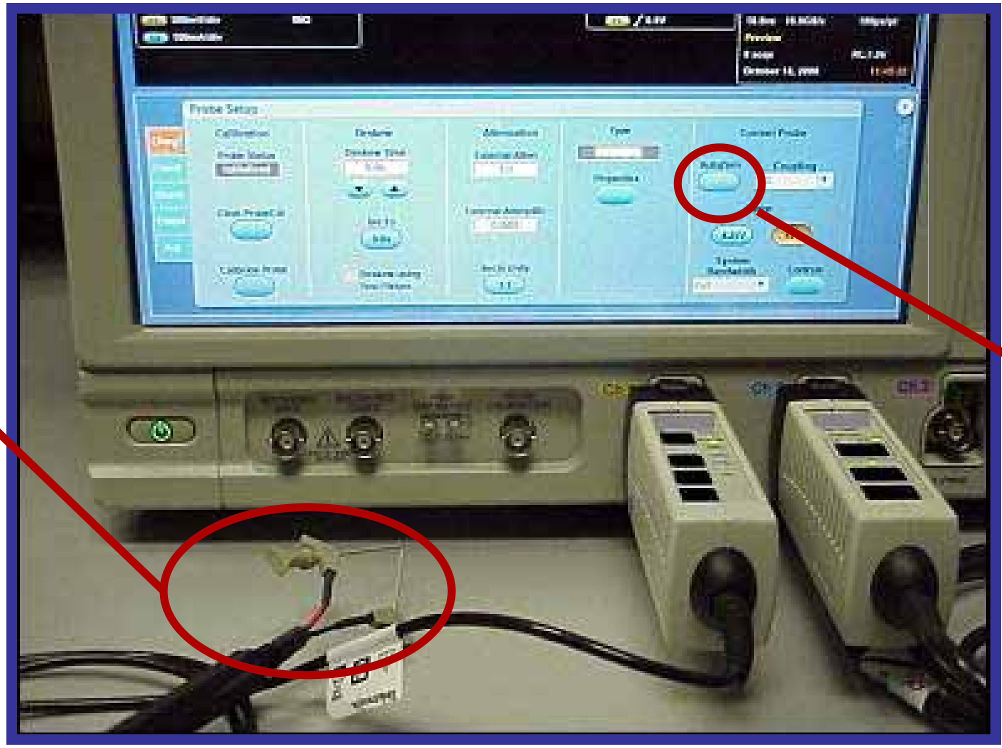
15.5% Error

With 1 V DC offset,
Conduction Loss = 86.13 mW.

With DC offset removed,
Conduction Loss = 72.75 mW.

Solution: Eliminate Probe Offset

Short the probe inputs together



Push the "AutoZero" button on the Probe Setup Menu

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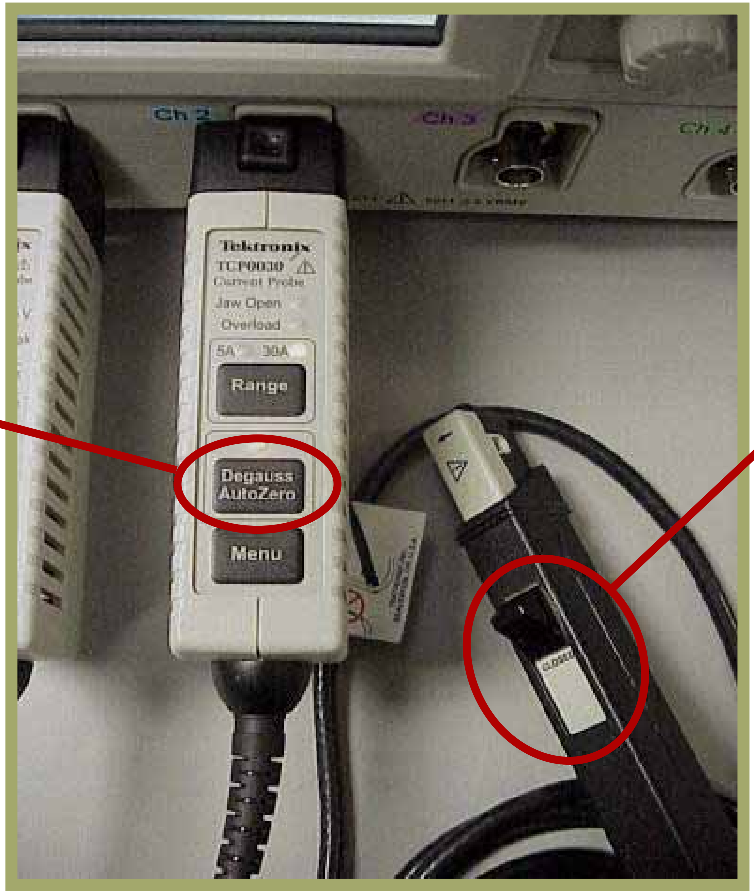
Solution: Degauss The Current Probe

- Removes residual magnetic flux from probe's magnetic components

Push the "Degauss AutoZero" button on the probe Comp. box.



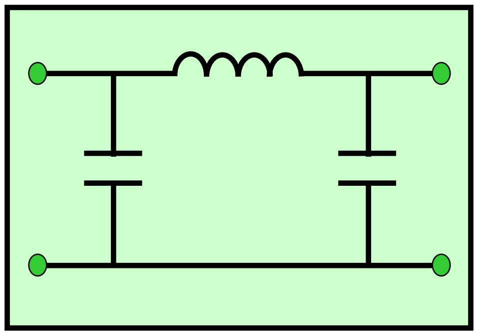
Set the probe armature to the "Closed" position.

Agenda

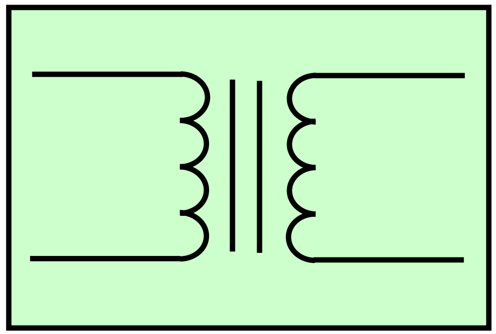
- Today's Power Supplies
- Switching Device Measurements
- ***Magnetic Component Measurements***
- Power Line Measurements
- Choosing the Right Solution

Passive Component Measurements: Magnetics

- Focus on the inductors and transformer
- Common measurements:
  - Magnetic Power Loss
  - Magnetic Properties



Input and Output Filters



Transformer

Magnetic Power Loss Basics

- Magnetic Power Loss = Core Loss + Copper Loss
- Core Loss
  – Includes hysteresis loss and eddy current loss
- Copper Loss
  – Due to resistance of the copper winding wire

Magnetic Power Loss Measurements

- Important to know different power loss components to identify root cause
  - Measure Total Magnetic Loss
  - Derive Core Loss from vendor's data sheet
  - Solve for Copper Loss

Tektronix DPO7000 Oscilloscope with DPOPWR

- Multiple-winding inductor:

$$TotalPower\ Loss = PowerLoss_{L1} + PowerLoss_{L2} + PowerLoss_{L3} + \cdots$$

Hysteresis Curve Basics

- Shows relationship between ***B*** and ***H***
- Characterizes the operating region of the magnetic component within the SMPS
- Magnetic Field Strength:

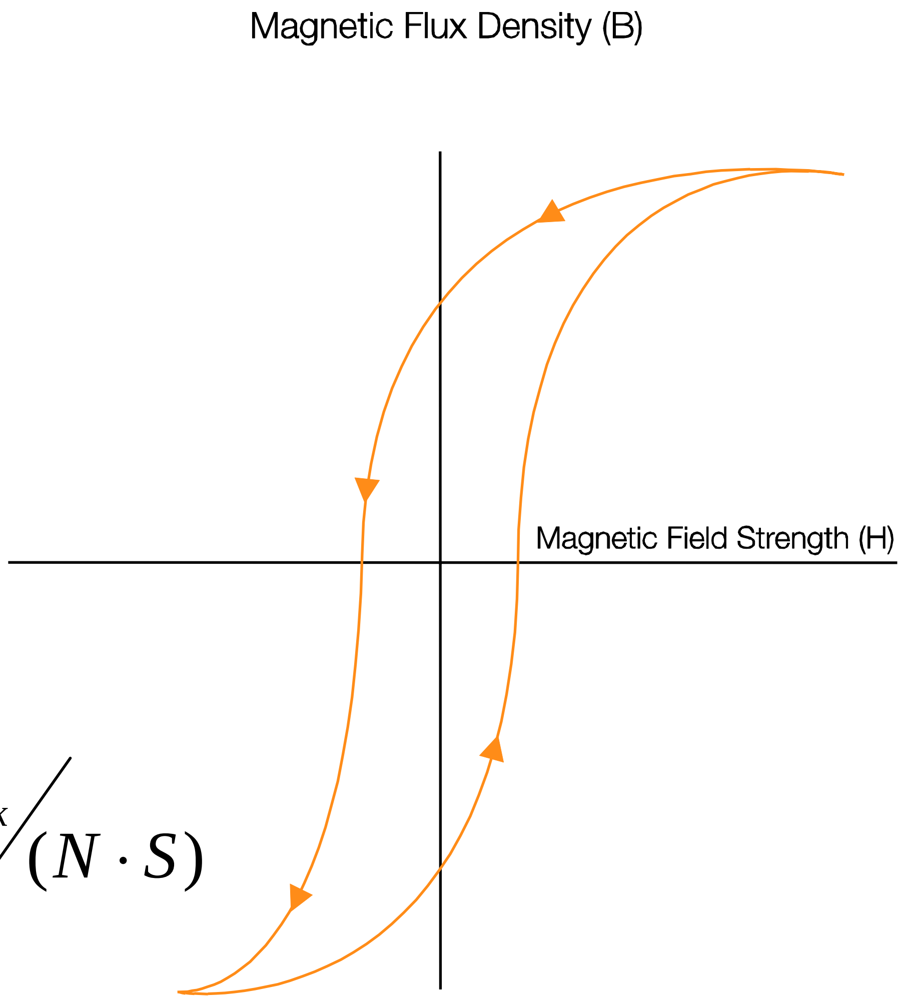
$$H_k(t) = I_k(t) \cdot \frac{N}{l}$$

Where:
- $H_k(t)$ is the magnetic field strength
- $I_k(t)$ is the magnetizing current
- N is the number of turns
- l is the magnetic length

- Flux Density:

$$\varphi_k = \int V_k(t)dt \quad \text{and} \quad B_k(t) = \varphi_k \big/ (N \cdot S)$$

Where:
- S is the surface Area



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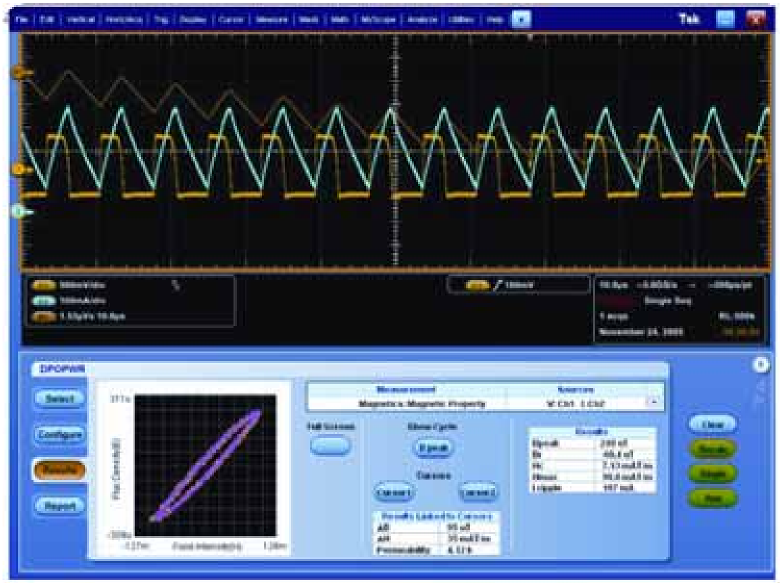
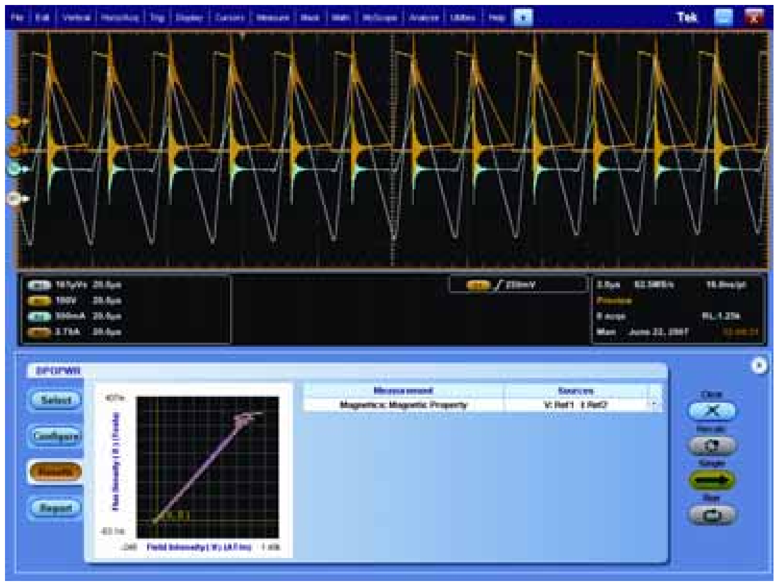
Hysteresis Curve and Magnetic Properties Measurements

- Power measurement software greatly simplifies these measurements
  - Measure voltage and magnetizing current
  - Input number of turns, magnetic length, and cross-sectional area
  - Software calculates magnetic properties like
    - Maximum Magnetic Flux Density, Remanence Flux Density
    - Permeability, Coercive Force
- Also measure multi-winding magnetic elements



B-H plot for single winding inductor



B-H plot for transformer

Agenda

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- ***Power Line Measurements***
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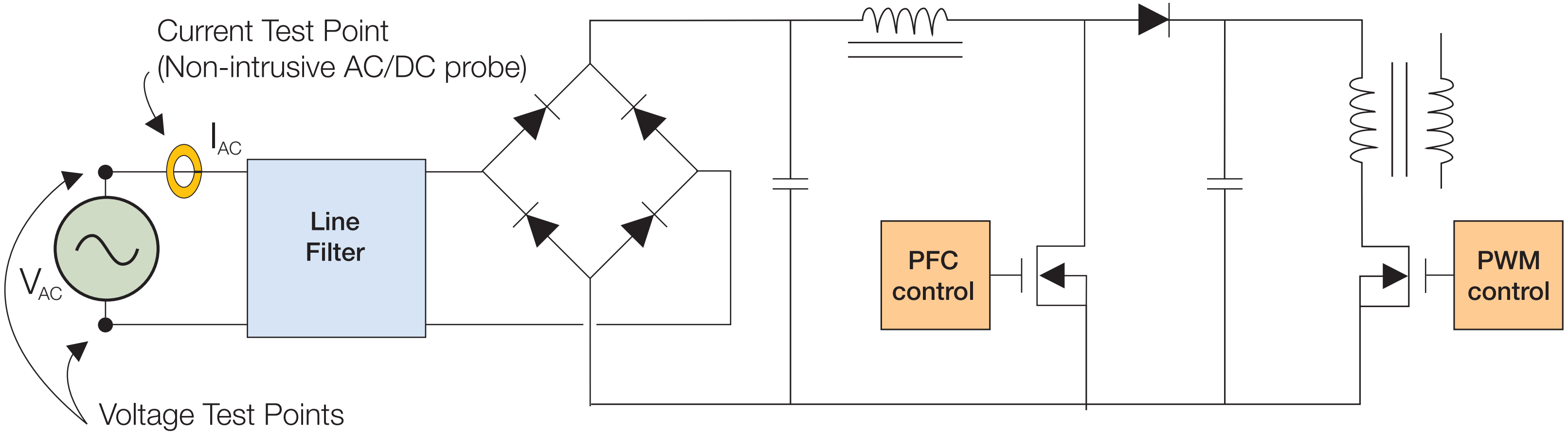
Power Line Measurements



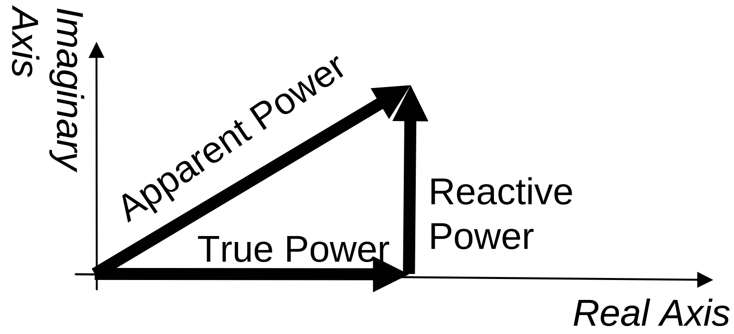
- Characterize the interaction of the supply and its service environment
- Must measure voltage and current directly on the input power line
- Requires high-voltage probe, usually differential

Power Quality Measurement Basics

- In reality, input voltage and current waveforms are not identical
  - Real-world electrical power lines never supply ideal sine waves
  - A SMPS is a non-linear load to the source
- SMPS creates harmonics on input current waveform which must not violate standards like EN61000-3-2
- Power Quality measurements include:
  - True Power
  - Reactive Power
  - Apparent Power
  - Power Factor
  - Crest Factor
  - Current Harmonics Measurements
  - THD

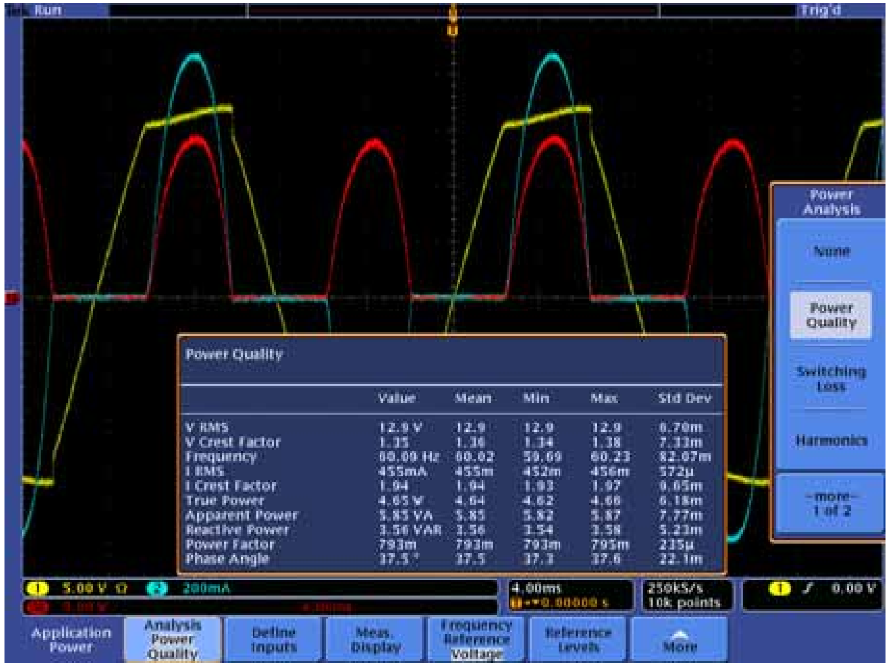
Power Quality Measurements

- Apparent Power = $I_{rms} * V_{rms}$



- Power Factor = $\dfrac{\text{True Power}}{\text{Apparent Power}}$

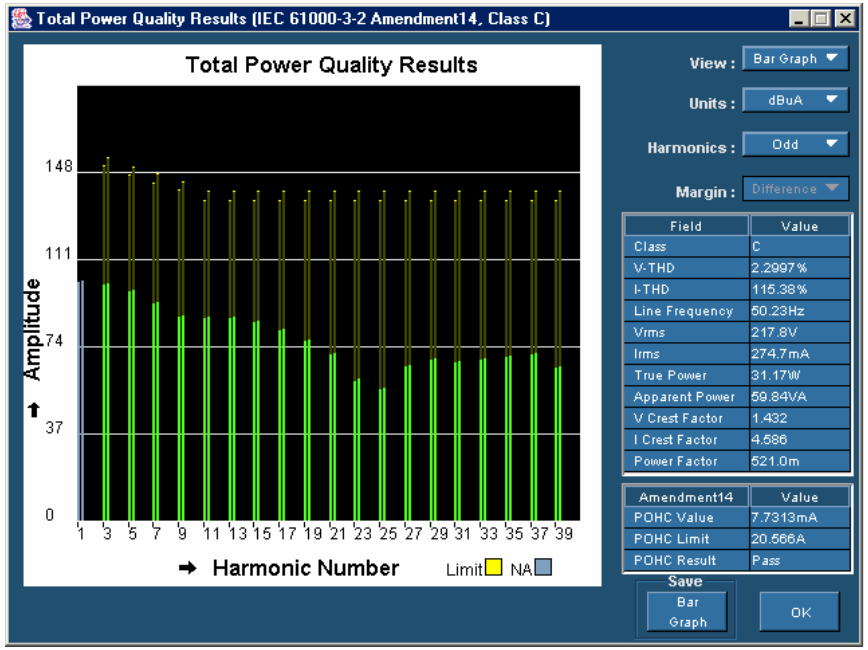
- Crest Factor = $\dfrac{V_{peak}}{V_{rms}}$



Tektronix MSO/DPO4000 Oscilloscope with DPO4PWR

Harmonics and Pre-Compliance Measurements

- Must capture up to 40th harmonic
- Compare harmonics and THD to industry standards like EN61000-3-2



Tektronix TDS5000B Oscilloscope with TDSPWR3

Agenda

- Today's Power Supplies
- Switching Device Measurements
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- Power Line Measurements
- ***Choosing the Right Solution***

Summary: Choosing the Right Solution

- Determine your measurement requirements
  - What are the characteristics of your switching signal?
  - Do you need to analyze magnetic components?
  - Is Power Quality, and pre-compliance testing to standards like EN61000-3-2, important?
- Carefully choose the right oscilloscope for your signal and needs
  - Oscilloscope rise time, sample rate, record length
  - Automated measurements and level of analysis required
- Don’t forget the probes!
  - AC/DC current probe
  - High-voltage differential probe
  - Mid-voltage differential probe
  - Consider deskew options for best measurement accuracy

Tektronix Power Measurement Solutions – www.tektronix.com/power

- Automatic
- Manual

		TPS2000 Series with TPS2PWR1 Module	TDS3000C Series with TDS3AAM Module	MSO/DPO4000 and DPO3000 Series with DPO4PWR or DPO3PWR Module	TDS5000B Series with TDSPWR3 Option	DPO7000 Series with DPOPWR Option
Typical Specs	Bandwidth	100 MHz to 200 MHz	100 MHz to 500 MHz	100 MHz to 1 GHz	350 MHz to 1 GHz	500 MHz to 3.5 GHz
	Record Length	2.5 k	10 k	Up to 10 M	Up to 16 M	Up to 200 M
	Sample Rate	Up to 2 GS/s	Up to 5 GS/s	Up to 5 GS/s	Up to 5 GS/s*1	Up to 40 GS/s*1
Line Power Quality Measurements	V_{RMS}	Automatic	Automatic	Automatic	Automatic	Automatic
	I_{RMS}	Automatic	Automatic	Automatic	Automatic	Automatic
	True (Real) Power	Automatic	Manual	Automatic	Automatic	Automatic
	Reactive Power	Automatic		Automatic	Automatic	Automatic
	Apparent Power	Manual	Manual	Automatic	Automatic	Automatic
	Power Factor	Automatic	Manual	Automatic	Automatic	Automatic
	Crest Factor	Automatic	Manual	Automatic	Automatic	Automatic
	Phase Angle	Automatic	Manual	Automatic	Automatic	Automatic
	Harmonics	Automatic	Manual	Automatic	Automatic	Automatic
	Total Harmonic Distortion	Automatic		Automatic	Automatic	Automatic
Emission Compliance Tests	Pre-Compliance Testing to EN61000-3-2	Manual		Automatic	Automatic	Automatic
	MIL Standard 1399	Manual		Automatic	Automatic	Automatic
Active Component Measurements	Switching Loss Measurements	Automatic	Manual	Automatic	Automatic	Automatic
	Safe Operating Area	Manual	Manual	Automatic	Automatic	Automatic
	Dynamic Resistance (dv/dt, di/dt)	Automatic	Manual	Automatic	Automatic	Automatic
	Modulation Analysis			Automatic	Automatic	Automatic
Passive Component Measurements	Inductance				Automatic	Automatic
	Magnetic Power Loss				Automatic	Automatic
	Flux Density			Manual	Automatic	Automatic
	B-H Plots				Automatic	Automatic

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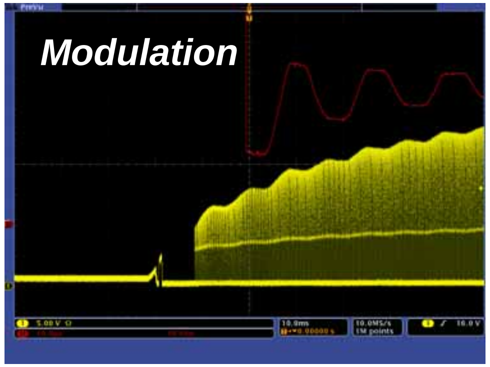
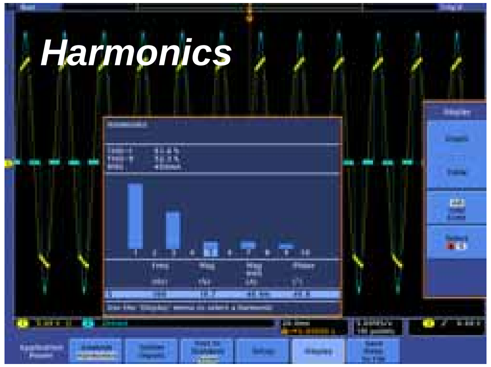
MSO/DPO4000 and DPO3000 Series: Power Supply Debug

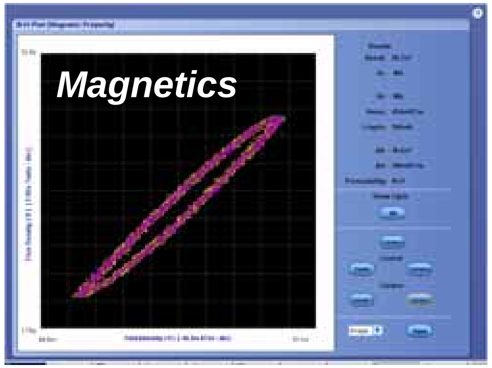
- Automated power measurements:
  - Power quality
  - Harmonics
  - Switching loss measurements
  - Safe Operating Area (SOA)
  - Slew rate
  - Ripple
  - Modulation
- Fast deskew of probes

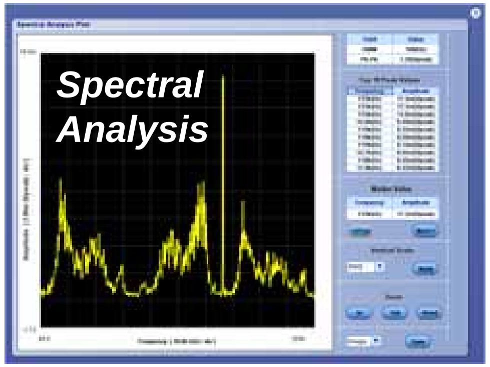


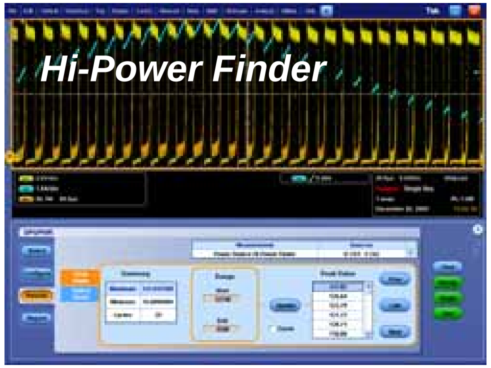


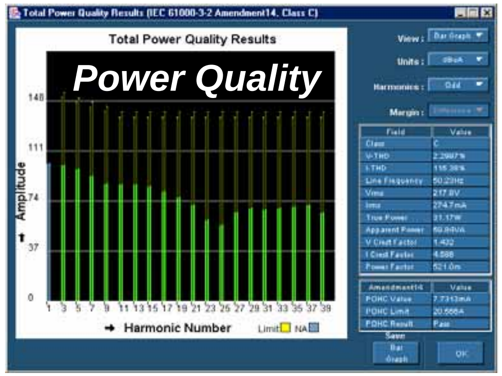
TDS5000B and DPO7000 Series: In-depth Characterization of Power Supplies

- Automated power measurements:
  - Switching loss, slew rate and SOA
  - Power quality and harmonics
  - Modulation and ripple
  - Magnetic components (core loss and BH curves)
  - Spectral Analysis and Hi-Power Finder
- Quickly generate customized reports
- Automatically deskew probes









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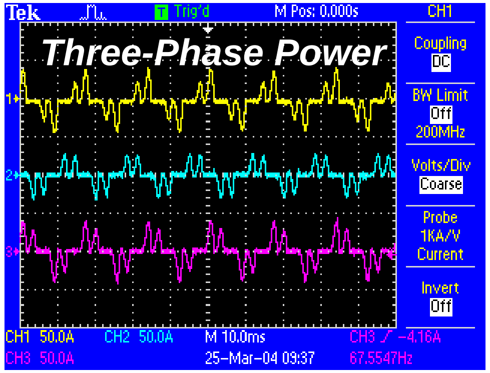
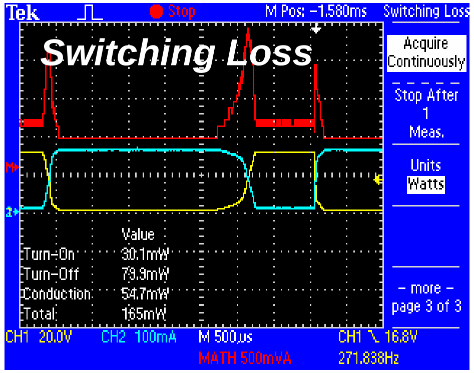
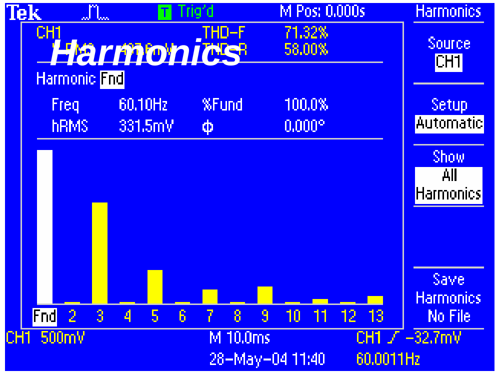
TPS2000 Series: Portable Power Troubleshooting

- Isolated channels for floating or grounded measurements
- Portable design with up to 8 hours of continuous battery life
- Integrated power measurements available:
  - Display watts, VA and VAR
  - Harmonics analysis
  - Switching loss analysis







Power Measurement Information

www.tektronix.com/power

- Primer & application notes
- Power measurement poster
- Manuals

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