Power Supply Measurement and Analysis with DPOPWR Application Software

Application Note

Introduction

Today's power supply designers are faced with increasing pressure to achieve power conversion efficiencies of 80% and even higher. This trend is driven by consumer demand for portable electronics with longer battery life and "greener" products that consume less power.

For the design engineer, this means performing numerous specialized power measurements to characterize the supply's behavior and troubleshoot problems. Historically, making these measurements meant taking static current and voltage measurements with a digital multimeter and performing painstaking calculations on a calculator or computer. Today, most engineers turn to the oscilloscope as their preferred power measurement tool.

This application note will describe common power supply measurements using a Tektronix MSO/DPO5000, DPO7000, or MSO/DSA/DPO70000 Series oscilloscope with DPOPWR power analysis software. These oscilloscopes with their complementary software provide automated power measurements for fast analysis and simplified deskew of probes for maximum accuracy.
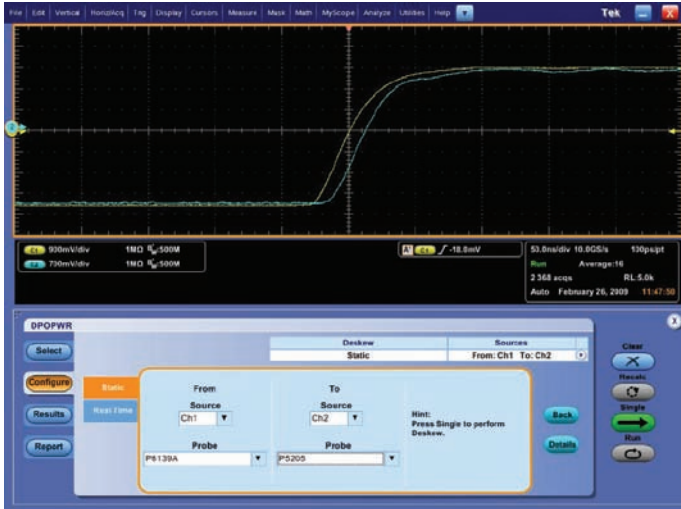
Tektronix®

Figure 1. Static Skew Compensation Between Two Probes, BEFORE Adjustment.

Preparing for Power Supply Measurements

In order to make accurate measurements, the power measurement system must be setup correctly to precisely capture waveforms for analysis and troubleshooting. Important topics to consider are:

- Eliminating skew between voltage and current probes
- Eliminating probe offset
- Degaussing your current probe

Eliminating skew between voltage and current probes

To make power measurements with an oscilloscope, it is necessary to measure voltage across and current through the device under test. This task requires two separate probes: a voltage probe (often a high voltage differential probe) and a current probe. Each voltage and current probe has its own characteristic propagation delay and the edges produced in these waveforms more than likely will not be automatically aligned. The difference in the delays between the current probe and the voltage probe, known as skew, causes inaccurate amplitude and timing measurements.

For example, if the voltage probe has a 1.5 meter cable and the current probe has a 1 meter cable, the resulting waveforms will not arrive at the measurement system comparators at the same time, in large part due to delays in the cable lengths of the probes. Other possible causes of skew include differences in the lengths of the signal paths and circuit delays inherent in the oscilloscope design.

Since skew creates a timing delay, it can cause inaccurate measurements of timing differences, phase relationships, and power factors between signals. Many measurement systems can "auto-calibrate" for internal product delays, but when you add probes to your system, new variables have been added that need to be compensated for.

Figure 1 shows an example of skew between two different voltage probes on two different channels that are connected to the same signal source but do not display identical timing relationships. Note that there is about 10 ns of delay between the two waveforms, caused mostly by probe length differences.

The Tektronix MSO/DPO5000, DPO7000, and MSO/DSA/DPO70000 Series allow you to compensate for the delays from your probe tips to the measurement system to ensure you make the most accurate timing measurements. This deskew step involves connecting your probes to the same waveform source, and adding delay to the trigger path of the faster signal. This allows the signals to be aligned in time without having to physically add cable to the shorter probe cable. Less capable measurement systems only deskew the path internal to the oscilloscope, and do not allow the user to compensate for probe lengths – leading to a major source of error.

Figure 2. Static Skew Compensation Between Two Probes, AFTER Adjustment.

Figure 3. Tektronix TCP0030 AC/DC Current Probe with Degauss/AutoZero.

Automated Deskew with DPOPWR

With the DPOPWR application for the MSO/DPO5000, DPO7000, and MSO/DSA/DPO70000 Series oscilloscopes, the deskew operation is automatic once you have connected your probes to the deskew fixture. The automated deskew feature takes only seconds to run, relieving you from the tedium of manually deskewing multiple probes and channels.

Figure 2 shows the same test setup used in Figure 1 after the DPOPWR deskew function has been run. By simply pressing the "Single" button, the DPOPWR software automatically aligned the two signals, compensating for timing delays between the two paths. The waveforms now cross at the same point in time.

Eliminating Probe Offset

Differential probes tend to have a slight voltage offset. This offset can affect accuracy and should be removed before proceeding with measurements. Most differential voltage probes have built-in DC offset adjustment controls, which makes offset removal a relatively simple procedure.

Similarly, it may be necessary to adjust offset on current probes before making measurements. Current probe offset adjustments are made by nullifying the DC balance to a mean value of 0 amperes or as close as possible. TekVPI®-enabled probes, such as the TCP0030 AC/DC current probe, have an automatic Degauss/AutoZero procedure built in that's as simple as pressing a button on the probe compensation box, as shown in Figure 3.

Degaussing Your Current Probe

A current probe should also include an easy to use degaussing feature. Degauss removes any residual DC flux in the core of the transformer, which may be caused by a large amount of input current. This residual flux results in an output offset error that should be removed to increase the accuracy of the measurements being made.

Tektronix TekVPI current probes offer a Degauss warning indicator that alerts the user to perform a degauss operation. A degauss warning indicator feature is critical for users performing power measurements as current probes may have significant drift over time, which will considerably affect the measurement.

Power Supply Characterization

Magnetic Characteristics

Magnetic components are an important part of any power supply system. Inductors and transformers are used as energy storage devices in both switch-mode as well as linear power supplies. Some power supplies also use inductors in filters at their output. Given their important role in the system, it is essential to characterize these magnetic components to determine the power supply's stability and overall efficiency.
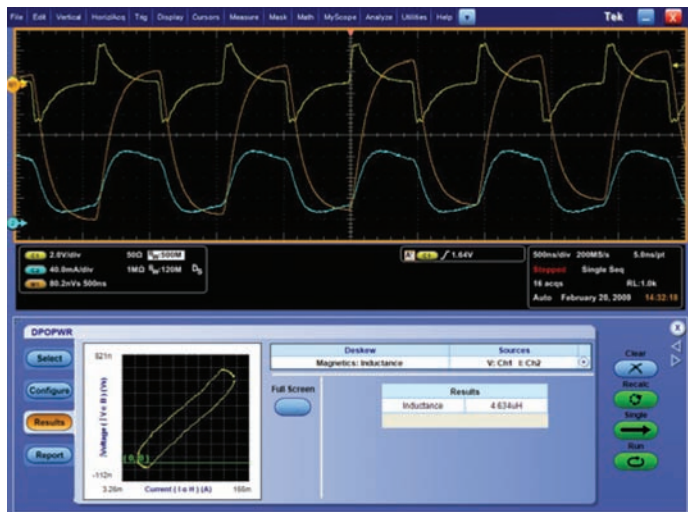
Figure 4. Magnetic Characteristics display using DPOPWR.

Figure 5. Magnetic Power Loss results using DPOPWR.

Inductance

Inductors exhibit increasing impedance with frequency, impeding higher frequencies more than lower frequencies. This behavior is known as inductance and is measured in units of Henries. The inductance parameters of various devices such as an inductor or transformer can be measured automatically with an oscilloscope.

Making the measurement:

The DPOPWR application measures the change in voltage with the change in current relative to time and calculates the inductance value. Making the measurement is as simple as probing the voltage across and the current through the magnetic component. After hitting the "Run" button, the inductance measurement results are presented as shown in Figure 4. The yellow (Ch1) waveform is the voltage across the inductor, the blue (Ch2) is the current through the inductor, and the orange (M1) is the math waveform composite used to calculate the induction value. Note the B-H curve is also displayed.

What to look for in the Results tab:

■ Inductance: The inductance value of the device or circuit

Magnetic Power Loss

An analysis of magnetic power losses is essential to accurately characterize the efficiency, reliability and performance of a switching supply. The two primary magnetic losses are core losses 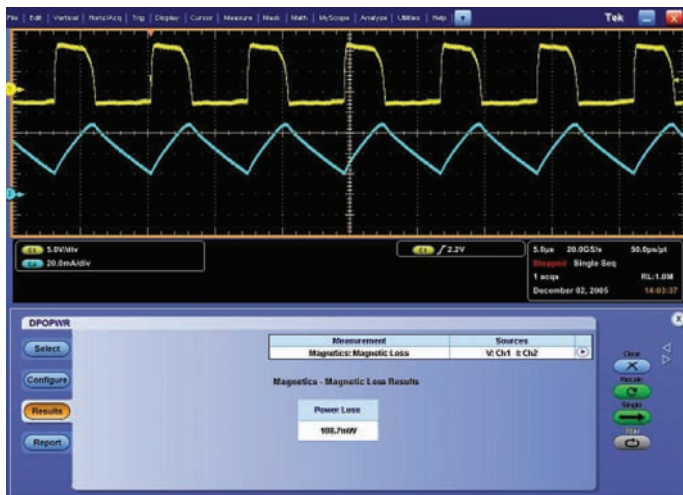and copper losses. The resistance of the copper winding wire contributes to the copper losses in a power supply. Core losses are a function of Eddy current losses and hysteresis losses in the magnetic core. Core losses are independent of DC flux, but are influenced by the AC flux swing and the frequency of operation.

In real world measurements, it is nearly impossible to isolate core losses from copper losses. A solution to this problem is to measure the total magnetic power loss and subtract the core loss value, as specified in the magnetic component's data sheet. The result will give a fairly accurate calculation of the copper loss.

Making the measurement:

DPOPWR is capable of calculating the magnetic loss in a single winding inductor, a multiple winding inductor or even a transformer.

In the case of a single-winding transformer, a differential probe is connected to measure the voltage across the primary winding. A current probe measures the current through the transformer. The oscilloscope and power measurement software can then automatically calculate the magnetic power loss.

After hitting the 'Run" button, the magnetic power loss results are presented as shown in Figure 5.

What to look for in the Results tab:

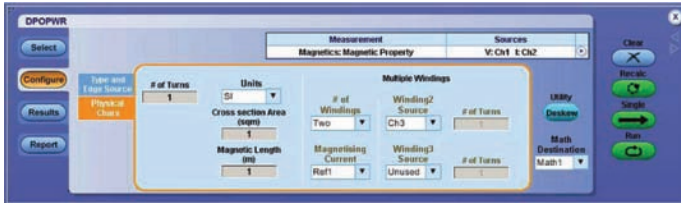■ Power Loss: The total power loss due to the magnetic component

Figure 6. DPOPWR configure tab for B-H Plots.

B-H Plots

The symbols B, H and μ are used to describe the magnetic properties of materials. Magnetic induction or magnetic flux density B, measured in units of Tesla, is the strength of the magnetic field. It determines the force that is exerted upon a moving charge by the magnetic field. The magnetic field intensity or field strength H, measured in A/m, is referred to as the magnetizing force. The magnetic permeability of a material, μ, is measured in H/m. It measures the degree of magnetization of the material due to the applied magnetic field.

Physical characteristics such as the magnetic length and the number of windings around the core help determine the B and H of the magnetic material. B-H curve plots are often used to verify the saturation (or lack thereof) of the magnetic elements in a switching supply and provide a measure of the energy lost per cycle in a unit volume of core material. The curve plots the magnetic induction, B, against the field strength, H. Since both B and H depend on the physical characteristics of the magnetic component, such as the magnetic length and the number of windings around the core, these curves define the performance envelope of the component's core material.

Making the measurement:

In order to generate a B-H plot, the voltage across the magnetic element and the current flowing through it are measured. In the case of a transformer, the current through the primary as well as secondary windings is of interest.
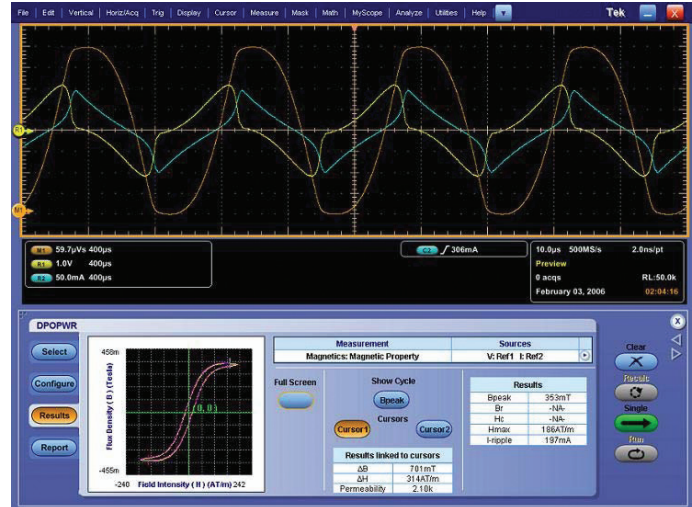

Figure 7. B-H Plot using DPOPWR.

A high-voltage differential probe is connected to channel 1 on the oscilloscope and across the primary winding of the transformer. This measured voltage is a result of the magnetic induction B of the magnetic component. Channel 2 measures the current through the primary with a current probe. Current probes are also used to measure the current through the secondary windings on channel 3 and channel 4, if needed. The power analysis software can then calculate the magnetizing current using the data from oscilloscope channels 2, 3 and 4. The magnetizing current value is then used to determine H component.

The number of turns of the inductor (N), the magnetic length (l) and the cross-sectional area of the core (Ae) must first be entered as shown in Figure 6, before the power analysis software can compute a B-H plot.

After hitting the 'Run" button, the magnetic property results are presented as shown in Figure 7.

Figure 8. Switching Loss Measurements Using DPOPWR.

What to look for in the Results tab:

- ΔB: The change in flux density

- ΔH: The change in field strength

- Permeability: The degree of magnetization of the material

- Bpeak: The maximum magnetic flux density induced in a magnetic component

- Br: The point on the curve where H = 0 but B still has a positive value. This is known as the Remanence of the component, a measure of its Retentivity. The higher the remanence, the more magnetization the material will retain.

- Hc: The point on the curve where B = 0 and H is a negative value. This represents the external field required to cause B to reach zero. This value of H is known as the coercive force. A small coercive force value means that the component can be demagnetized easily.

- Hmax: The maximum value of H at the intersection of the H-axis and the hysteresis loop

- I-ripple: The peak-to-peak value of the current

Electrical Characteristics

The accurate calculation and evaluation of energy loss in power supplies has become even more critical with the drive to higher power conversion efficiency. Almost all components of a power supply contribute to energy losses in some form. In the case of a switch-mode power supply (SMPS), a majority of the energy losses occur when the switching transistor transitions from an Off to an On (turn-on loss) state and vice versa (turn-off loss). Conduction and radiation in the switch are other sources of energy loss in the system.

Losses are minimized when all components of the system operate within their specified performance limits. An evaluation of the Safe Operating Area (SOA) of the switching transistor ensures that the device is not being stressed and is working under proper operating conditions.

Switching Loss Measurements

Switching losses occur when the switching circuit is energized or turned on, and when the switching circuit is de-energized or turned off. Turn-on losses occur as various physical and parasitic capacitors are charged, inductors generate magnetic fields, and related transient resistive losses occur. Likewise, when the switching supply turns off there is energy still available to discharge and interact with various components even though the main power has been removed, and so losses occur here too.

Making the measurement:

Measuring switching loss with DPOPWR is as simple as probing the voltage across and the current through the switching transistor. After hitting the 'Run" button, the switching loss results are presented as shown in Figure 8.

What to look for in the Results tab:

- Ton: The Turn On Power Loss and Energy calculations

- Toff: The Turn Off Power Loss and Energy calculations

- Total Avg: The Total Average Power Loss and Average Energy calculations

Figure 9. Hi Power Finder results window using DPOPWR.

Hi Power Finder

Dynamically changing loads on a switching power supply can impact the overall power loss of the switching device. This may result in the supply exceeding its voltage and current operation limits, and in turn, its power rating. It is therefore important for the designer to actively analyze the power loss in switching components, to ensure that the instantaneous power is within the specified limits.

The Hi Power Finder is a unique feature on DPOPWR that enables you to determine the instantaneous peak power on the switching waveform. This analysis tool calculates and identifies every peak power data point and provides a summary of these peak power events. This evaluation is performed automatically in a matter of seconds, sparing you from a tedious analysis of data.

Along with an analysis of peak instantaneous power in the system, the Hi Power Finder also calculates the energy loss at any given peak power value. This result may viewed by selecting the Switch Finder tab in the results window.

Making the measurement:
To determine the instantaneous power using Hi Power Finder, the measurement set up is the same as the one used to measure switching losses. A differential voltage probe measures the voltage across the switching transistor and a current probe measures current through the transistor. The waveform height on the scope should be at least 2 - 4 divisions to make accurate measurements.
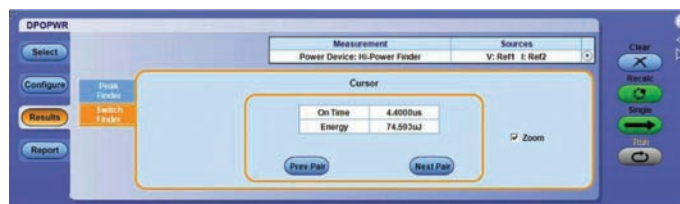

Figure 10. Switch Finder results tab displaying energy loss.

After configuring Hi Power Finder by providing information such as expected Ton and Toff levels, and hitting the "Run" button, the HiPower Finder results will be displayed as shown in Figure 9.

What to look for in the Results tab:

- Summary Table: This table includes Maximum, Minimum and # Cycles

  - Maximum: This is the maximum power of the waveform peaks in the data sample

  - Minimum: This is the minimum power of the waveform peaks in the data sample

  - # Cycles: The number of On and Off peaks in the data sample

- Range Panel: This panel displays the Start and End limits for the range of data. These limits may be changed as needed for the analysis by entering the input values and hitting the Update button.

- Peak Value Panel: The peak values, that fall in between the End and Start limits, are displayed in this panel in descending order

- Link Button: This identifies the peak portion in the voltage and current waveforms using cursors

- Prev: Moves the cursors to the previous peak

- Next: Moves the cursors to the next peak

- Zoom: Selecting this box creates a Zoom window for the cursor location for detailed waveform analysis

- Switch Finder Tab: This tab displays the energy loss at the cursor point as shown in Figure 10
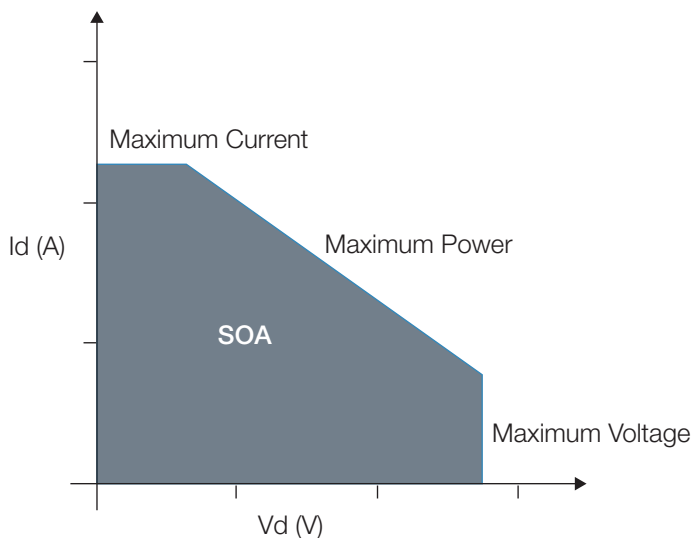
Figure 11. Safe Operating Area (SOA) graph of a transistor.

The datasheet for the transistor usually provides a graph that plots V_{CE} (or V_{DS} for a FET¬) against I_{CE} (or I_{DS}), as shown in Figure 11. The SOA is the area under the curve. Other performance limitations of the transistor such as the maximum voltage, maximum current, power, secondary breakdown, and junction temperature may also be inferred from this graph. Because this information is presented in one curve, SMPS designers can use the information from SOA measurements to test the switching transistors in the power supply over diverse operating conditions. This simplifies the task of designing protection circuitry.

Making the measurement:

One of the main challenges with determining the SOA of a transistor while operating in a power supply is successfully and accurately capturing voltage and current data under a variety of load scenarios, temperature changes and variations in line input voltages. DPOPWR greatly simplifies this task by minimizing the number of connections to the device under test and automating the data capture and analysis process. The measurement setup is as simple as probing the voltage across and the current through the switching transistor.

There are two Plot Types that may be generated using the DPOPWR power analysis software:

Safe Operating Area (SOA)

■ SOA/ SOA Normal plots the Voltage and Current waveform in a single record in XY mode. The result may be seen as a plot on the Results tab that may be expanded to full screen. This plot will be based on a single acquisition cycle.

■ SOA X-Y/SOA DPO measures and plots the voltage and current waveforms using the X-Y display mode of the oscilloscope itself. This feature may be used for multiple acquisitions of the same waveform in real time testing.
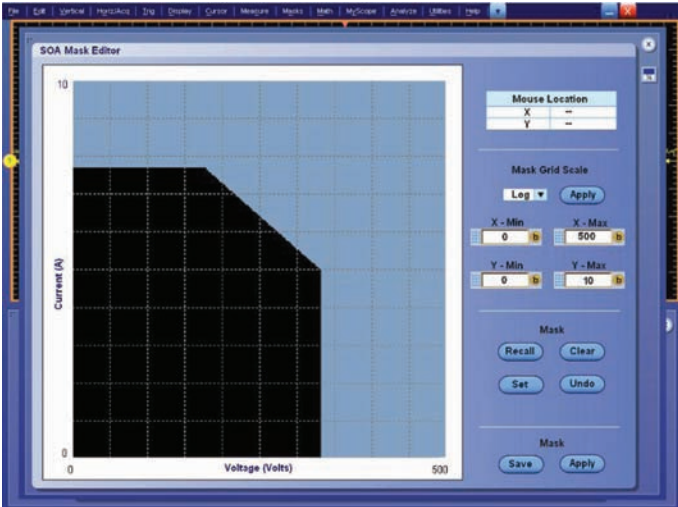
Safe Operating Area

The safe operating area (SOA) of the switching transistor in a switch-mode power supply defines the current that can run through the transistor at a given voltage. As the transistor transitions between ON (saturated) and OFF (cut-off) states, it becomes important to understand the voltage and current conditions over which it can operate without self damage. Since the transistor may fail if these limits are exceeded, an understanding of the SOA is important for the accurate and safe operation of the power supply. The SOA may be forward-biased or reversed-biased, depending on whether the transistor is transitioning to the ON state or OFF state respectively.

Figure 12. SOA Mask Editor window for DPOPWR. The X and Y Max. and Min. values are customizable.
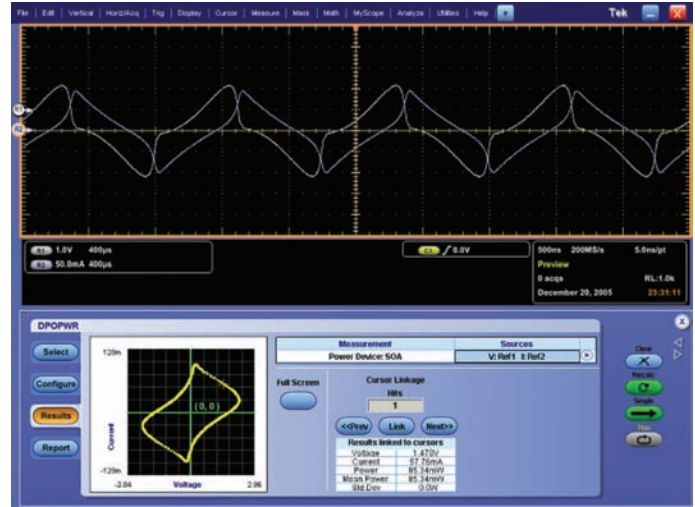

Figure 13. SOA using DPOPWR.

Safe Operating Area Mask Editor

- As shown in Figure 12, the SOA Mask editor sets up a mask based on the maximum and minimum voltage and current limits for the transistor, as defined in its datasheet. This enables the evaluation and comparison of the measured SOA of the transistor with the maximum limits defined by the manufacturer. If the data points fall inside the mask zone, they are green to indicate 'pass' and if they fall outside the mask zone, they are red to indicate 'fail'.

After completing the setup and hitting the 'Run" button, the SOA results are presented as shown in Figure 13.

What to look for in the Results tab:

- Results Table: This table presents data related to the position of the cursor. It highlights the Voltage, Current, Power, Mean Power and Std. Dev. for the selected measurement point.

- Full Screen: This button will enlarge the SOA plot and make the same size as the scope screen

Input Analysis

The transport of electricity from the source to the end user is a very complex system – it includes electricity generation, transmission and distribution. Changes in the amount of power generated at the utility as well as the overall demand for this power along with variations in weather, quality of power lines and wiring at the end user, all have an impact on the overall quality of the power that finally reaches the load.

Because a switching power supply presents a non-linear load to the power line, the input voltage and current waveforms are not identical. Current is drawn for some portion of the input cycle, causing the generation of harmonics on the input current waveform. Power quality, total power quality, and current harmonics are common measurements used for analyzing the effect of a power supply on the power line.

Power Quality

Power quality refers to a load's ability to function properly with the electric power that is supplied to it. These measurements help understand the effects of distortions caused by non-linear loads. For example, an SMPS is a non-linear load added to the overall power system, and it can impact the quality of the line power being delivered to it. Measuring the power quality at the input of the SMPS gives a better understanding of how well the SMPS performs, with the given quality of the line power.

Making the measurement:

Power quality measurements are easily made by using a differential probe to measure the line voltage of the system and a current probe to measure the line current of the system. This same setup may be used to measure current harmonics and total power quality as well.

Figure 14. Power Quality results using DPOPWR.

DPOPWR software provides a deskew utility to align the current and voltage waveforms and eliminate any propagation delay variations.

After the "Run" button is selected the, results of the power quality analysis are presented as seen in Figure 14.

What to look for in the Results tab:

- Vrms: The Root-Mean-Square value of the displayed voltage waveform

- True Power: The real power of the system measured in Watts (W)

- VCrestFactor: The peak amplitude of the voltage divided by the RMS value of the voltage

- Frequency: The frequency in hertz of the voltage waveform

- Irms: Root-Mean-Square value of the displayed current waveform

- Apparent Power: The absolute value of the complex power measured in Volt-Ampere (VA)

- ICrestFactor: The peak amplitude of the current divided by the RMS value of the current

- Power Factor: Ratio of the True Power to the Apparent Power
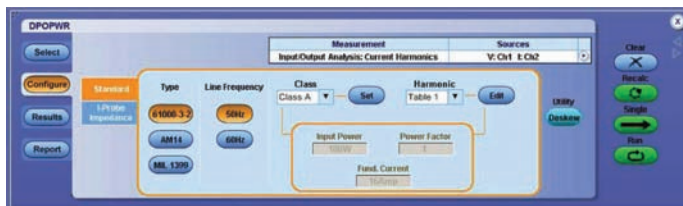
Figure 15. DPOPWR configure tab for Current Harmonics.

Current Harmonics

Real-world power supplies have non-linear loads, meaning the load increases and decreases as the user changes operating functions, devices heat up or cool down, etc. These load changes cause distortions to the voltage and current waveforms. This non-linearity happens because as the power supply turns on and off there are surge currents caused by the resistive, capacitive, and inductive loads placed on the incoming power lines. Also changes in the source voltage can cause non-linearity in power supply function. The DPOPWR application provides a simple and fast report for the reaction of the input power to those load changes.

Making the measurement:
The equipment setup to make these measurements stays the same as that for Power quality in the previous section. The differential voltage probe is set up to measure the line voltage whereas the current probe measures the line current.

In the configuration tab, the Current Harmonics standard and line frequency need to be selected, along with the Class (A, B, C or D) of the standard as seen in Figure 15. Other specifics such as Input Power, Power Factor and Fundamental Current values may also be provided, depending on the Class of the Standard that has been selected.
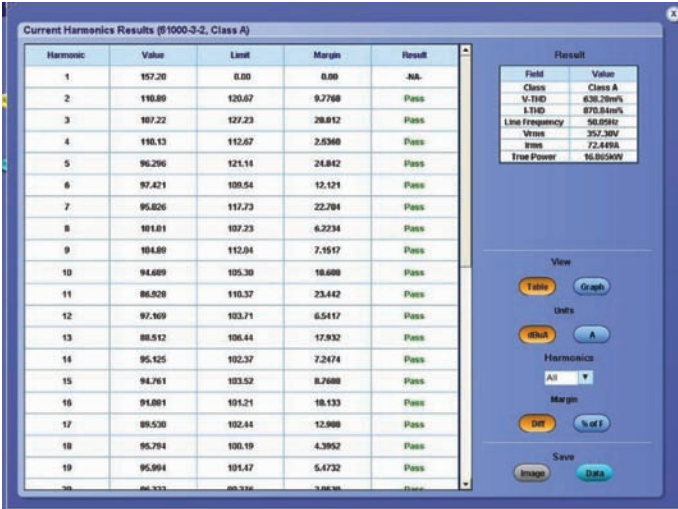
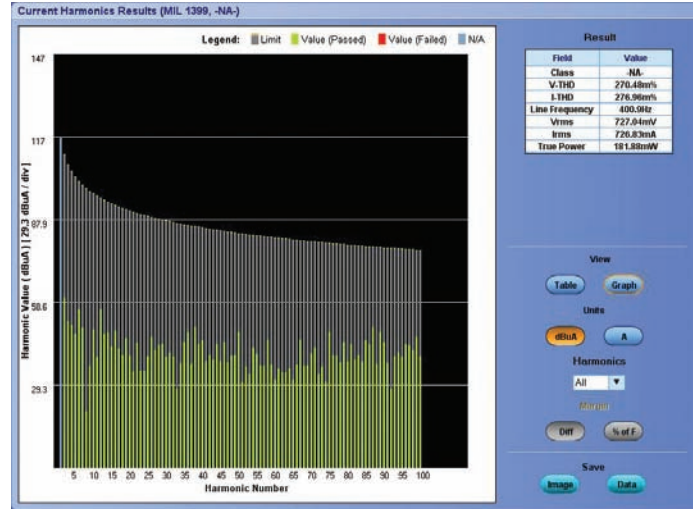**Figure 16a.** Current Harmonics results using DPOPWR.

Figure 16b. Up to 100 Current Harmonics are displayed in graphical form using DPOPWR.

After the "Run" button has been selected, the results of the Current Harmonics evaluation are presented as shown in Figure 16a and 16b.

What to look for in the Results tab:

■ Harmonics Table: This table includes the Harmonic, Value, Limit, Margin and Result

- Harmonic: This is the harmonic number

- Value: The measured value of the current harmonic in dBμA

- Limit: The harmonic limit per the IEC standard chosen in dBμA

- Margin: The difference between the Value and Limit numbers

- Result: Displays a Pass (green) or Fail (red) result for each harmonic

■ Result Table: This table includes the following information:

- Class: This is selected by the user in the Configuration tab. The selected Class may be A, B, C or D. This depends on the type device under test and, in some cases, the shape of the current waveform.

- V-THD: Total Harmonic distortion of the voltage, as a percent value

- I-THD: Total Harmonic distortion of the current, as a percent value

- Line Frequency: This is the line frequency value in Hertz. It was selected in the configuration tab.

- Vrms: The line voltage in Volts

- Irms: The line current in Amperes

- True Power: Total power in Watts

■ View: Allows the user to view the Harmonics Table data in a table format or graph format. In the bar graph format, a green bar indicates pass and a red bar indicates fail.

■ Units: Allows the user to view the data presented in the Harmonics table in units of decibel microamperes (dBμA) or amperes (A)

■ Harmonics: This drop down menu allows the user to see All harmonics, Even numbered harmonics or Odd numbered harmonics

■ Margin: The user may select whether the margin should be calculated as a difference between the measured Value and the Limit or as a percentage of the fundamental

■ Amendment 14 Table: This table includes the Partial Odd Harmonic Current (POHC) Value, Limit and Result
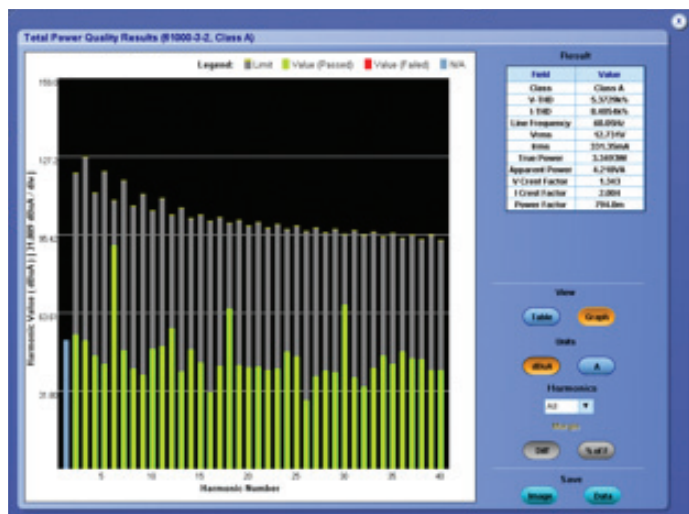
Figure 17. Total Power Quality results using DPOPWR. Current Harmonics and Power Quality results are presented together.

Total Power Quality

DPOPWR enables a Total Power Quality analysis. This analysis provides a summary of the Power Quality as well as the Current Harmonics of the system.

The Measurement setup for a Total Power Quality analysis is the same as that for a Power Quality Analysis. The Configuration is similar to that for the Current harmonics evaluation discussed in the previous section.

The Results of a Total Power Analysis are presented in Figure 17. They are a sum of the Power Quality and Current Harmonics results.

Output Analysis

Important output measurements, especially for switching power supplies, are line ripple, switching ripple, spectral analysis, and turn-on time.

Line and Switching Ripple

The quality of power supply's DC output should be clean with minimal noise and ripple. Simply stated, ripple is the AC voltage that is superimposed onto the DC output of a power supply. It is expressed as a percentage of the normal output voltage or as peak-to-peak volts.
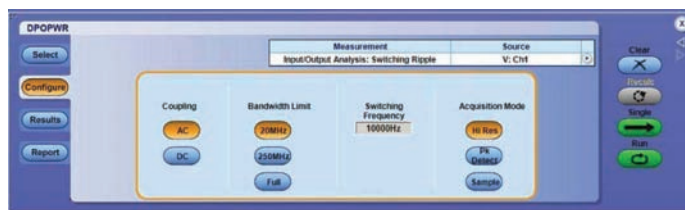
Figure 18. Line Ripple configuration tab for DPOPWR.

There are two kinds of ripple that show up at the output of a power supply. Line ripple measures the amount of ripple related to the line frequency. On the other hand, switching ripple measures the amount of ripple detected from the switching supply output based on the switching frequency that you identify.

The output line ripple is usually twice the line frequency; whereas the switching ripple is typically coupled with noise and in the kHz frequency range. Separating line ripple from switching ripple is one of the biggest challenges in power supply characterization. Power analysis software greatly simplifies this task.

Making the measurement:
In order to measure the ripple of the system, only a voltage probe is needed. The differential probe needs to be connected to the output of the system to measure the output line and switching ripple voltages.

The configuration tabs (see Figure 18) for line and switching ripple are very similar. Both ripple measurements require the selection of the Coupling (AC or DC) mode, bandwidth limit required (20MHz, 150/250MHz or Full) and the oscilloscope's acquisition mode – Sample, Peak Detect or High Resolution (Hi Res). In the case of a line ripple measurement, the line frequency of the system, 50 Hz or 60 Hz or 400 Hz, needs to be defined. Switching ripple measurements require input about the switching frequency of the switching transistor.
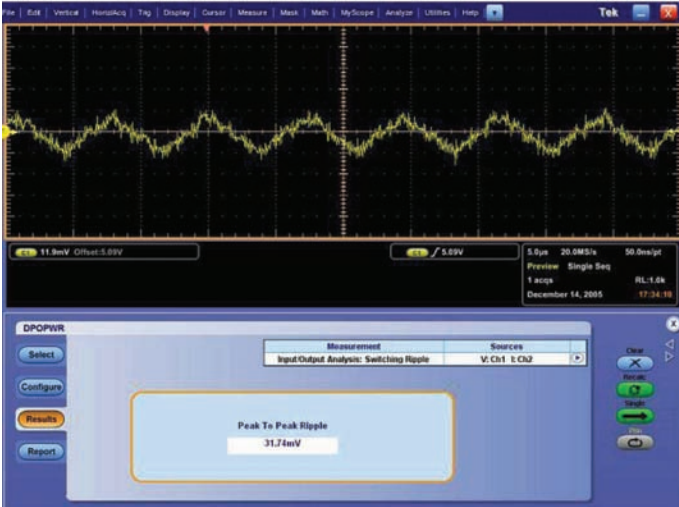
Figure 19. Switching Ripple results using DPOPWR.

Once the measurement has been configured, the "Run" button is selected and the results are presented as shown in Figure 19.

What to look for in the Results Tab:

■ Peak to Peak Ripple: This is the peak to peak value of the Line or Switching ripple of the system

Spectral Analysis

With the Spectral Analysis feature, you can analyze the frequency components that contribute to the electromagnetic interference (EMI) of your system. It also measures the noise/ripple at the output DC voltage frequency range. This analysis helps you decide if there are filtering issues with your supply under test.
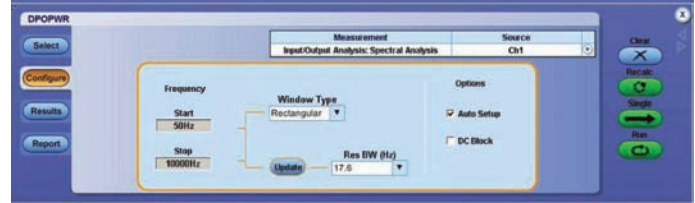
Figure 20. Spectral Analysis configuration tab for DPOPWR.

Making the measurement:

Unlike previous measurements, this analysis does not require the use of any probes. The output of the supply under test simply needs to be connected to a channel on the oscilloscope.

To configure DPOPWR for this measurement (Figure 20), the frequency range of interest needs to be setup. The values for the start frequency range from 0 Hz to 499 MHz where as the stop frequency range is as small as 50 Hz to 500 Hz. Next, the Window Type needs to be determined. This helps define how much spectral leakage is reduced in the analysis. The available window types are: Rectangular, Hamming, Hanning, Black-Harris, Gaussian, Flattop2, Kaiser-Bessel and TekExp.

If the Auto Setup box is checked in the Options pane, then the power analysis software automatically selects the optimum record length and time base for the spectral analysis, given the Window Type. Otherwise, the software uses the existing time base and record length for the analysis.
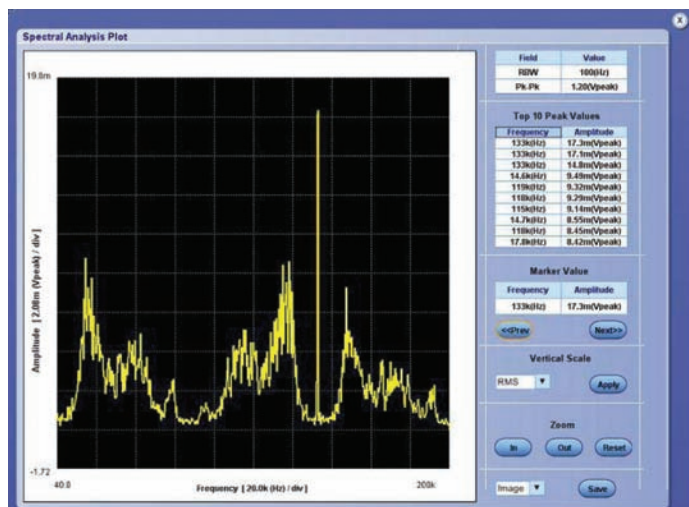
Figure 21. Full Screen view of Spectral Analysis Results, using DPOPWR.

The result of this analysis is presented in Figure 21. The spectrum amplitude is the Y-axis and frequency is the X-axis (in units Hz).

What to look for in the Results tab:

- Plot: This displays the frequency values on the X-axis and the amplitude on the Y-axis. The Start and Stop range values are also displayed.

- Top 10 Peak Values: Displays the highest 10 peak values with the corresponding frequency

- Marker Value: Identifies the peak value selected

- Prev: Selects the previous peak value

- Next: Selects the next peak value

- Vertical Scale: Allows the user to select dB, dBm, RMS, and Peak vertical scale units

- Zoom: Allows the user to Zoom In or Zoom Out of the plot

Turn-On Time

Turn-on time is defined as the time it takes from when the power supply is turned on to when a valid, useable output is available. In other words, turn-on time defines the sum of the delay time and the rise time of the output voltage after the power supply is turned on. It is important to get a good understanding of the turn-on time of a power supply to minimize line and load regulation issues.
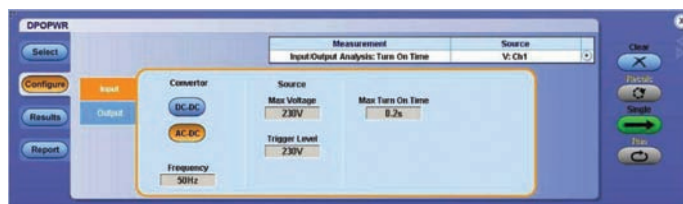
Figure 22. Turn-on time configuration tab for DPOPWR.

Traditionally this value has been determined by tedious calculations or simulations using SPICE or mathematical models. As far as turn-on time measurements are concerned, they are a challenge to make by traditional methods; especially if the relative scales of the input and output voltages are quite different. In the case of multiple output supplies, the analysis becomes even more difficult.

DPOPWR simplifies this process by automatically adjusting the scales of the oscilloscope and determining the overall turn-on time and providing the results. As an additional feature, these power analysis tools enable the time analysis of up to three different outputs simultaneously.

Making the measurement:
The measurement setup to measure turn-on time is quite simple. It only requires the use of two voltage probes – one at the input of the power supply and one at the output. It is better to use differential probes for these measurements.

The configuration tab shown in Figure 22, requires information about the input as well as the output of the supply. First, in the Input pane, you must identify whether the turn-on time is being measured for an AC to DC converter or a DC to DC converter. In the case of an AC to DC converter, the line frequency of the AC input needs to be specified. Next, the maximum voltage of the source needs to be defined along with the anticipated maximum turn-on time. These numbers help the software determine the scale and timing window for the measurement.

As mentioned above, the software allows the measurement of the turn-on time of up to three outputs at the same time. Once the output pane has been selected, the number of outputs that will be tested is chosen and the corresponding oscilloscope channel that is being used to measure that output voltage is defined. The maximum output voltage also needs to be entered to complete the setup.
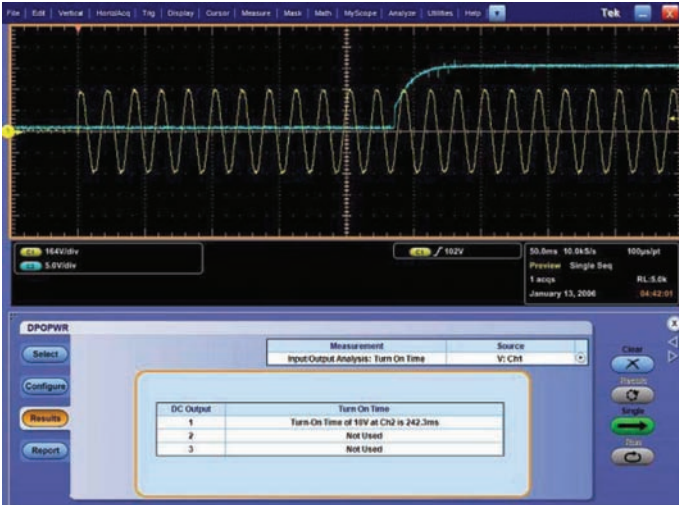
Figure 23. Turn-on Time results using DPOPWR.

Finally, selecting the "Run" button presents the results shown in Figure 23.

What to look for in the Results tab:

■ Turn on time: The turn-on time for the specified output

Power Supply Pre-Compliance Testing

Power system quality has become more important with the ever increasing consumption of energy in industry, neighborhoods and homes. Odd numbered harmonics from switching power supplies may find their way back to the power grid. And as the number of switching supplies connected to the grid increases, the total percentage of harmonic distortion returned to the grid also increases. This results in heat build-up in the cabling and transformers of the power grid and may cause harm to property and life. It therefore becomes essential to reduce the harmonics of power system.

One step in this direction is the testing of power systems against IEC defined Compliance Standards such IEC61000-3-2 Class A, B, C and D, IEC61000-3-2 AMD14 Class C and D as well as Military Standard MIL-STD-1399. These are regulation mechanisms to ensure the power quality from non-linear loads. While IEC61000-3-2 may be considered more generic power grid compliance standards, the MIL-1399 is aimed at military shipboard electric power systems.

The IEC61000-3-2 standard limits the current harmonics injected into the public mains power supply system. It applies to all electrical and electronic equipment that has input current up to 16A per phase that will be connected to public low voltage distribution systems (230V AC or 415V AC 3 phase). The standard is further divided into Class A (balanced 3-phase equipment), Class B (portable tools), Class C (lighting equipment and dimming devices) and Class D (equipment with unique current waveform requirements).

On the other hand the MIL-STD-1339 deals with power conversion systems aboard military ships used for a variety of applications such as computers, air conditioners, communication equipment checks the current harmonics generated from power conversion. These power conversion systems connect to power panels that in turn are connected to the central power generator(s) via switchboards.

DPOPWR enables designers to quickly compare performance of their devices against compliance standards before going through certification, an often time-consuming and expensive process. This not only simplifies the design and debug task, but also helps reduce time-to-market.

Making the measurement:
Use a differential voltage probe to measure the line voltage. Use a current probe to measure the line current.
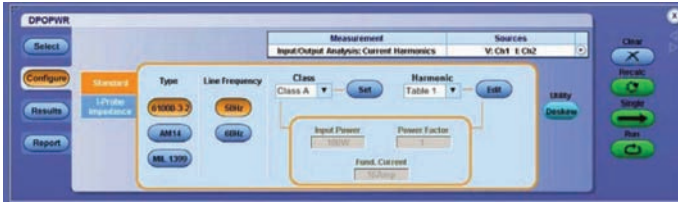
Figure 24. Pre-Compliance Testing configuration tab on DPOPWR.

If Tektronix voltage and current probes are used in the above measurement, the frequency response of the two measurements will automatically be synchronized. This can be done by selecting the probes being used from a drop down menu and hitting the Deskew button. This will ensure an accurate current harmonics measurement. On the other hand, if non-Tektronix probes are used, you will need to define the frequency range for the current measurement, manually deskew the voltage and current waveforms and configure the current probe settings.

After the probes have been set up, the IEC Standard and Line Frequency need to be defined, as shown in Figure 24. Finally, the Class type needs to be selected and after hitting the Set button; the pre-defined limit table will be loaded and made available for comparison. In the case of Class C or D standards, the Input Power, Power factor and Fundamental current will also need to be entered. Finally, after hitting the "Run" button, the pre-compliance results will be presented as shown in Figure 25.

What to look for in the Results tab:

- Harmonics Table: This table includes the Harmonic, Value, Limit, Margin and Result

  - Harmonic: This is the harmonic number

  - Value: The measured value of the current harmonic in dBµA

  - Limit: The harmonic limit per the IEC standard chosen

  - Margin: The difference between the Value and Limit numbers

  - Result: Displays a Pass (green) or Fail (red) result for each harmonic

- Result Table: This table includes the following information:

  - Class: This is selected by the user in the Configuration tab. The selected Class may be A, B, C or D. This depends on the type device under test and, in some cases, the shape of the current waveform.

Figure 25. Pre-Compliance Testing results table using DPOPWR.

  - V-THD: Total Harmonic distortion of the voltage, as a percent value

  - I-THD: Total Harmonic distortion of the current, as a percent value

  - Line Frequency: This is the line frequency value in Hertz. It was selected in the configuration tab.

  - Vrms: The line voltage in Volts

  - Irms: The line current in Amperes

  - True Power: Total power in Watts

- View: Allows the user to view the Harmonics Table data in a table format or graph format. In the bar graph format, a green bar indicates pass and a red bar indicates fail.

- Units: Allows the user to view the data presented in the Harmonics table in units of decibel microamperes (dBµA) or amperes (A)

- Harmonics: This drop down menu allows the user to see All harmonics, Even numbered harmonics or Odd numbered harmonics

- Margin: The user may select whether the margin should be calculated as a difference between the measured Value and the Limit or as a percentage of the fundamental
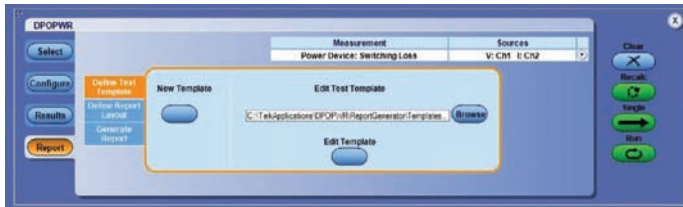
Figure 26. Report tab in DPOPWR.

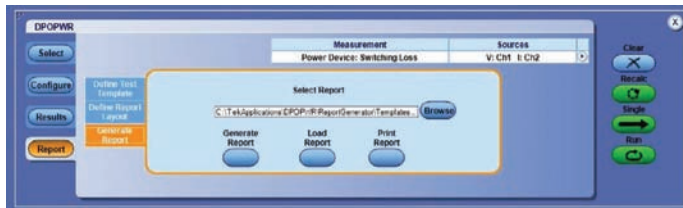**Figure 27.** Define Test Template tab using DPOPWR.

Figure 28. Generate Report tab using DPOPWR.

Report Generation

Data collection, archiving and documentation are often tedious but necessary tasks in the design and development process. DPOPWR is equipped with a report generation tool that makes the documentation of measurement results easy and effortless.

DPOPWR has a special Report tab (shown in Figure 26) that is a part of the Power Analysis window.

Instead of simply generating standard reports for all measurements, DPOPWR allows you to customize report templates and layout. In the Define Test Template tab (shown in Figure 27), you have an option of either editing the standard template provided for the specific measurement by selecting the Edit Template button; or developing a brand new template all together by selecting the New Template button. In a similar manner, the layout of the report can be edited by selecting the Define Report Layout tab. The modified templates and layouts can be saved at a desired location for future use as well.

By selecting the Generate Report button in the tab with the same name (showing in Figure 28), the final report with the desired template and layout is generated and displayed on the oscilloscope screen. Finally, a Print Report button allows you to print the report.

Summary

By using the DPOPWR application with MSO/DPO5000, DPO7000, or MSO/DSA/DPO70000 Series oscilloscopes, engineers can make accurate measurements quickly and with very little setup time. Best of all, we don't need to do manual calculations! The oscilloscope applications do the work, and by using screen capture and file save features of those products, engineers also can save excellent documentation of how the instrument was set up, what the waveforms looked like, and the results, all in one graphic.

Which oscilloscope and probe is right for you?

The MSO/DPO5000, DPO7000, and MSO/DSA/DPO70000 Series oscilloscopes achieve the best power measurement performance when combined with the proper power probes. For a complete listing of compatible probes for each oscilloscope, please refer to www.tektronix.com/probes for specific information on the recommended models of probes and any necessary probe adapters.

High Voltage Differential Probes

Features

- Safely make measurements of floating or elevated circuits with the oscilloscope grounded.
- Wide dynamic voltage range from mV to kV.

Current Probes

Features

- Transformer and Hall effect technology enhance AC/DC measurement capabilities.
- Wide dynamic current range from mA to kA.

The MSO/DPO5000 and DPO7000 Series oscilloscopes are equipped with the Tektronix Versatile Probe Interface (TekVPI). TekVPI™ probes are versatile, feature-rich, and easy-to-use.

TekVPI High Voltage Differential Probes

Features

- Offers GHz performance to analyze Switch Mode Power Supply (SMPS) designs.
- Versatile device under test (DUT) connectivity and ease-of-use.

TekVPI Current Probes

Features

- Exceptional bandwidth (DC to 120 MHz) and broad dynamic range (mA to hundreds of Amps).
- Split core construction makes it easier and quicker to connect to the device under test (DUT).

For Further Information
Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit **www.tektronix.com**

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