A Review Of Common Measurement Errors While Debugging Modern High Efficiency DC/DC and AC/DC Converters.

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TELEDYNE LECROY
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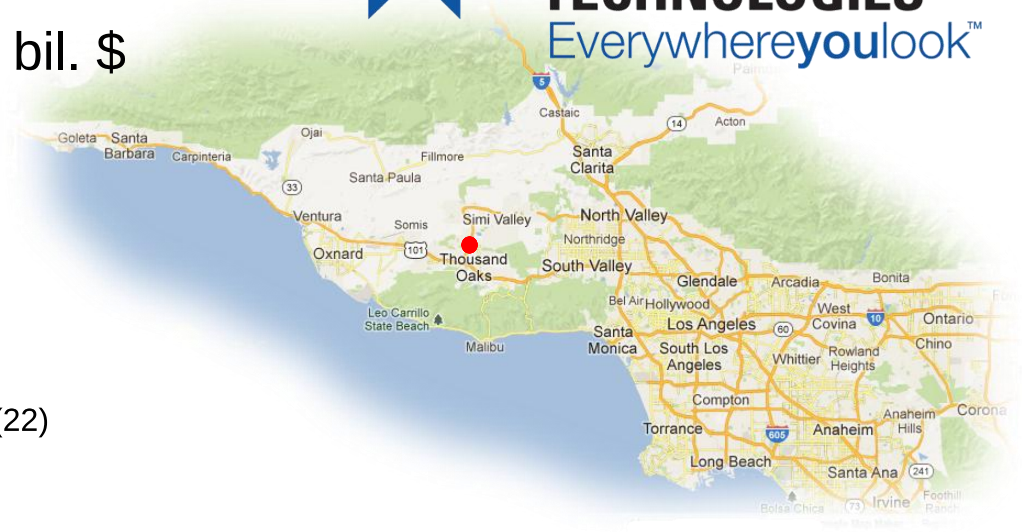
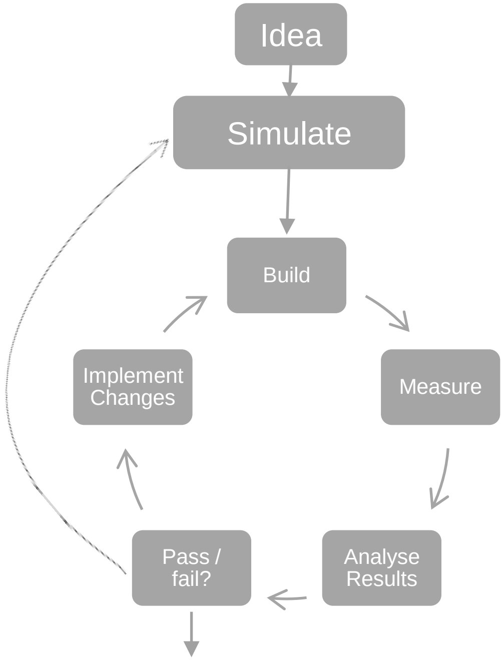
Teledyne Technologies Incorporated

- Founded: 1960
- Headquarter: Thousand Oaks, California, USA
- Turnover 2012:   2'127 bil. $
- ca. 9'600 Employees Worldwide
- 4 Main Branches:
  - Instrumentation (26)
  - Digital Imaging (7)
  - Aerospace & Defense Electronics (22)
  - Engineered Systems (5)



What are measurement instruments used for?

- Three main areas
  - Analysis, debug, validation
  - Product research, design and development
  - Education (Research)
  - Largest section of the oscilloscope market
- Other areas
  - Repair, service, maintenance, manufacturing
  - Education (Student use)
  - Usually lower cost purchases



Power supply design Challenges

- The last decade has seen dramatic improvements in power supplies and increased challenges for the design engineers:
  - Efficiency
  - Reliability
  - Stability
  - Compliance
  - Power density
  - Cost and time-to-market reduction

- Tips and Tricks on using a Digital Oscilloscope in Power supply design and testing.

Which measurements

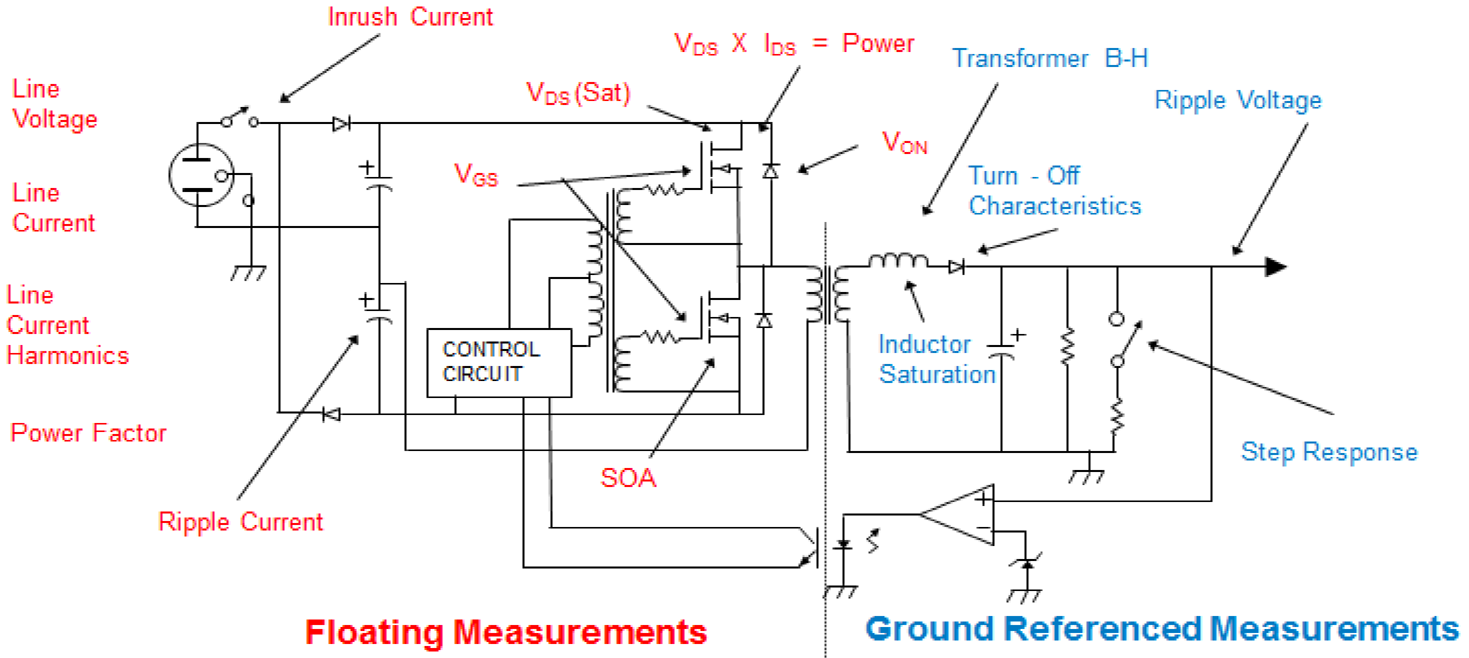
- "No-Ground referenced" measurements
- Sources of Measurement Errors
- Power quality
  - Real, Apparent and Reactive Power
  - Power Factor
  - Crest Factor
  - Phase
  - Total Harmonic Distortion THD
  - Line Current harmonics : EN61000-3-2 Pre-compliance
- Performance Analysis
  - Efficiency
  - Load Regulation
  - Turn on/off time
  - Output Ripple
  - Ripple frequency analysis
  - Power line monitoring

Which measurements

- Device Measurements and Analysis
  - Measuring how much energy is being lost in the transition as the output transistor turns on and off, as well as how much is lost in conduction.
  - Improving Reliability of the Power Supply by monitoring device Stress Limits
  - Improving Rds(on) Measurement Accuracy
  - B-H Curve
  - Speed of a power device’s rate of change (dv/dt, di/dt) during turn-on and turn-off.

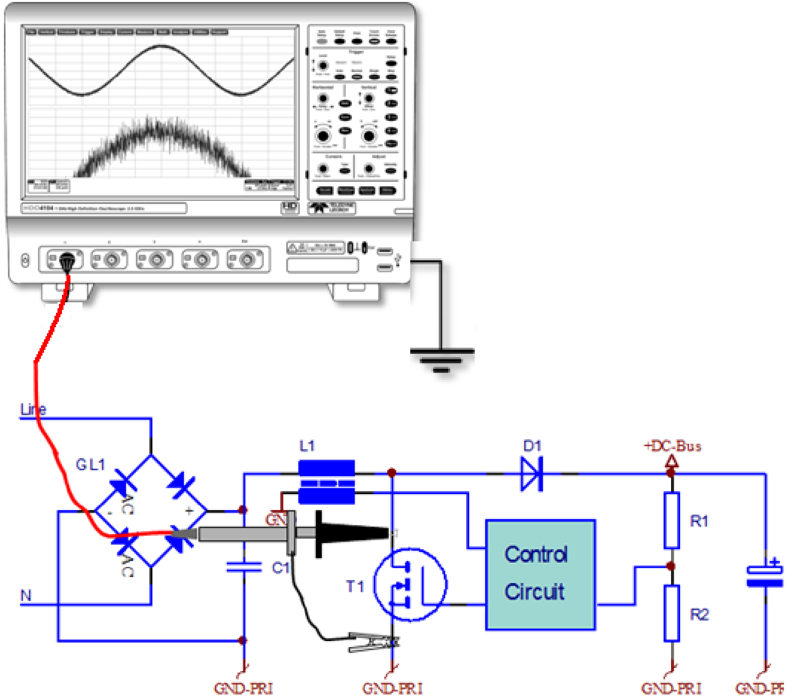
- Control Loop Analysis.
  - Measuring Feedback Loop Response in Power Systems

Which measurements



Examples of Power Measurements

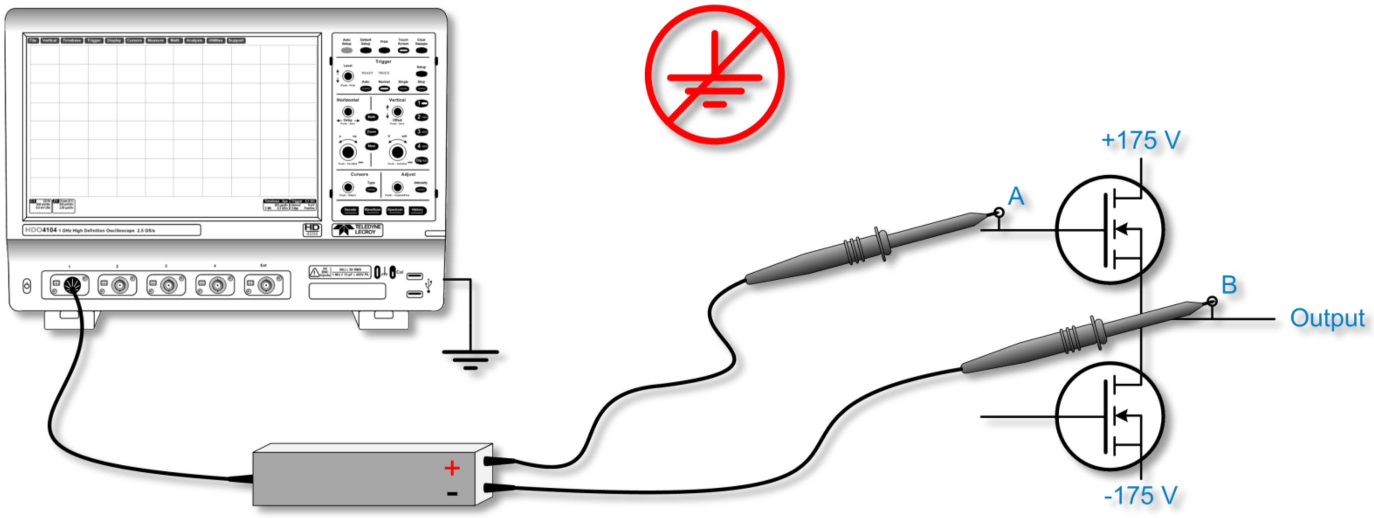
Ground Referenced Measurements



General Purpose oscilloscope can only measure “Ground Referenced” Voltage

While this configuration is adequate for many routine measurements, there are several applications where this restriction degrades the measurement quality, or prevents the measurement from being made altogether.

Non-ground Referenced Measurements- True Differential

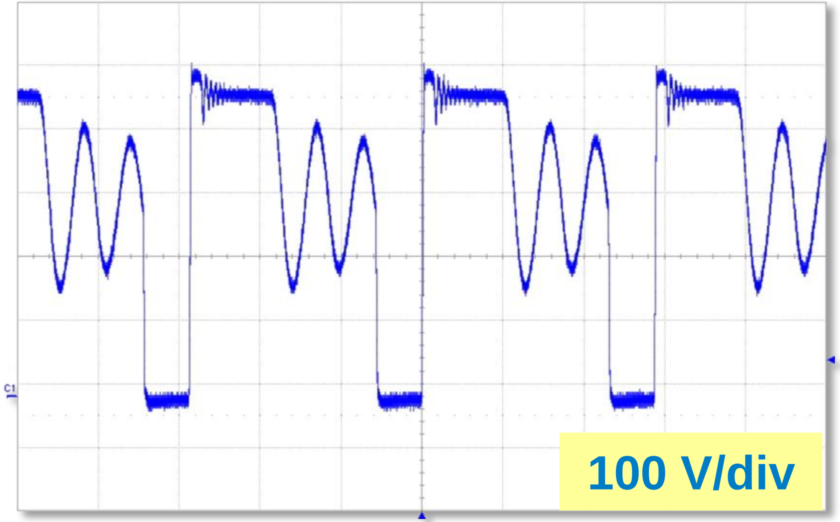


Important Characteristics

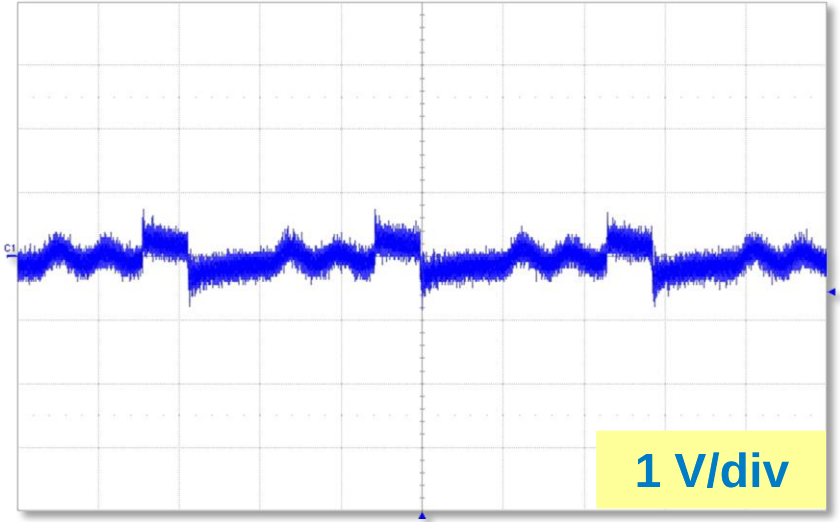
- Common Mode Range
- Common Mode Rejection Ratio
- True Balanced Inputs
    - Load "sees" high impedance
    - Lead parasitic effects cancel out!

Common Mode Rejection Ratio

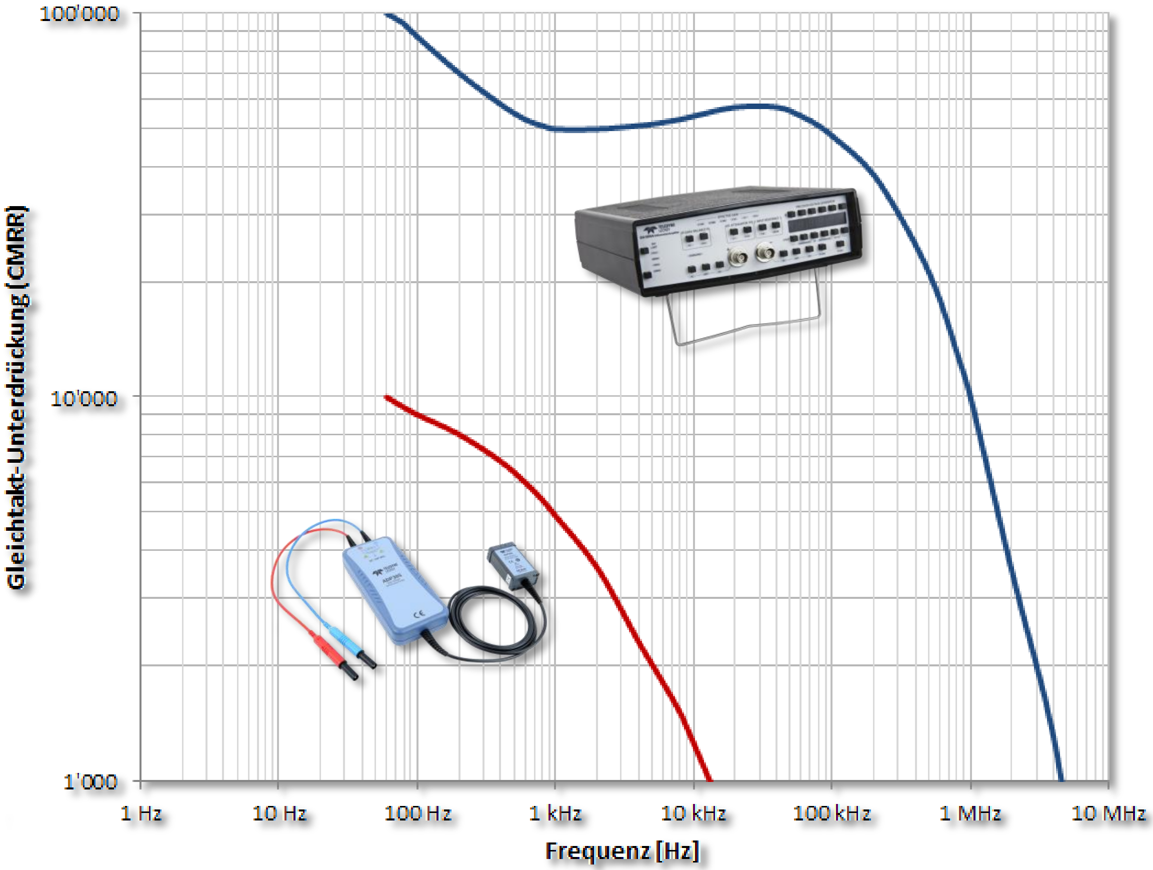
'Flyback'-Topology
Drain-Source Measurement



Remaining common mode in a high performance differential amplifier



Common Mode Rejection Ratio



- The **differential amplifier DA1855A** starts with a high CMRR value and maintains it over a large frequency range
- The **high voltage differential probe** has a good CMRR value for low voltages, but rapidly falls off at higher frequencies

Accuracy and Overdrive Recovery issues

How do we make fine granularity measurements on high voltage signals, such as overshoot, undershoot, ripple saturation voltage, RdsON,..

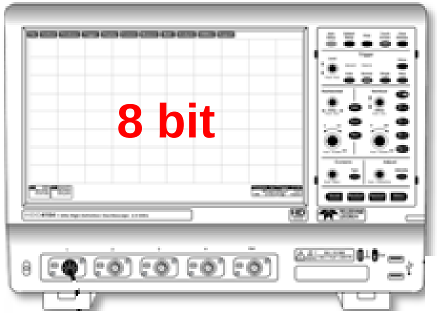
A common technique is to use the channel knob of the oscilloscope to <u>increase the vertical sensitivity</u> and <u>offset</u> the signal under test.

Whereas this does increase the vertical measurement granularity, and you would intuitively believe that it improves the accuracy, it also overloads the oscilloscope input channel amplifier.

Offsetting and expanding the signal over a wider range will drive major portions of the signal off-screen and beyond the dynamic range of the oscilloscope's input amplifier. Therefore the oscilloscope input amplifier can be driven into saturation causing waveform distortions and artefacts.

Accuracy and Overdrive Recovery issues

8 bit A/D Converter = 2^8 = 256 Levels



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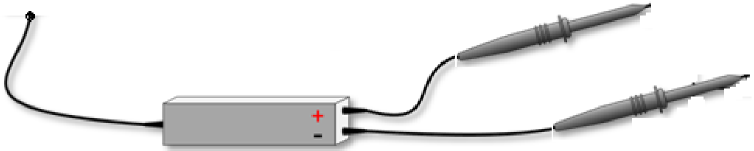
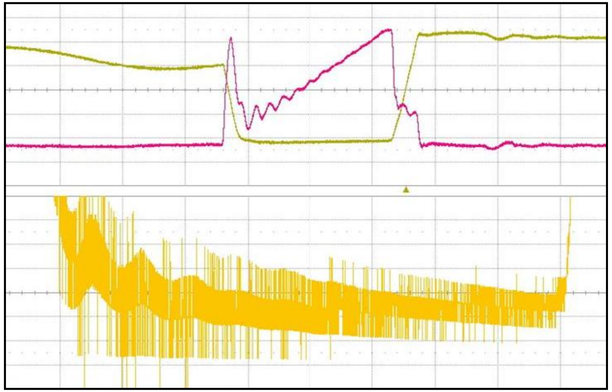


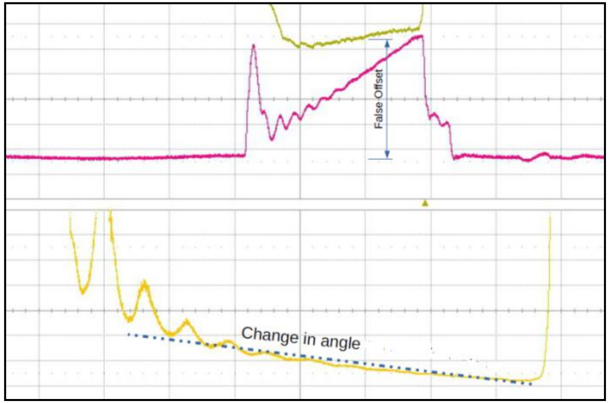
Differential probe

800V / 256 = 3.125V



- No offset
- Not increased vertical sensitivity
- Only Zoom

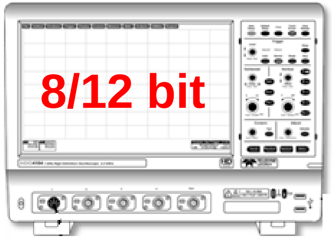
- Poor accuracy
- High quantization error



- Offset
- Increased vertical sensitivity

- Oscilloscope Input into Saturation
- Waveform distorted

Accuracy and Overdrive Recovery issues



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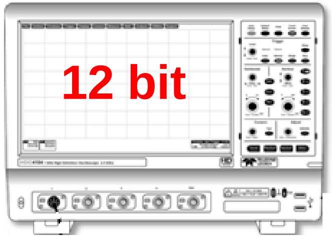
External Fast Recovery Differential Clipping Amplifier

8 bit A/D Converter = 2^8 = 256 Levels

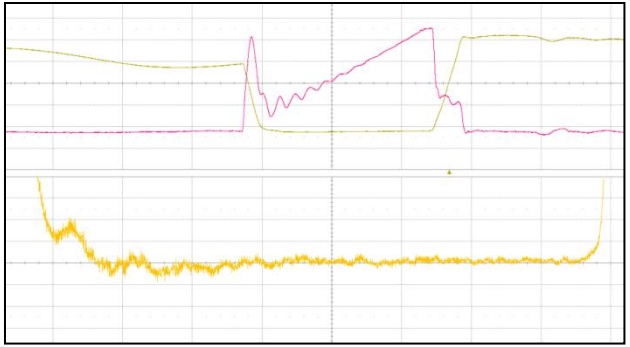
800V / 256 = 3.125V

Precision Offset Generator
We don't need to use the oscilloscope offset because the differential amplifier DA1855A features a built-in Precision Offset Generator.
Fast overdrive recovery
This unique capability allows the amplifier to make measurements that would normally be limited by oscilloscope input saturation because of poor overdrive recovery.



12 bit A/D Converter = 2^{12} = 4096 Levels

800V / 4096 = 195mV



- No offset needed
- Not increased vertical sensitivity needed
- Only Zoom

- High accuracy
- High vertical resolution (12 bit = 4096 level)
- Waveform details

Sources of Measurement Error

Voltage Probing

- Ground loops in non-ground referenced measurements
- Probe effects - matching impedance to your design (R and C)
- Signal propagation differences (skew between voltage and current)
- DC Offsets
- Scope’s amplifier and probe CMRR to circuit’s common-mode and differential-mode levels

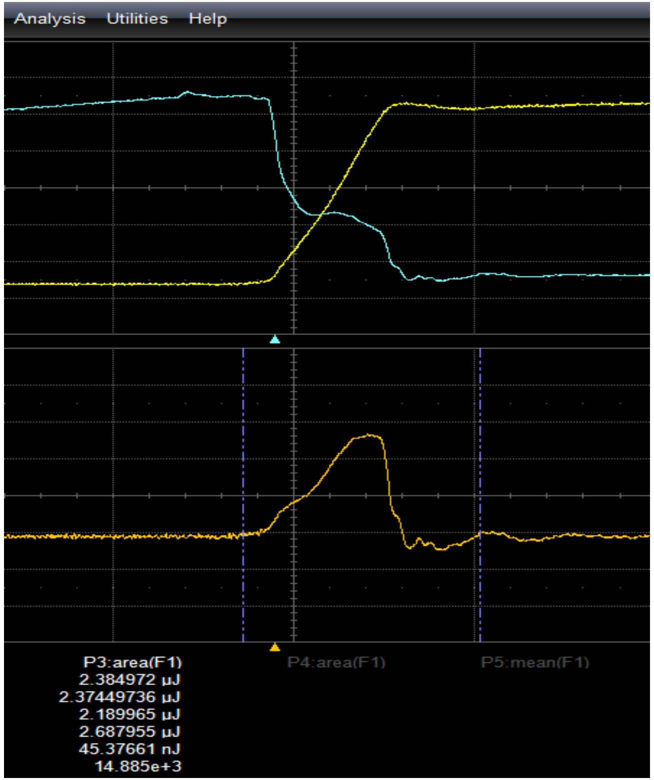
Current Probing

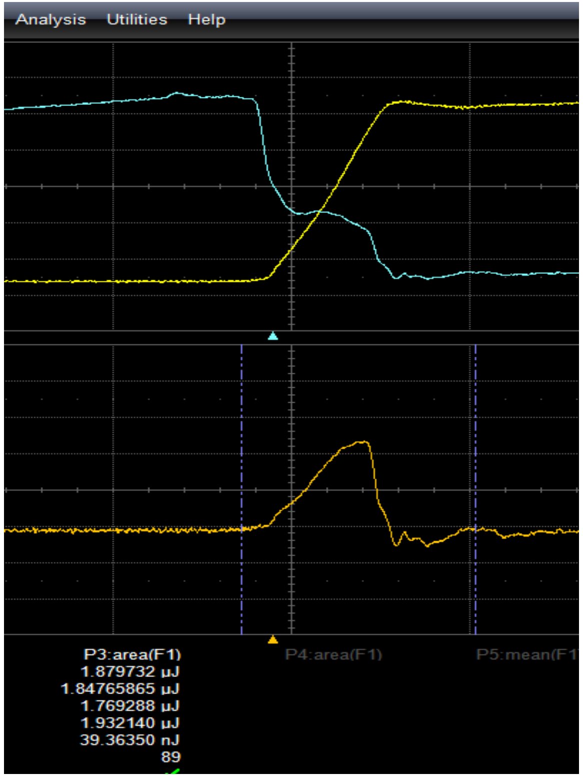
- Flux accumulation – Degauss
- DC Offsets – Autozero

Scope Acquisition

- Vertical dynamic range, consideration of 8 bits vs. 12 bits
- Sampling rate determines maximum frequency (effective digital bandwidth)

Sources of Error – Skew Between Voltage and Current Probes

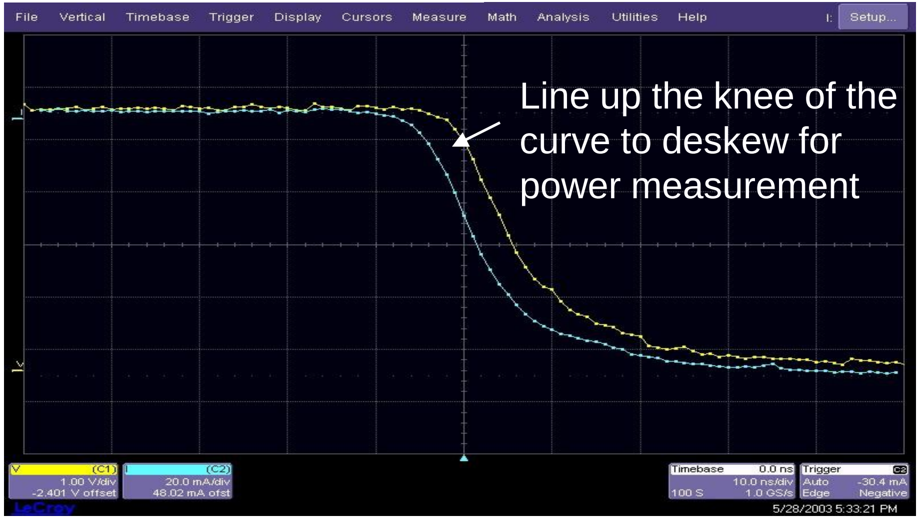




- Timing Skew between Voltage and Current Probes Results in Measurement Error
- Device Turn-off Loss, V x I, is properly measured at 2.37uJ of energy loss versus 1.84 uJ without proper deskew

Sources of Error: Deskewing Voltage and Current Probes

Use a deskew calibration source to remove any skew between voltage and current probes



Power Quality

LinePower	Vrms	Irms	rpwr	apwr	pf	reactpwr	phase	Icrest
value	245.13 V	122.72 mA	14.24 W	30.160 VA	472.0e-3	26.59 VA	61.83 °	3.63
status	✓	✓	✓	✓	✓	✓	✓	✓

Parameters are automatically measured and displayed with statistic and Histicons

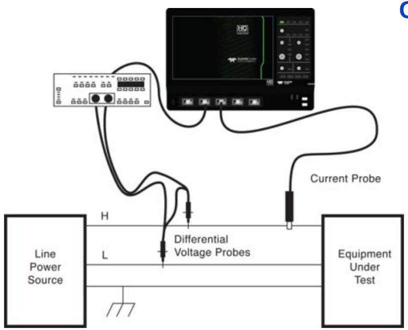
- Real, Apparent and Reactive Power
- Power Factor
- Crest Factor
- Phase

Power Quality measurements
No PFC

Power Quality measurements
With PFC

Voltage and Current Connections for 12 Bit Oscilloscope

(With Power Analysis Software installed)



Line Current Harmonics

- Electronic equipment and devices that cause nonlinear current waveforms produce many damaging effects on the ac power distribution. Equipment connected to the same circuit could operate improperly due to severe voltage distortion caused by harmonic currents

- The **IEC standard 61000-3-2** imposes limits on the harmonic currents

- **Classification of equipment**

  Class A : Balanced three-phase equipment, household appliances (excluding those in class D), non-portable tools, audio equipment, dimmers for incandescent lamps, and all other equipment except that stated in the classes B, C or D.

  Class B: Portable tools, non-professional arc welding equipment.

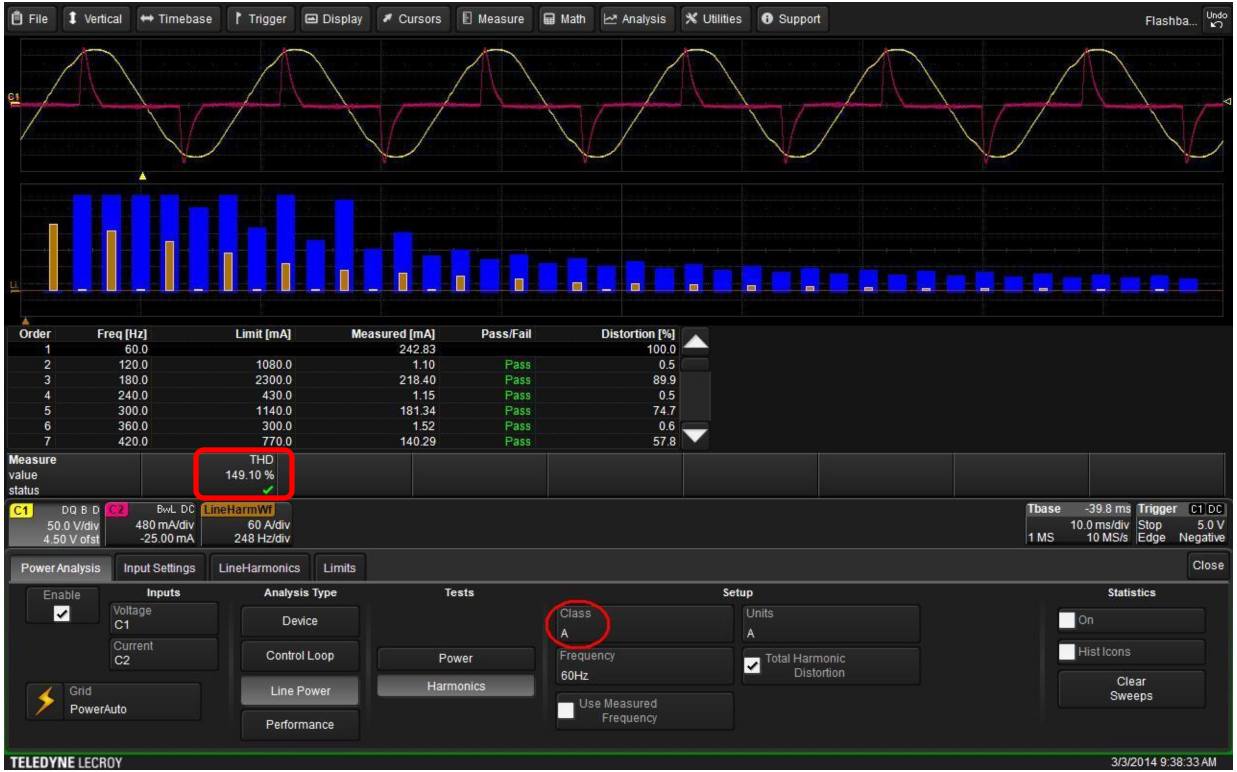
  Class C: Lighting equipment, above and below 25 W.

  Class D: Personal computers and computer monitors, radio or TV receivers (75W- 600W). For the Class D the maximum Harmonic Current per Watt (mA/W) has to be checked.

Why perform a Pre-compliance test?

Pre-compliance testing is traditionally used during product development to provide significant confidence that the equipment under development can meet the standard prior to full compliance testing at external testing services. Before discovering that the equipment doesn't meet the requirement, the Pre-compliance testing offers an important solution to save costs and time.

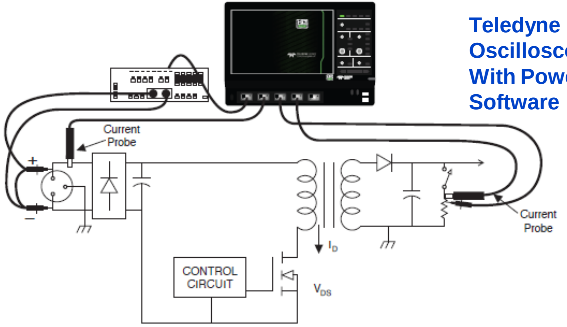
Line Current Harmonics



After selecting the Class (A, B, C or D) of the standard, the current harmonics are automatically calculated and the Pre-compliance test is easily performed by comparing the Current Line Harmonics with the relative limits.

The table shows the result of the harmonic analysis and the Total Harmonics Distortion (THD) is also calculated.

Performance Analysis : Efficiency



Teledyne LeCroy Oscilloscope HDO4000 With Power Analyzer Software

$$\text{Efficiency} = \frac{Pout}{Pin} = \frac{Vout\ x\ Iout}{Vin\ x\ Iin}$$

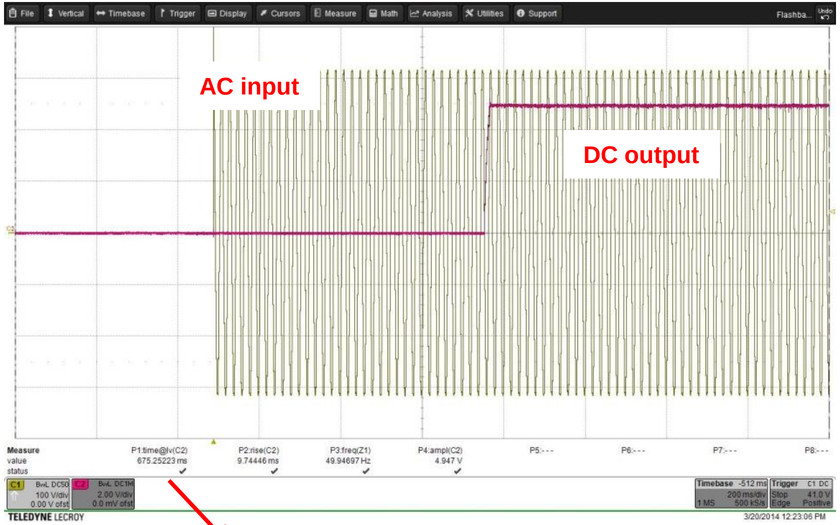
Measure	P1:rms(C1)	P2:rms(C2)	P3:mean(C3)	P4:mean(C4)
value	117.64 V	822.6 mA	13.002 V	6.1561 A
status	✓	✓	✓	✓
Performance	**InputPower**	**OutputPower**	**Efficiency**	
value	94.89 W	80.041 W	84.35 %	
mean	94.89 W	80.041 W	84.35 %	
min	94.89 W	80.041 W	84.35 %	
max	94.89 W	80.041 W	84.35 %	

Performance Analysis : Load regulation, Turn-on/off Time

- **Load regulation** is the capability to maintain a constant voltage (or current) level on the output channel despite changes in the supply's load

Turn-on/off analysis measures the time between when power is initially switched on until the dc output reaches steady output voltage and vice versa.

Measure	P1:mean(C1)	P2:ampl(C1)	P3:base(C1)	P4:top(C1)
value	4.91185 V	38.83 mV	4.89241 V	4.93124 V
status	✔	✔	✔	✔

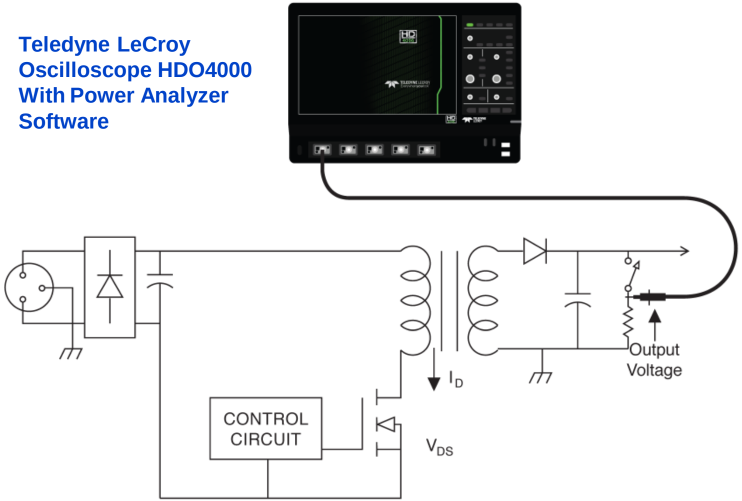


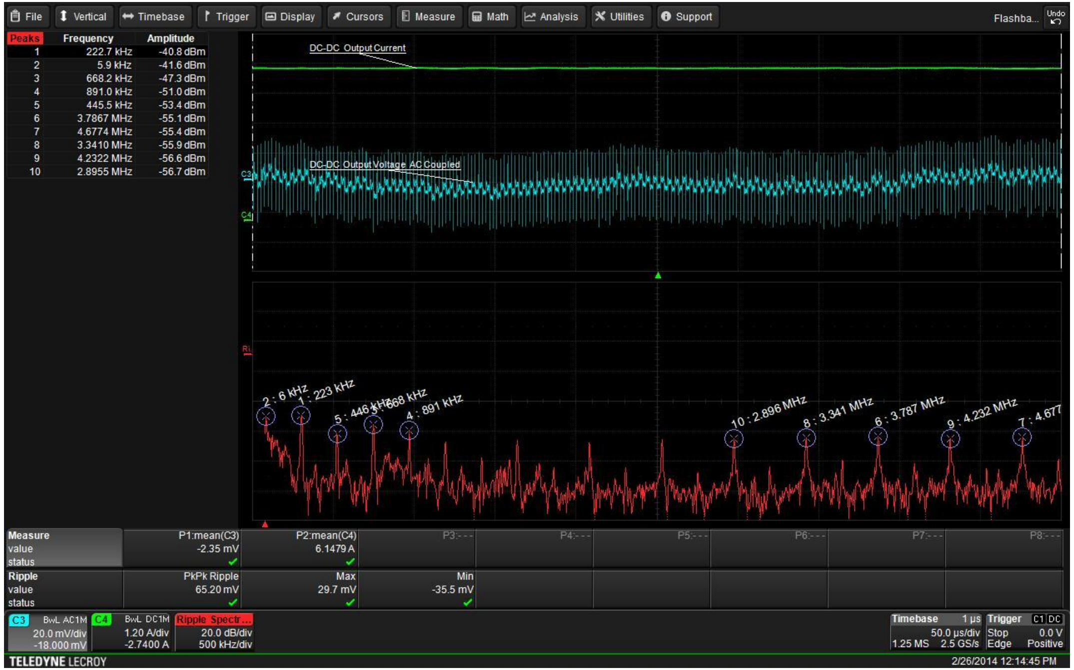
Measure	P1:time@lv(C2)	P2:rise(C2)	P3:freq(Z1)	P4:ampl(C2)
value	675.25223 ms	9.74446 ms	49.94697 Hz	4.947 V
status	✔	✔	✔	✔

Performance Analysis : Output ripple and frequency analysis

- **Output ripple** : small unwanted AC components of the DC Output voltage
- Measurements include **the peak to peak ripple**, the **maximum and minimum values** of ripple, and the **spectral content** of ripple are provided

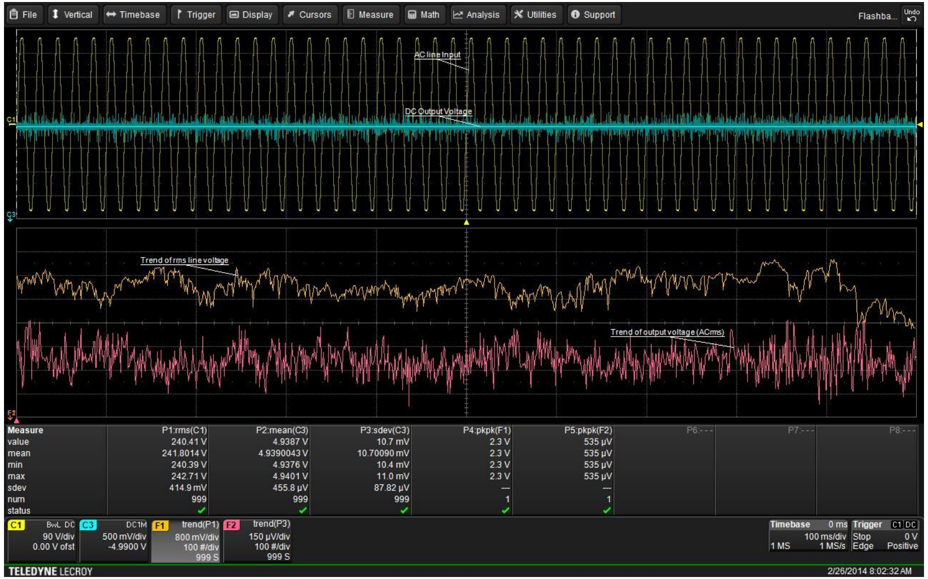
Teledyne LeCroy Oscilloscope HDO4000 With Power Analyzer Software





Performance Analysis : Power Line monitoring

- The Digital oscilloscope HDO4000 can be used for monitoring long term processes such as power supply input and output voltages.
- The **Trend function** is a waveform composed of a series of parameter measurement values presented in the order they were taken.



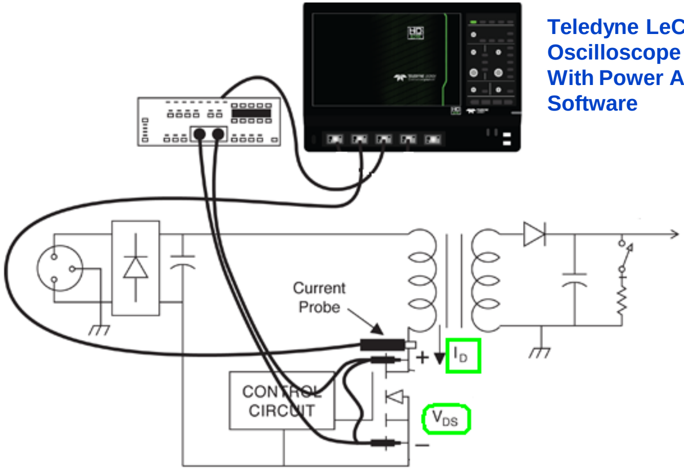
AC input Voltage (Yellow trace) and DC output (Blue trace) are acquired and the trend functions are used to monitor their variations during a long acquisition, 17 min.

The parameters measure these variations

The Trend function is an ideal data logging tool, for applications like this, taking place over seconds, minutes, hours, or days.

Device Measurement – Power Losses

Power-supply efficiency is a measure of how much energy is wasted between the unit's input and output. **Turn-on, turn-off, and conduction losses** within the supply are converted into heat, which can compromise the health and longevity of the power supply itself as well as that of the system it powers. Thus, regardless of a power supply's efficiency, it's important to know how much energy is being lost in the transition as the output transistor turns on and off, as well as how much is lost in conduction.



Teledyne LeCroy Oscilloscope HDO4000 With Power Analyzer Software

Device Measurement – Power Losses

- Areas of power loss are automatically detected, measured and annotated across many cycles
- Color coded overlay highlights all areas of power losses on both power and voltage traces
- Measurements are automatically calculated and displayed with proper power terminology
- No manual gating of switching losses required

Device	TurnOn	Conduction	TurnOff	OffState	AllZones	SwitchFreq
value	4.8213 µJ	1.2035 µJ	8.0182 µJ	23.8 nJ	14.1575 µJ	140.022 kHz
mean	4.88683 µJ	1.15436 µJ	8.011493 µJ	16.677 nJ	14.07420 µJ	139.92983 kHz
min	4.8213 µJ	1.0592 µJ	8.0081 µJ	9.6 nJ	13.9909 µJ	139.838 kHz
max	4.9252 µJ	1.2035 µJ	8.0182 µJ	23.8 nJ	14.1575 µJ	140.022 kHz
sdev	46.56 nJ	67.30 nJ	4.758 nJ	7.102 nJ	83.26 nJ	92.06 Hz
num	3	3	3	2	2	2
status	✓	✓	✓	✓	✓	✓

Improving Reliability by Monitoring Device Stress Limits.
Safe Operating Area (SOA)

- Every switching device has a maximum voltage, current and power specified by the device manufacturer, displayed on its technical application note. Reliability of the power supply is dependent on not exceeding these limits.
- Safe Operating Area (SOA) plot help to determine if the device exceeds its maximum voltage, current, or power ratings.
- Easily display SOA for comparison to component specs
- Power loss annotator identifies losses on all cycles in long captures
- Loss measurements calculated across all cycles with statistics

Improving Rds(on) Measurements accuracy

This is the measurement of the conduction resistance of the switching FET or IGBT.
The overall calculation accuracy depends on accurate current and voltage measurements, and therefore fine granularity in the oscilloscope vertical resolution.

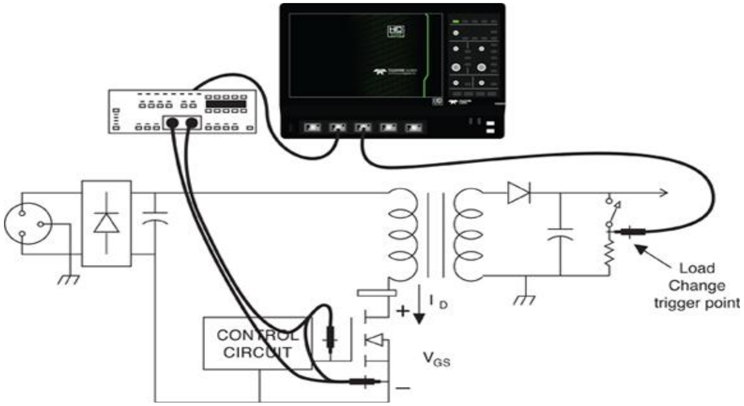
Benefits of 12 bit Oscilloscope vs 8 bit Oscilloscope
The enhanced resolution is relatively straight forward, an 8 bit A/D converter has 2^8 discrete levels, therefore 256 levels, whereas a 12 bit A/D converter has 2^12 discrete levels, therefore 4096 levels. Quite a difference!

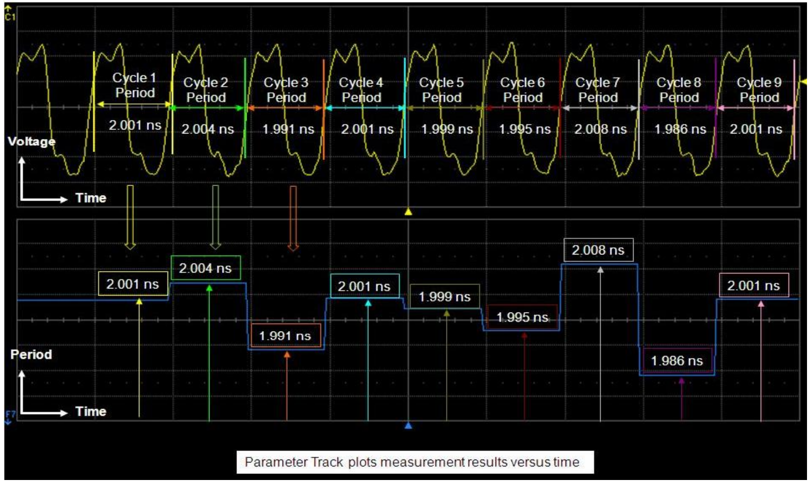
12 bit Oscilloscope

8 bit Oscilloscope

Control Loop Analysis – Feedback Loop Response

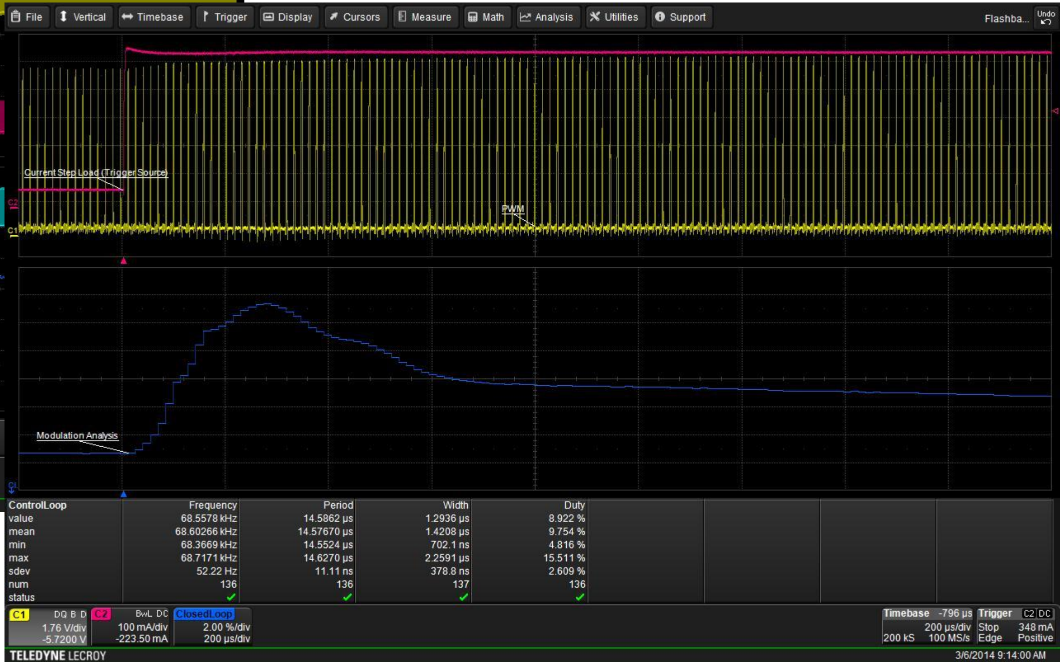
- Every power supply has a feedback loop that monitors the output voltage or current and keeps the device's on-time appropriate to the load.
- Output regulation is achieved by modulating the amount of energy transferred in each cycle. The most common method is Pulse Width Modulation (PWM) but other methods, such as frequency modulation, are also used.
- Modulation analysis can be used to characterize power supply stability under load changes, line changes, soft-starts, dropouts and short circuits.
- We can see on a cycle-by-cycle basis, the behaviour of the entire control loop by demodulating the PWM signal and extracting the underlying modulation signal in order to assess the correct tracking and linearity in PWM regulator/controller.





Control Loop Analysis – Feedback Loop Response

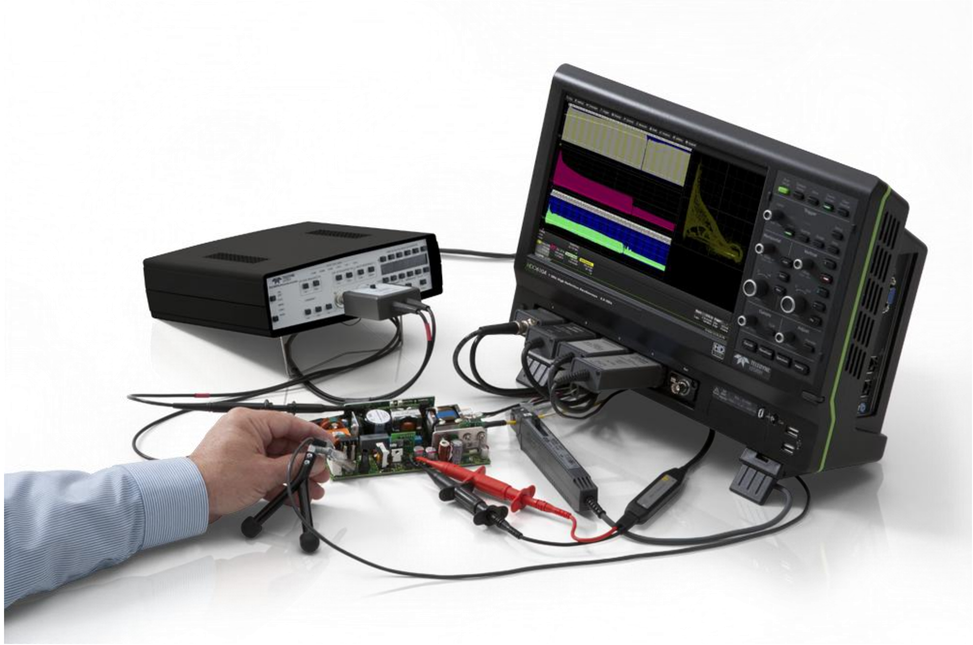
Measuring the start-up in a switched mode power supply



Measuring the step load response in a switched mode power supply

Teledyne LeCroy Power Measurements Product Portfolio

- HDO4000 and HDO6000
  - 12 Bit Oscilloscopes
    - 4 Analogue measurement channels
    - Optional 16 digital channels
  - High Voltage Differential Probes
  - High voltage / fast recovery differential clipping amplifiers
  - Current Probes
  - Probe Deskew Fixtures
  - Power Analysis software option
  - Ideal system for single phase analysis
  - Optional Serial Bus Deciders



Teledyne LeCroy Power Measurements Product Portfolio

- HDO8000
  - 12 Bit Oscilloscopes
    - 8 Analogue measurement channels
    - Optional 16 digital channels
  - High Voltage Differential Probes
  - High voltage / fast recovery differential clipping amplifiers
  - Current Probes
  - Probe Deskew Fixtures
  - Power Analysis software option (single phase)
  - Ideal system for single or three phase system analysis
  - Optional Serial Bus Deciders

Thank you for you attention and any Questions?

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Power Primer

What is Power?

- In physics, **power** is the rate at which energy is transferred, used, or transformed. Measurement unit is Joule per Second(J/s) or Watt.

- **Electric power** is the rate at which electric energy is transferred by an electric circuit. Measurement unit is Joule per Second(J/s) or Watt.

- Mathematically, Electric power is defined as:

$$\text{Power (P)} = \text{Voltage(V)} \times \text{Current(I)}$$

What is Power?

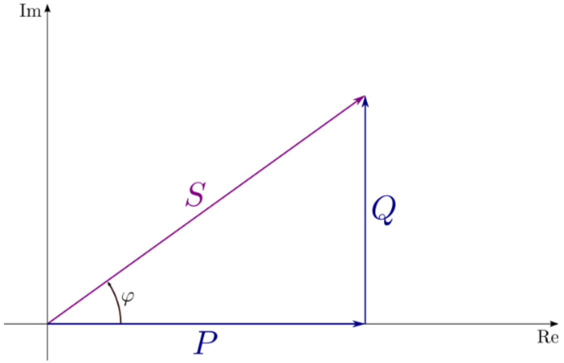
- AC Power
  - Real Power: In a simple alternating current (AC) circuit consisting of a source and a linear load, both the current and voltage are sinusoidal. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive, indicating that the direction of energy flow does not reverse. In this case, only real power is transferred. Generally denoted by P and the unit is Watt(W).
  - Reactive Power: If the loads are purely reactive, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. There is no net energy flow over one cycle. In this case, only reactive energy flows. Since there is no net transfer of energy to the load, reactive power is sometimes also called "Wattless Power". Generally denoted by Q and the unit is Volt-Ampere reactive(VAR).
  - Apparent Power: Practical loads have resistance, inductance, and capacitance, so both real and reactive power will flow to real loads. Power engineers measure apparent power as the magnitude of the vector sum of real and reactive power. Apparent power is the product of the root-mean-square of voltage and current. Generally denoted by S and the unit is Volt-Ampere(VA).
  - Average Power: The average power is given by the following mathematical formula:

$$P(avg) = VI \cos \phi$$

Where: V and I are the rms voltage and current respectively and $\cos \phi$ is the Power Factor.

What is Power?

- Complex Power:The complex power is the vector sum of real and reactive power. The apparent power is the magnitude of the complex power. Reactive power (Q) does not do any work, so it is represented as the imaginary axis of the vector diagram. Real power (P) does do work, so it is the real axis. S is the complex power and the length of S is the apparent power.



Where:

Real power (P)
Reactive power (Q)
Complex power (S)
Apparent Power (|S|)
Phase of Current (φ)

S = P + jQ

What is Power?

- Power Factor: The **power factor** of an AC electrical power system is defined as the ratio of the real power flowing to the load, to the apparent power in the circuit, and is a dimension-less number between -1 and 1.

Power Factor=

$$\frac{P}{S}$$

In the case of a perfectly sinusoidal waveform, P, Q and S can be expressed as vectors that form a vector triangle such that:

If ϕ is the phase angle between the current and voltage, then the power factor is equal to the cosine of the angle, $|\cos\varphi|$, and:

$$S^2 = P^2 + Q^2$$

$$|P| = |S|\,|\cos\varphi|$$

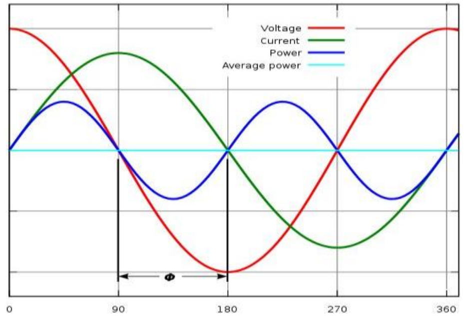
What is Power?

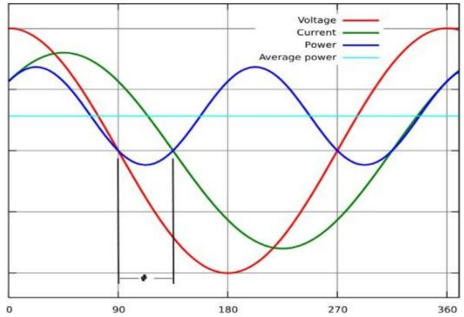
- ## Leading or Lagging:

When power factor is equal to 0, the energy flow is entirely reactive, and stored energy in the load returns to the source on each cycle. When the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle. Capacitive loads are leading (current leads voltage), and inductive loads are lagging (current lags voltage).

- Top figure: Instantaneous and average power calculated from AC voltage and current with a zero power factor ($\phi = 90^\circ$, $\cos \phi = 0$). The blue line shows all the power is stored temporarily in the load during the first quarter cycle and returned to the grid during the second quarter cycle, so no real power is consumed.

- Bottom figure: Instantaneous and average power calculated from AC voltage and current with a lagging power factor ($\phi = 45^\circ$, $\cos \phi = 0.71$). The blue line shows some of the power is returned to the grid during the part of the cycle labelled φ





What is Power?

- Why is Power Factor important?

A power factor of one or "unity power factor" is the goal of any electric utility company since if the power factor is less than one, they have to supply more current to the user for a given amount of power use. In so doing, they incur more line losses. They also must have larger capacity equipment in place than would be otherwise necessary. As a result, an industrial facility will be charged a penalty if its power factor is much different from 1.

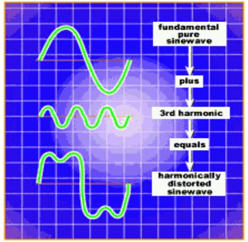
- Power Factor Correction in Linear Loads:

Conventionally, capacitors are considered to generate reactive power and inductors to consume it. If a capacitor and an inductor are placed in parallel, then the currents flowing through the inductor and the capacitor tend to cancel rather than add. This is the fundamental mechanism for controlling the power factor in electric power transmission; capacitors (or inductors) are inserted in a circuit to partially cancel reactive power consumed by the load. For example, the inductive effect of motor loads may be offset by locally connected capacitors.

- Power Factor Correction in non-Linear Loads:

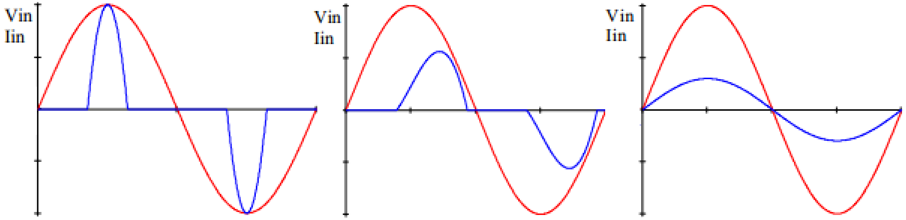
A non-linear load on a power system is typically a rectifier (such as used in a power supply). Non-linear loads create harmonic currents in addition to the original (fundamental frequency) AC current. It is actually these harmonics that cause problems with the power generation and distribution system. As the current distortion is conducted through the normal system wiring, it creates voltage distortion according to Ohm's Law. While current distortion travels only along the power path of the non-linear load, voltage distortion affects all loads connected to that particular bus or phase. Filters consisting of passive components (capacitors and inductors) or active components (transistors and ICs) can prevent harmonic currents from entering the supplying system.

A popular example of a non-linear load is Switch Mode Power Supply(SMPS).



What is Power?

- Comparison without / with harmonic line current reduction:



Typical input current without harmonic line current reduction.

Typical input current with passive harmonic line current reduction.

Typical input current with active harmonic line current reduction

What is Power?

- Advantages / disadvantages of Active and Passive PFC :
  - Passive harmonic line current reduction advantages:
    - Simple and robust circuitry
    - Less costly than active PFC (Especially in 3 phase applications)
  - Passive harmonic line current disadvantages:
    - Large and heavy low frequency magnetics needed
    - Not applicable for wide input range and high power
    - No sinusoidal input current
  - Active harmonic line current reduction advantages:
    - Extensive elimination of line current harmonics
    - Power factor near 1 (typically 0.6 uncorrected) and increased available power from the wall socket (public mains)
    - Wide input voltage range possible
  - Active harmonic line current reduction disadvantages:
    - Additional expense of circuitry
    - Increased number of parts
    - Negative impact on efficiency

Passive harmonic line current reduction (e.g. for 3 phase applications and applications up to approximately 400W) is sometimes a more economic and effective solution. Yet wide input range and meeting the EN 61000-3-2 standard under all load conditions are often not possible.

What is Power?

- ## Total Harmonic Distortion:

The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. THD is used to characterize the linearity of audio systems and the power quality of electric power systems.

In power systems, lower THD means reduction in peak currents, heating, emissions, and core loss in motors. Measurements for calculating the THD are made at the output of a device under specified conditions. The THD is usually expressed in percent as distortion factor or in dB relative to the fundamental as distortion attenuation.

When the input is a pure sine wave, the measurement is most commonly the ratio of the sum of the powers of all higher harmonic frequencies to the power at the first harmonic, or fundamental, frequency:

$$\mathrm{THD} = \frac{P_2 + P_3 + P_4 + \cdots + P_\infty}{P_1} = \frac{\sum_{i=2}^{\infty} P_i}{P_1}$$

What is Power?

- ## EN61000-3-2 Harmonics Standard:

Since 1st of January 2001, all electrical and electronic equipment that is connected to the public mains up to and including 16A max. rated input current must comply with EN 61000-3-2. Passive and active harmonic line current reduction solutions can be used to fulfill the limits of the standard which greatly influences the design of all power supplies.

EN 61000-3-2 is part of the European 'EMC-directive', which must be complied with for the purpose of CE marking as of 01/01/2001.

There are 4 different classes in the EN 61000-3-2 that have different limit values:

Class A: Balanced 3-phase equipment, household appliances excluding equipment identified as class D, tools, excluding portable tools, dimmers for incandescent lamps, audio equipment, and all other equipment, except that stated in one of the following classes.

Class B: Portable tools, arc welding equipment which is not professional equipment

Class C: Lighting equipment.

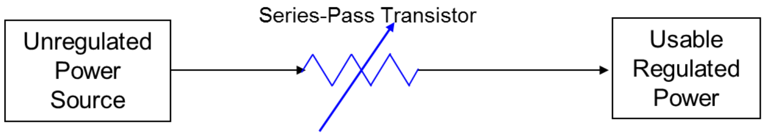
Class D: PC, PC monitors, radio, or TV receivers. Input power P <= 600 W

Why measure Power Devices?

- Assure design reliability
- Analyze fault and non-standard operation
- Determine operating efficiency
- Cost optimization
- Assure compliance to regulatory standards
  - Safety
  - Power Quality
  - Efficiency

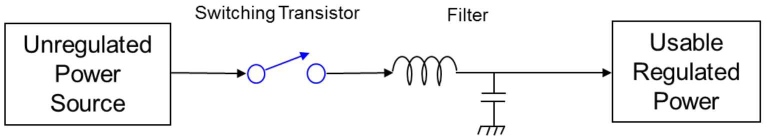
Switch Mode Power Supply(SMPS)

Linear Supply



Power is regulated with a transistor operated in its linear region - partially on.
The output of the transistor is clean DC voltage.

Switchmode Supply



Power is regulated with a transistor operated in saturation or fully off.
Varying the ratio of ON to OFF time (duty cycle) controls the average power transferred.
A passive filter integrates the pulsed waveform into clean DC voltage.

Switch Mode Power Supply(SMPS)

- Switch Mode Power Supply VS Linear Power Supply:
  - Switching Power Supply (SMPS)
    - Voltage regulation via controlled Power transfer
    - High Efficency, ≥ 85 %
    - Wide Input Voltage range
    - Smaller size – Less weight
    - Easier PFC (Power Factor Control) support
    - Lower cost x watt
  - Linear Power Supply
    - Voltage regulation via power dissipation
    - Power dissipation creates Heat problems
    - Low efficency, ≤ 30 %
    - Restricted Input Voltage range

Switch Mode Power Supply(SMPS)

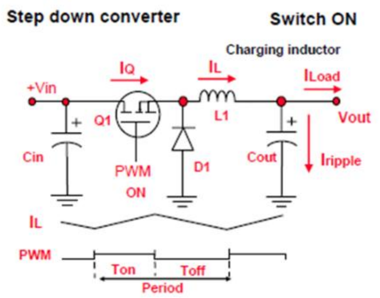
- DC-DC SMPS Topologies:

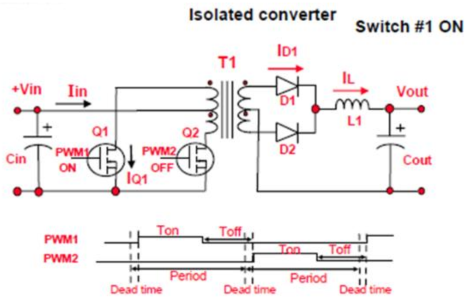
  - Buck – It's a step down converter that changes a higher input voltage to a lower input voltage

  - Boost – It's similar to a Buck but the output voltage is higher than the input voltage

  - Buck-Boost – Provides a negative output voltage relative to the input

  - Push-Pull - Trasformer based converter. Any combination of input to output voltages and polarities is achievable

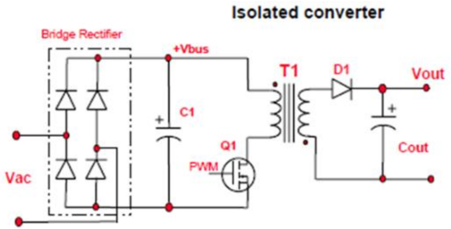




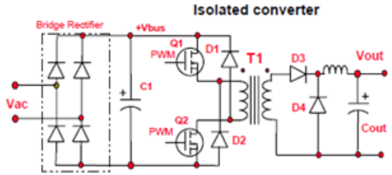
Switch Mode Power Supply(SMPS)

- AC-DC SMPS Topologies:

  - FlyBack – Use the transformer as an energy storage device as well as energy transfer device. Duty cycle < 50% for preventing unstable operation.



  - Forward Converter – The two devices are switch on and off at the same time. Very reliable design that doesn't stress the transistor with voltage spikes.



  - Push Pull - Uses two transistors that operate in an alternating fashion. Both are "ground referenced" wich makes easy driving.