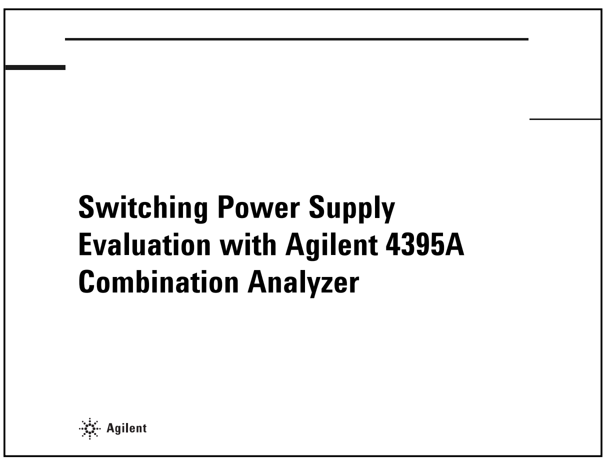
Agilent 4395A 500 MHz Network/Spectrum/Impedance Analyzer

Switching Power Supply Evaluation

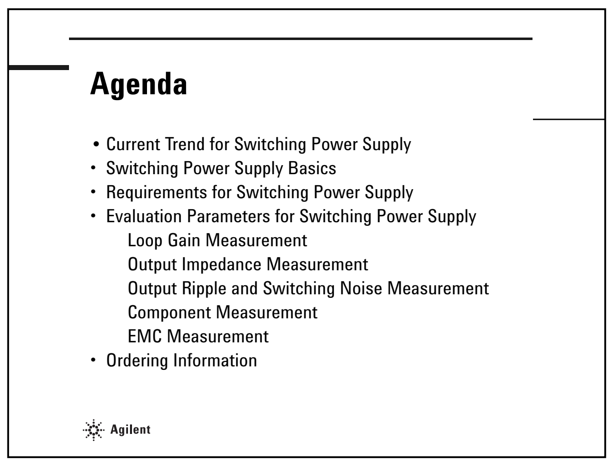
Product Note 4395-2

Slide 1



This module introduces you to how the combination analyzer, which has the network, spectrum, and impedance functions, contributes to a switching power supply evaluation, and other applications.

Slide 2



This is the agenda.

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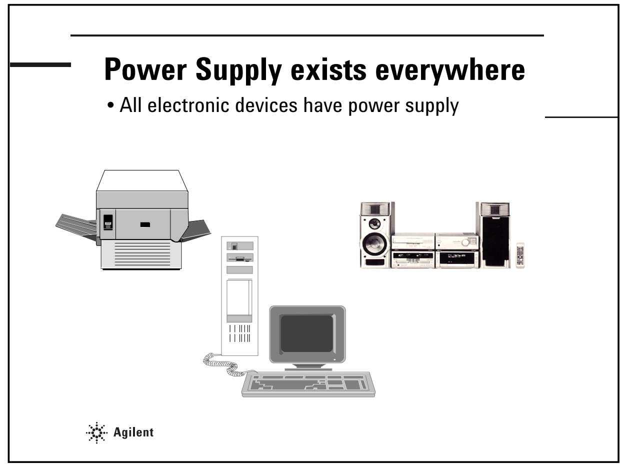
Innovating the HP Way

Slide 3

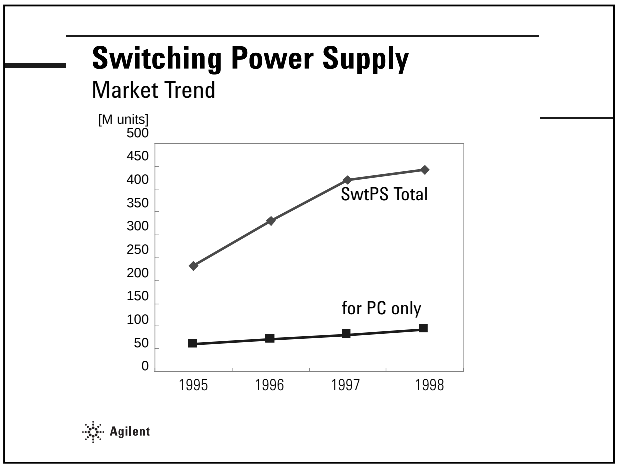
A switching power supply evaluation method with the Agilent Technologies 4395A Network/Spectrum /Impedance Analyzer.

Slide 4



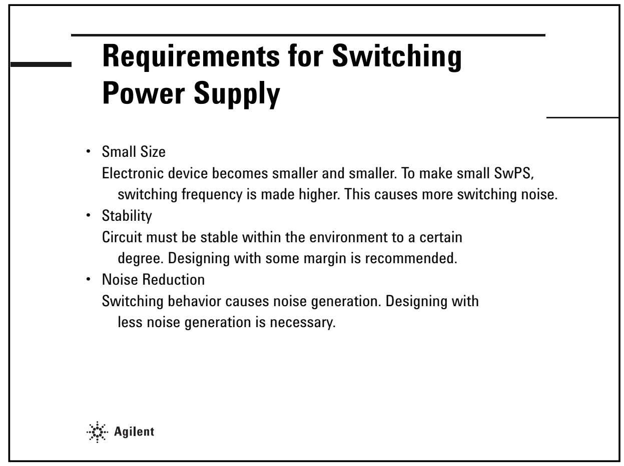
Recently, there is a strong need for electronic equipment to be small, lightweight, and have low power consumption. The power supply for such equipment must help meet the requirements described above. To satisfy these requirements, a switching power supply is often used these days. However, the switching power supply generates a noise because of its switching behavior. This means that a designer needs to consider the noise generation carefully.

Slide 5



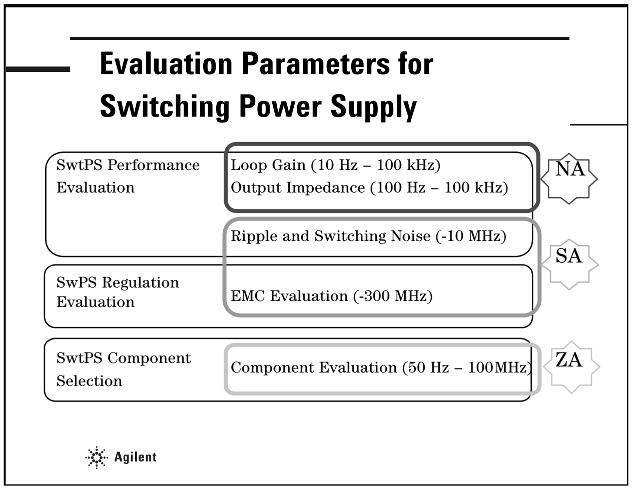
This graph shows the market trend for the switching power supply. Notice that the switching power supply market has been growing year by year. This growth rate is caused by the growth of the communication equipment and personal computers, etc.

Slide 6



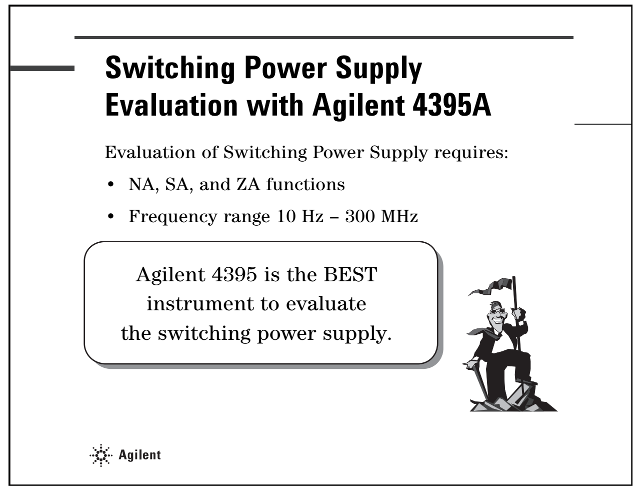
This slide shows the requirements for the switching power supply in recent years.

Slide 7



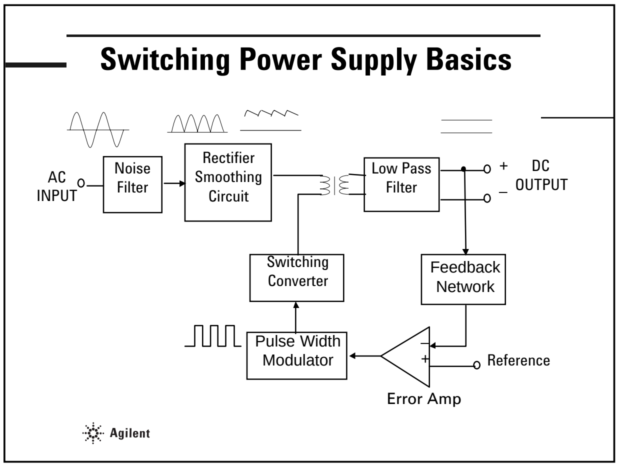
Designers evaluate the switching power supply for various reasons, such as for performance evaluation, regulation evaluation, and components selection. The summary of the evaluation parameters for switching power supply are shown in this figure. As you can see from this figure, the designers need three different analyzers; network, spectrum, and impedance analyzers with the frequency range from 10 Hz to 300 MHz.

Slide 8



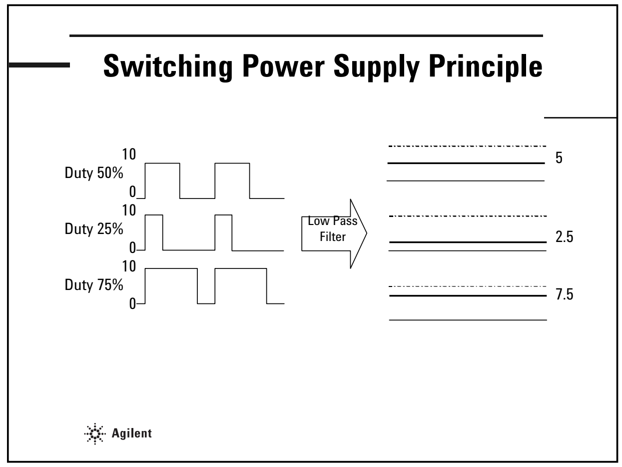
To evaluate the switching power supply requires three different analyzers (network, spectrum, and impedance analyzers), and the frequency range from the low frequency (10 Hz) to about 300 MHz. These requirements are satisfied by the Agilent 4395A combination analyzer only. Now, we can say that the 4395A is the BEST instrument to evaluate the switching power supply.

Slide 9



This figure shows a block diagram of the switching power supply. Notice that the AC input wave changes to DC output by transmitting through the noise filter, a rectifier/smoothing circuit, and a low pass filter. The feedback loop controls the output to be stable. The error amplifier is the op-amp which senses the value of the output voltage and compares it to the reference voltage. If the output voltage is too high, the inverting input of the op-amp will be more positive than the non-inverting input, and the output of the op-amp will swing negative, reducing the output of the power supply. The opposite happens if the output voltage is too low. The difference between these inputs is amplified by the error amplifier and causes the pulse width modulator to change the pulse width. The switching converter switches on/off according to the pulse width generated from the pulse width modulator.

Slide 10



This figure illustrates the switching behavior. The pulse width modulator generates the pulse where duty rate is changed according to the output of the error amplifier. The right-hand side of this figure shows the output of the pulse width generator, and the left-hand side of this figure shows the output voltage from the low pass filter. You can see that the output level of the voltage is changed by the duty rate of the pulse.

Slide 11

Evaluation Parameters for Switching Power Supply

- Loop Gain Measurement
- Output Impedance Measurement
- Output Ripple and Switching Noise Measurement
- Component Measurement
- EMC Measurement

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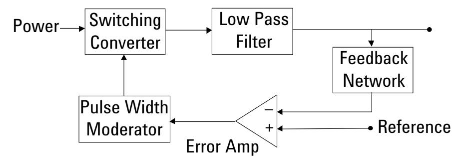
The evaluation parameters of the switching power supply will be presented from here.

Slide 12

Loop Gain Measurement



Evaluate the stability of the control system by measuring two parameters:
Phase Margin
Gain Margin

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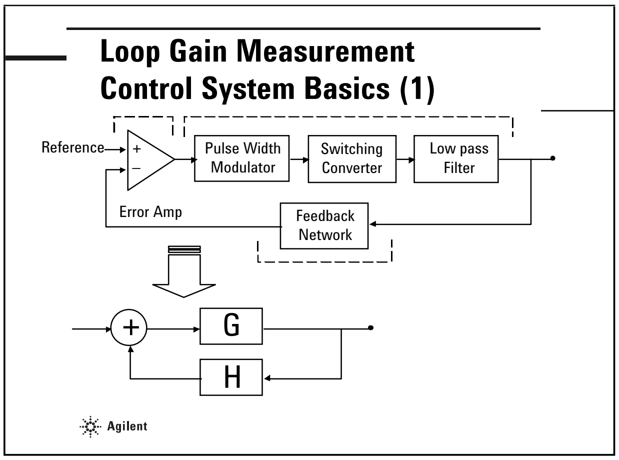
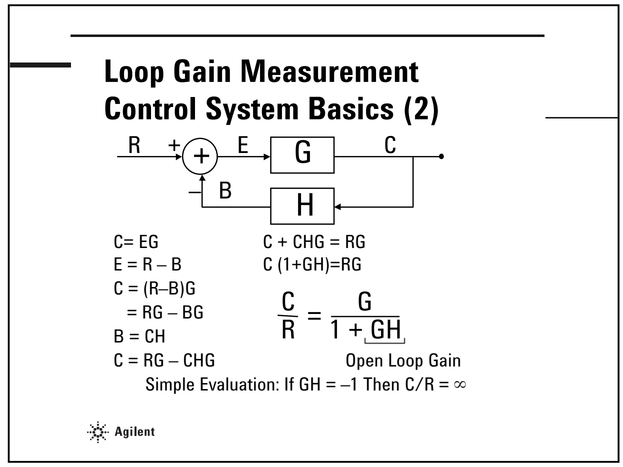
Closed-loop control systems are becoming more and more common and can be found in many of today's consumer products, as well as in very technically sophisticated products. Historically, testing control systems during the development cycle has been difficult because the desired result is the open-loop frequency response characteristic and the loop must remain closed to achieve stable operation. The open-loop characteristic, sometimes called the loop-gain characteristic, is an important measurement because it is used in defining, as well as refining, a mathematical model for the control system. It is also used to design stability compensation networks and determine stability parameters such as gain and phase margins.

Slide 13



A block diagram of the switching power supply described earlier is shown again in this figure. The position of each box has been slightly changed. This figure shows that the circuit of the switching power supply can be considered as a simple feedback control system.

Slide 14

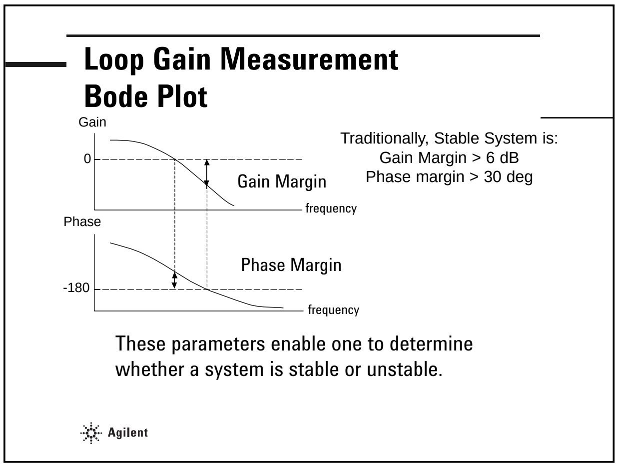


The simple feedback control system model is shown again in this figure. From this simple model we can derive the input/output relationship of a closed-loop system as C/R = G/G(1 + GH). This expression is known as the closed-loop transfer function. GH is the open-loop gain function. A simple evaluation of this equation shows that:

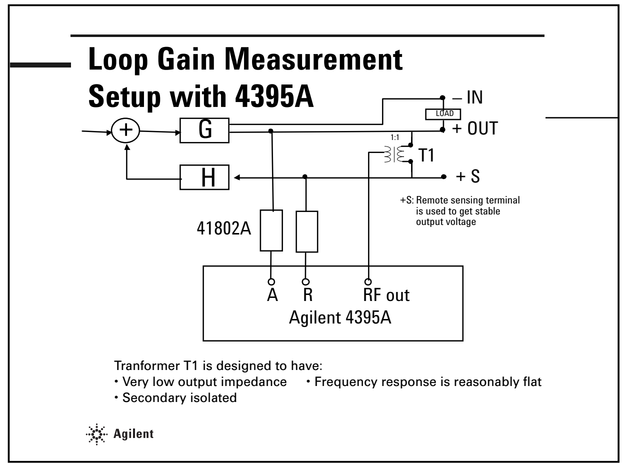
If GH = -1, then C/R = ∞

We can see that oscillations will occur if GH = -1.

Slide 15



Slide 16

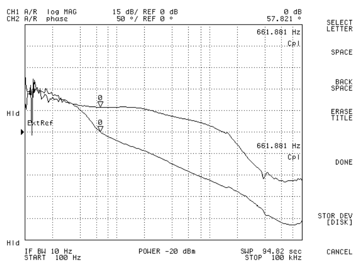


GH provides a fundamental and straightforward way to describe and understand the stability of a control system. The Bode diagram is used to enable one to determine whether a system is stable or unstable, with the concept in the form of gain and phase margin. This figure presents these two margins with the Bode diagram. The gain margin is simply the reciprocal of the gain where the open-loop frequency response function's phase is at –180°. The phase margin is equal to 180°minus the phase of the open-loop frequency response at the point where the gain is 0 dB. Traditionally, a system that has less than 30° of phase margin or less than 6 dB (a gain factor of 2.0) of gain margin is considered unacceptable.

This figure shows the detailed equipment setup with the Agilent 4395A combination analyzer. To know the gain and phase margins of the control system in closed-loop operation, the measurement has to proceed without breaking the feedback loop. The signal from the 4395A is connected between the external output (+OUT) and the remote sensing terminals (+S). Transformer T1 is designed to have very low output impedance and reasonably flat frequency response at the measuring frequency range. The Agilent 41802A is a 1 MΩ input adapter that is used to monitor the ratio A/R. The R channel is used to measure the signal injected into the input of the loop, and the A channel measures the output signal of the loop. The injected signal level must be sufficiently small (ex. -20 dB) so that no part of the control loop is taken outside its linear operating range. To carry out an accurate measurement, you need the response (thru) calibration before measuring the parameter.

Slide 17

Loop Gain Measurement
Example of Evaluation



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This figure shows an example of the loop gain measurement with the 4395A.

Slide 18

Loop Gain Measurement
Requirements for the Instrument

Requirements for Instrument

a. Covering the range from low frequency 10 Hz to 50 kHz or more
b. Narrow bandwidth
c. Small increments of frequency
d. Log sweep
e. Gain and phase format
f. Marker function—at least 4 markers (2 markers for each margin) or delta-markers
g. Small power level

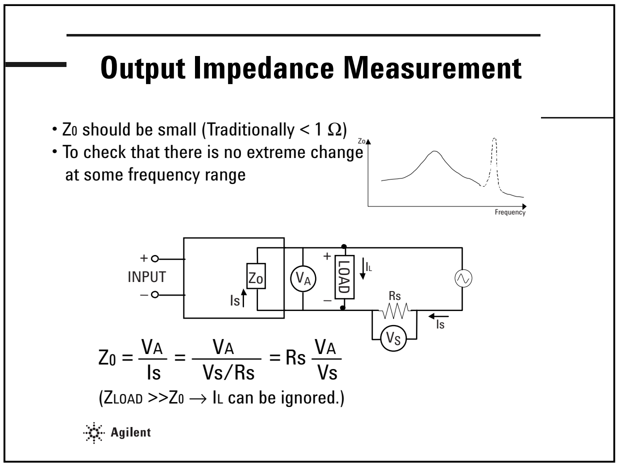
4395 (Network Analyzer)

a. Frequency range 10 Hz to 500 MHz
b. IFBW: 2 Hz to 30 kHz
c. NOP: 2 to 801 Frequency resolution: 1 mH
d. Sweep type: Log Sweep
e. Format: LogMag and Phase
f. Markers: 8 markers delta-marker function
g. Output Power Level: –60 dBm to 20 dBm

Agilent

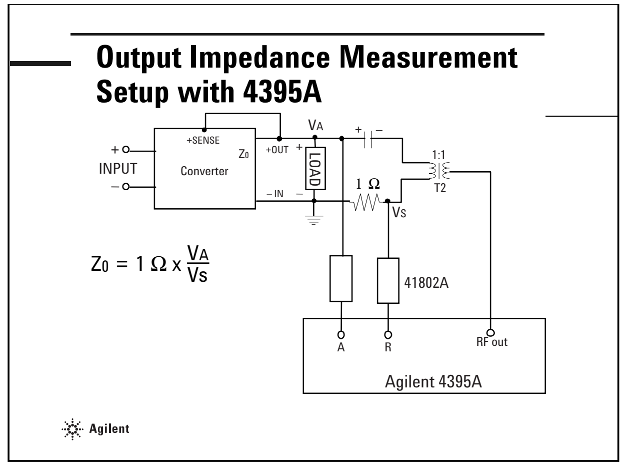
To implement the loop gain measurement, a measurement instrument with the various features described in this slide is required. Notice that the 4395A satisfies all these requirements.

Slide 19



Output impedance of a power supply is the frequency response of the output voltage to a small signal current source perturbation at the power supply output. The output impedance should be small (<1 Ω, unit:[m Ω]) to obtain good performance, and must not have an extreme change at some frequency range, as shown in this figure. This figure also shows the conceptual implementation for the measurement. As described in the figure, output impedance is derived as Z_0=Rs*Va/Vs.

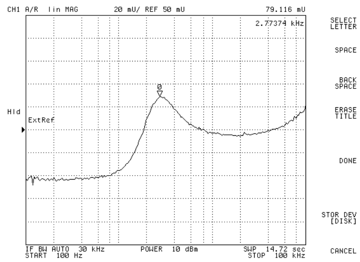
Slide 20



This figure shows the practical implementation of the output impedance measurement with Rs=1 Ω. The network analyzer measures the ratio of the output voltage perturbation to the output current perturbation. The signal from the network analyzer is transformer-coupled to the circuit, and a capacitor is used to block dc voltage from the output of the power supply. The current signal is measured with the Agilent 41802A connected across the 1 Ω register (RS). The R channel is used to measure the current signal, and the A channel is used to measure the output voltage perturbation. To carry out an accurate measurement, you need the response (thru) calibration before measuring the parameter.

Slide 21

Output Impedance Measurement
Example of Evaluation



Agilent

This figure shows an example of the output impedance measurement with the 4395A.

Slide 22

Output Impedance Measurement
Requirements for the Instrument

Requirements for instrument	4395A (Network Analyzer)
a. Covering the range from low frequency 100 Hz or less to 100 kHz or more	a. Frequency range 10 Hz to 500 MHz
b. Small increments of frequency	b. NOP: 2 to 801 Frequency resolution: 1 mH
c. Log sweep	c. Sweep type: Log Sweep
d. Marker function	d. Markers: 8 markers
e. Pass/Fail test	e. Built-in Limit Line Function for Pass/Fail test

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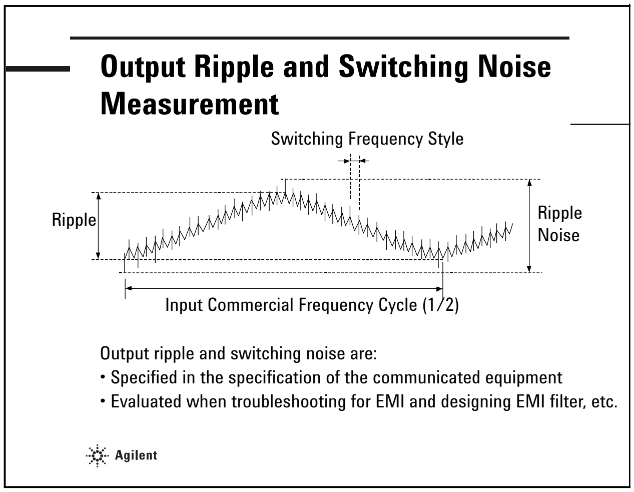
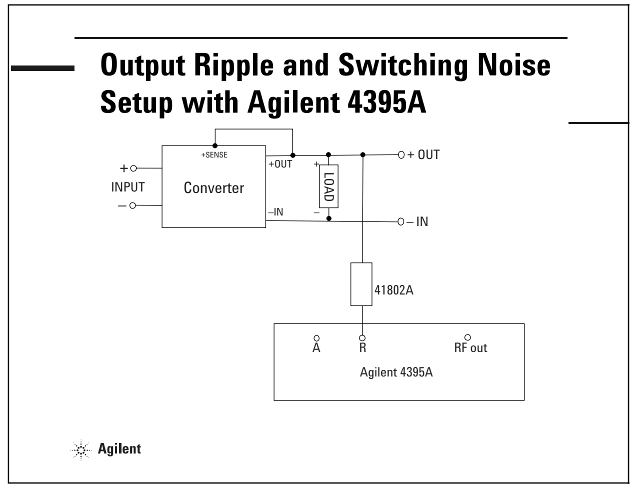
To implement the output impedance measurement, a measurement instrument with the various features described in this slide is required. Notice that the 4395A satisfies all these requirements.

Slide 23



The wave of a ripple noise is described in this figure. The ripple consists of the frequency that is twice as large as the power line frequency, the switching frequency, and other irregular ripples. They appear at the output of the switching power supply. The ripple noise is expressed in peak-to-peak volts in the specifications of the switching power supply. The spectral characteristics of power supplies used in communication equipment are frequently specified.

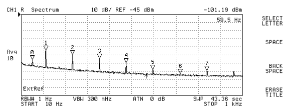
Slide 24



This figure shows the equipment setup for output ripple and switching noise measurement with the Agilent 4395A. The spectrum analyzer measures at the output terminal (+OUT) of the switching power supply with the Agilent 41802A.

Slide 25

Output Ripple and Switching Noise Evaluation Example (Lin Swp)



N	SWP PARAM	VAL
0	59.5 Hz	−101.19 dBm
1	120.138 Hz	−89.555 dBm
2	240.175 Hz	−95.279 dBm
3	360.213 Hz	−99.661 dBm
4	480.25 Hz	−105.16 dBm
5	600.288 Hz	−113.23 dBm
6	720.325 Hz	−118.42 dBm
7	840.363 Hz	−114.42 dBm

Commercial Frequency and
harmonics twice as great as its frequency

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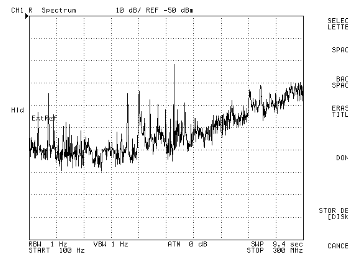
This is an evaluation example of the output ripple and switching noise measurement with linear sweep. You can see the spectrum generated from the power line frequency (60 Hz in this example), with the harmonics twice as large as its frequency (120 Hz, 240 Hz,...).

Slide 26

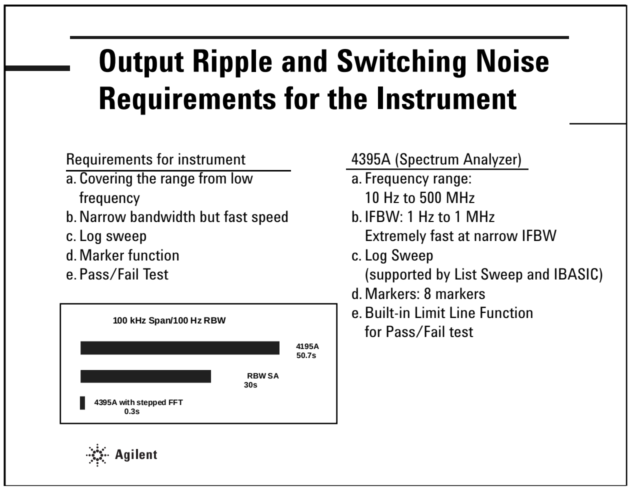
Output Ripple and Switching Noise Evaluation Example (Log Swp)



Agilent

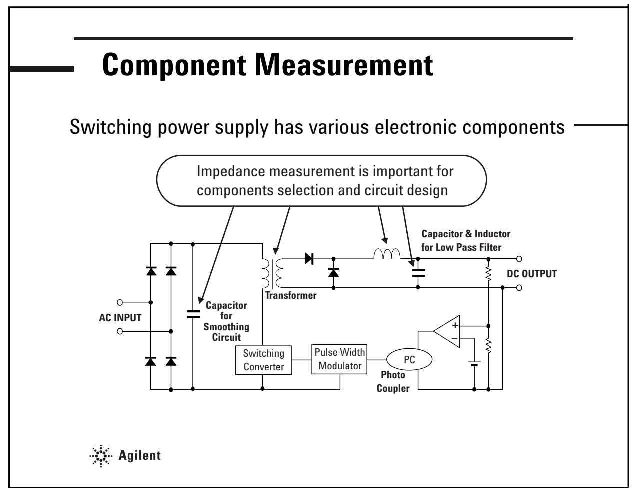
This is an evaluation example of the output ripple and switching noise measurement with log sweep. You can see a lot of spectrums generated from the switching frequency and its harmonics. The 4395A does not have the log sweep mode, but it can be executed with the list sweep mode and an IBASIC program.

Slide 27



To implement the output ripple and switching noise measurement, a measurement instrument with the various features described in this slide is required. Notice that the Agilent 4395A satisfies all these requirements.

Slide 28

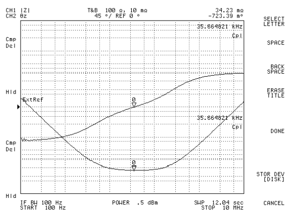


The switching power supply consists of various electronic components such as capacitors, inductors, transformer, diodes, etc. Capacitors, for example, are used in the smoothing circuit, low pass filter, noise filter, etc., and must be selected carefully. The transformer and filters must be small and lightweight at high frequencies because they are to be used for communication equipment that is small and lightweight. These are the reasons why component selection and circuit design have recently become difficult and vital. The impedance analyzer is useful for designers to know the impedance characteristics of each of their components.

Slide 29

Component Measurement Evaluation Example

Agilent 4395A can measure impedance parameters with Opt. 010.



Impedance Characteristic of Aluminum Electrolytic Capacitor

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This is an evaluation example of the impedance characteristic of an aluminum electrolytic capacitor. This example displays with the |Z| and θ formats.

Slide 30

Component Measurement

Requirements for the Instrument

Requirements for the Instrument	4395A (Opt. 010 Impedance Analyzer)
a. Wide frequency range and good accuracy	a. Frequency range 100 kHz to 500 MHz Z Accuracy: 3% (typical basic accuracy)
b. Various measurement parameters	b. Meas. Parameter |Z|, θz, R, X, |Y|, θy, G, B, Cp, Cs, Lp, Ls, Rs, D, Q, etc.
c. DC Bias	c. DC Bias ±40 V (20 mA max) (Opt. 001 DC source or External DC bias source is required)
d. Marker function	d. Markers: 8 markers
e. Equivalent Circuit Analysis	e. Eqivalent Circuit Analysis Function
f. Pass/Fail Test	f. Built-in Limit Line Function for Pass/Fail test
g. Source Level	g. Source Level: -56 dBm to +9 dBm (at DUT)

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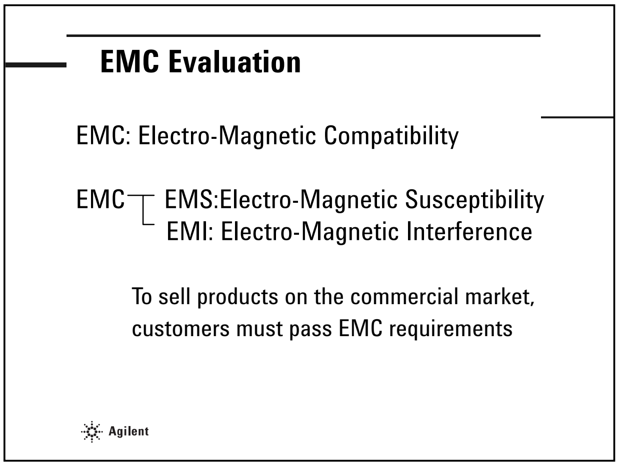
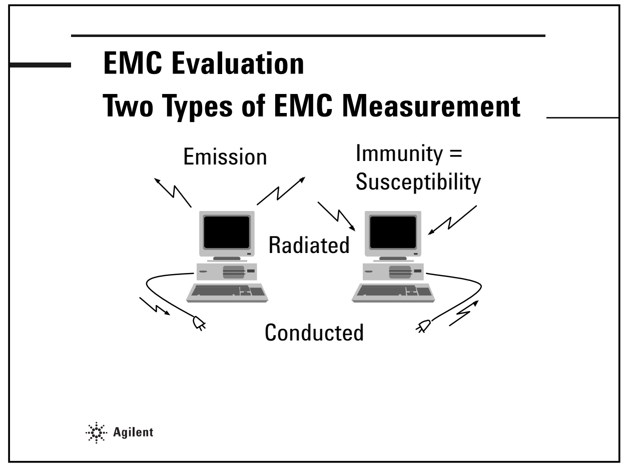
To implement the component measurement, a measurement instrument with the various features described in this slide is required. Notice that the 4395A satisfies all these requirements.

Slide 31



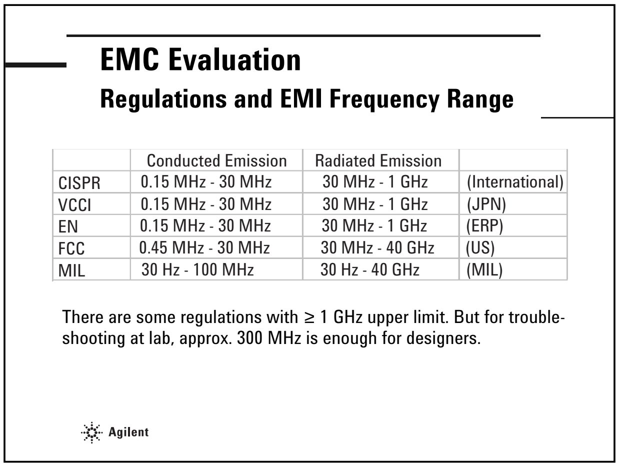
All manufacturers know that in order to sell their electronic products on the commercial market, they must meet EMC (electro-magnetic compatibility) requirements. The EMC regulation consists of two parts, (electro-magnetic susceptibility) EMS and (electro-magnetic interference)EMI.

Slide 32



This figure illustrates the relationship between radiated emissions, radiated immunity, conducted emissions, and conducted immunity. The radiated emissions testing looks for signals broadcast from the EUT (equipment under test) through space. The radiated immunity is the ability of a device or product to withstand radiated electromagnetic fields. The conducted emissions testing focuses on signals, present on the AC mains, that are generated by the EUT. The conducted immunity is the ability of a device or product to withstand electrical disturbances on power or data lines.

Slide 33



EMC Evaluation

Regulations and EMI Frequency Range

	Conducted Emission	Radiated Emission	
CISPR	0.15 MHz - 30 MHz	30 MHz - 1 GHz	(International)
VCCI	0.15 MHz - 30 MHz	30 MHz - 1 GHz	(JPN)
EN	0.15 MHz - 30 MHz	30 MHz - 1 GHz	(ERP)
FCC	0.45 MHz - 30 MHz	30 MHz - 40 GHz	(US)
MIL	30 Hz - 100 MHz	30 Hz - 40 GHz	(MIL)

There are some regulations with ≥ 1 GHz upper limit. But for trouble-shooting at lab, approx. 300 MHz is enough for designers.

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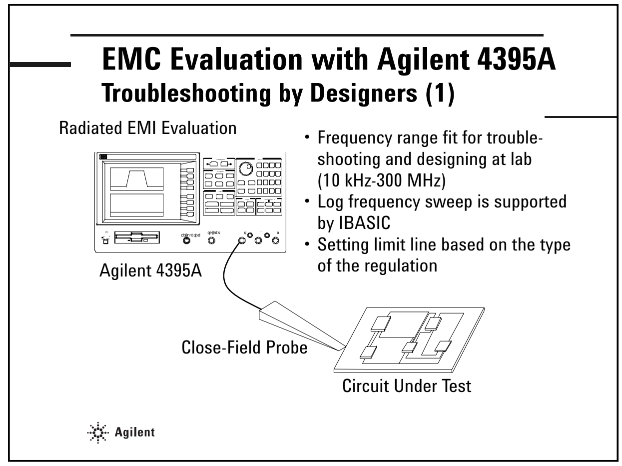
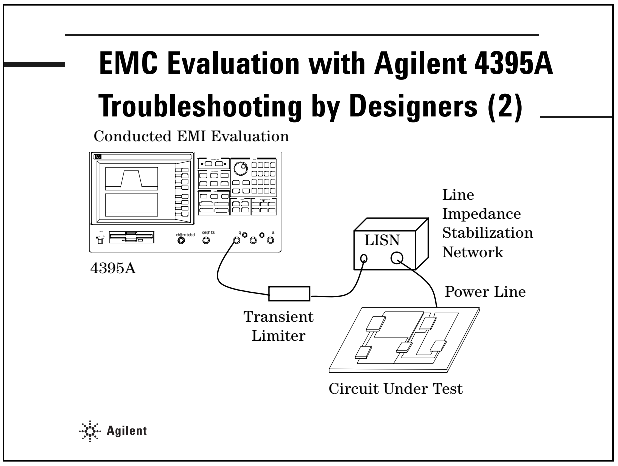
One of the most important standard setting organizations for commercial EMC standards is CISPR. It is an international group with members from many different countries that develops recommended EMC test limits and test procedures. The CISPR has no regulatory authority of its own. It is up to the regulatory agencies of each country to adopt their own EMC requirements. Most countries, however, use the CISPR standards, with some modifications, as the basis for their own national regulations, such as Voluntary Control Council for Interference by ITE (VCCI), Federal Communications Commission (FCC), and European Norms (ENs). For example, a product must pass the applicable FCC EMI requirements to be legally sold in the United States. To achieve this certification, EMI test data must be submitted to the FCC. The manufacturers must place an identification label on their product and a notice in the operating manual stating that the product meets the FCC requirements. Notice that the radiated emission at higher frequency is over 1 GHz. But for troubleshooting at R&D or in the laboratory, designers require up to about 300 MHz.

Slide 34



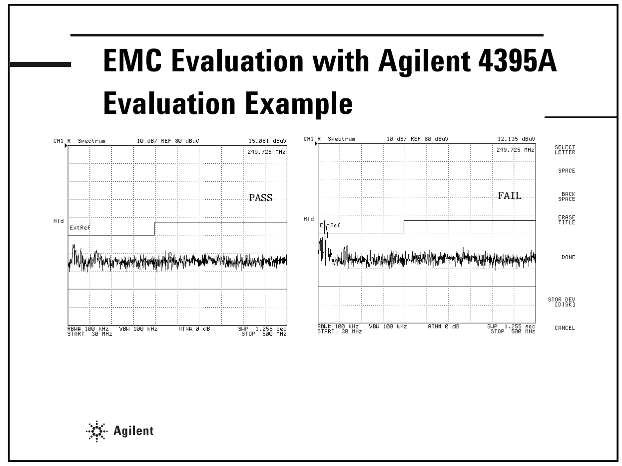
Full EMC evaluation requires a special facility and test site. And in all cases, it is located far from the place where the designers are developing their products. This means that the designers cannot do very many EMC evaluations at the site during the development cycle. But waiting until the end of the development cycle to find out whether or not a product passes regulatory agency requirements can be a gamble in cost and time. The best option for designers is to be able to perform an EMC test during the product development cycle at any time they want to. This figure shows an example of the radiated EMI evaluation setup for designers at a laboratory. A close-field probe is connected with the 4395A. Sometimes an amplifier is connected between the 4395A and the close-field probe to make radiated emission measurements more sensitive. As described in the previous slide, the frequency range in EMC testing is up to about 300 MHz. The 4395A is useful to evaluate EMC with the limit line function and log sweep (implemented by list sweep feature and IBASIC program).

Slide 35



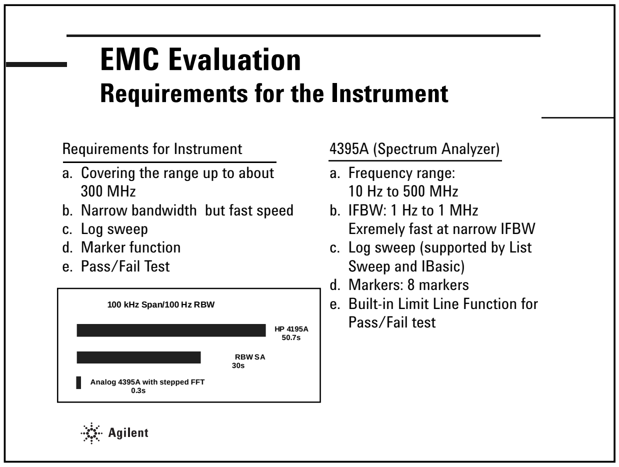
This figure shows an example of the conducted EMI evaluation setup for designers at a laboratory. A line impedance stabilization network (LISN) and transient limiter are connected with the Agilent 4395A. The transient limiter protects the spectrum analyzer input from damage caused by high-level transients from the LISN during EMI testing for conducted emissions.

Slide 36



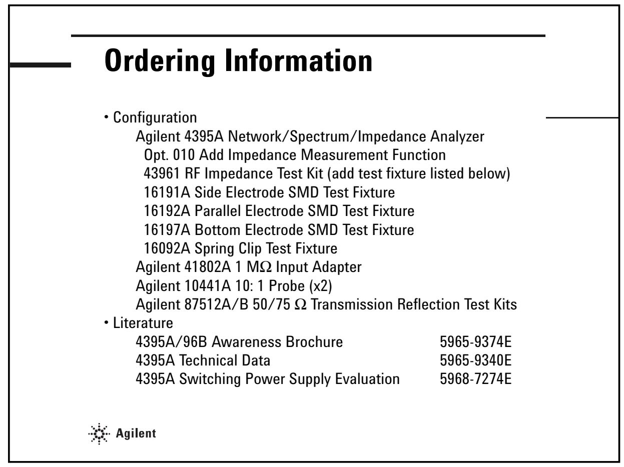
This figure shows an example of the EMC evaluation with the limit line function of the 4395A.

Slide 37



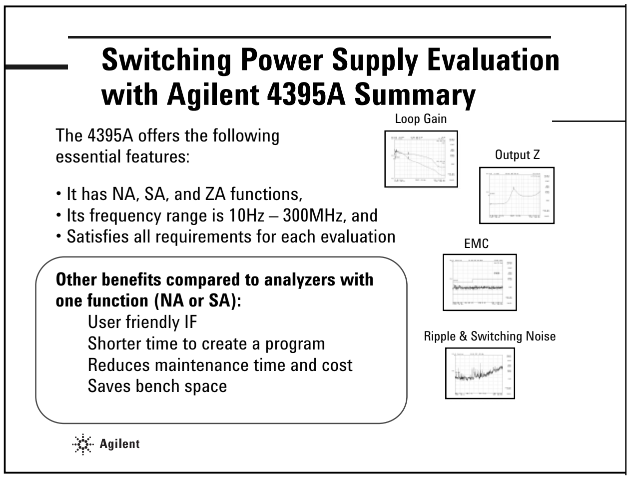
To implement EMC evaluations, a measurement instrument with the various features as described in this slide is required.

Slide 38



This slide shows the configuration list for switching power supply evaluation and the available literature for the 4395A combination analyzer.

Slide 39



The 4395A satisfies all requirements for every evaluation and also has more benefits for designers compared with analyzers that have only one function (NA or SA). We can offer that the Agilent 4395A is the best instrument for evaluating the switching power supply.

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