EMC Compliance Testing

TI Precision Labs – ADCs

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TEXAS INSTRUMENTS

Hello, and welcome to the TI Precision Lab video introducing electromagnetic compliance standard test methods. The details of these measurement setups and methods are covered in IEC 61000-4-x, CISPR 11 test standards. This document is meant to provide a short, simple overview of the common tests. Typical EMC testing includes conducted and radiated immunity and emissions as well as a number of electrical overstress type tests. This series on PCB design for good EMC has mainly focused on the concept of RF emissions and immunity, but there is a different precision labs video series focusing on electrical overstress. Nevertheless, optimizing a PCB layout to minimize RF emissions issues will also generally benefit electrical overstress protection. This document will cover a small subset of the possible standards as an introduction to the subject. There are many different standards, and your requirements may vary depending on your local regulations and product requirements. Let's start with a short overview of all the tests we will discuss.

Standards covered in this discussion

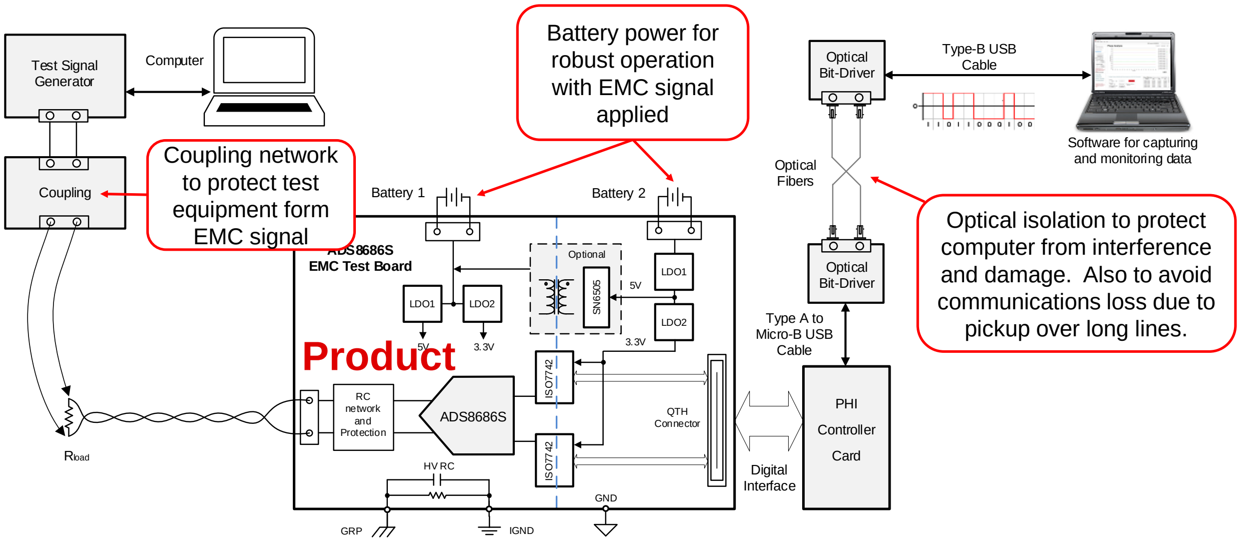
- IEC 61000-4-3: Radiated Immunity (RI)
- CISPR 11: Radiated Emissions (RE)
- IEC 61000-4-6: Conducted Immunity (CI)
- IEC 61000-4-4: Electrical Fast Transients (EFT)
- IEC 61000-4-5: Surge Immunity (SI)
- IEC 61000-4-2: Electrostatic Discharge (ESD)

Overstress training series:
https://training.ti.com/eos-and-esd-adc

Example EMC Compliance Testing for Precision ADC Systems:
http://www.ti.com/lit/pdf/sbac230

Here is a list of the different test standards that this video will cover. The first three standards relate to the radiated and conducted susceptibility and emissions the equipment under test (abbreviated EUT). The next three standards relate to electrical overstress type testing. Good PCB layout techniques will help to improve results for all the different test standards, but the overstress may require additional components that protect sensitive devices from damage. For example, TVS diodes, PTC fuses, gas discharge tubes, Schottky diodes, and RC circuits are all commonly used in protection circuits. The overstress training series covers these topics in detail.

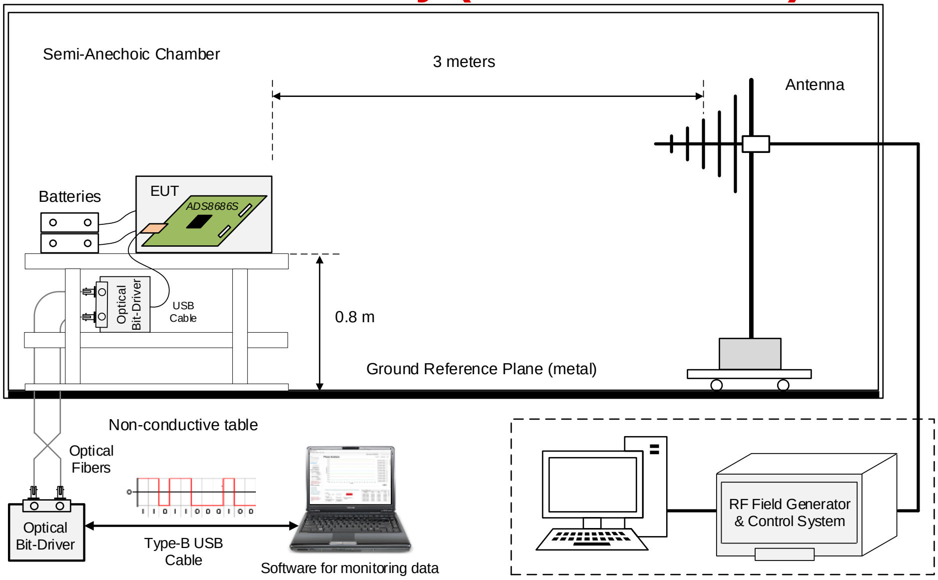
General EMC Hardware Setup



This shows an example hardware setup that Texas Instruments used to look at the ADS8686S device and associated circuitry. In general, EMC testing is done on a finished product PCB to assure robustness to overstress and RF interference signals. EMC testing also verifies that the product does not emit excessive RF so that it interferes with other products. The IEC 61000-4-x, CISPR 11 test standards quantify the system compliance and many products will need to confirm to these standards for release to market. When doing these tests, one objective is the make sure that support test equipment is not impacted by the test. For this reason digital communications may be optically isolated, and batteries are used in place of and AC-to-

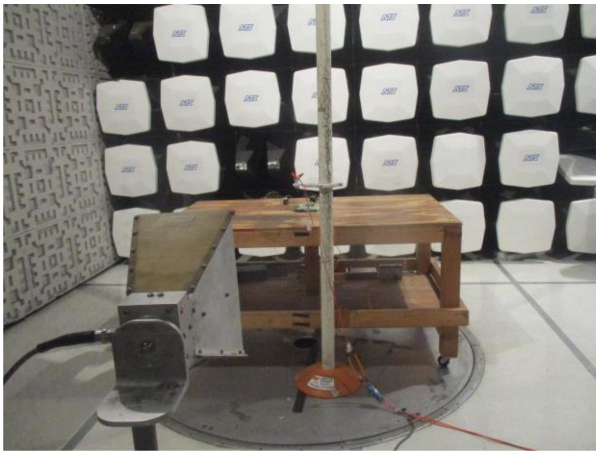
DC supply. Furthermore, test equipment may have some kind of filtering or decoupling to prevent the interference signal from impacting the equipment. In this example, the product itself is fully isolated from the digital controller.

Radiated Immunity (IEC 61000-4-3)

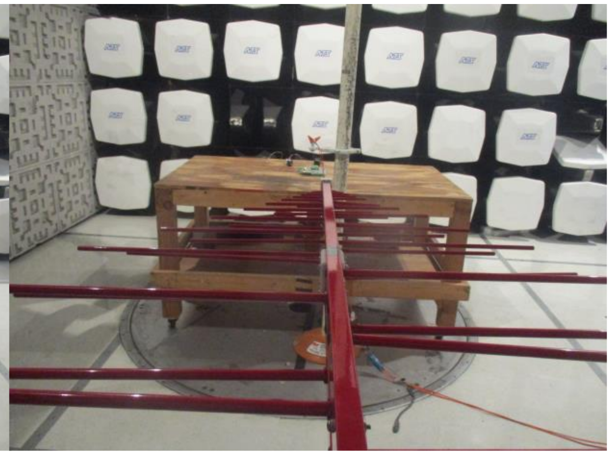


The IEC 61000-4-3 standard specifies the details of the radiated immunity test. The purpose of this test is to verify the immunity of the Equipment Under Test (abbreviated EUT) to electromagnetic radiation that is generated by radio transmitters, cellular phones, and other industrial electromagnetic sources. The test is performed in an anechoic chamber and the EUT is placed on a non-conductive table at 0.8-m height. The test distance between the EUT and the antenna is 3 m. The EUT is exposed and tested in an electromagnetic field with horizontal and vertical polarity at each rating. The RF test signal is swept from 80 MHz to 1 GHz with a Yagi antenna, and from 1 GHz to 2.7 GHz with a horn type antenna. The disturbance signal is 80% amplitude modulated with a 1-kHz sinusoidal signal. The field strength is 10 V/m and 18 V/m for each frequency range. The interference signal is created with an RF generator and control system which is situated outside the anechoic chamber. Typically, digital communications with the EUT are connected to the host PC using fully isolated optical fiber cables. Furthermore, battery power is used as opposed to an AC powered lab supply to avoid interference and potential disruption of the power source.

Radiated Immunity (IEC 61000-4-3)



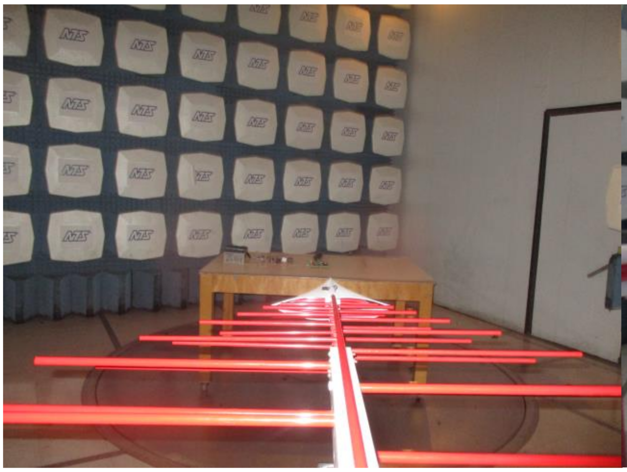
RF Immunity Test: 1 - 2.7GHz



RF Immunity Test: 80 – 1000MHz

For radiated immunity, depending on the frequency range, a different type of antenna is used. A horn style antenna is used for the frequencies above 1GHz and a Yagi antenna is used for testing frequencies below 1GHz. During the immunity test, the table will rotate so that the EUT is exposed to the RF interference at multiple angles. Also, the antenna orientation will be shifted by 90 degrees to change the polarization of the RF signal. All the tests are done in an anechoic chamber. An anechoic chamber is a specially designed room to eliminate electromagnetic reflections. It does this by covering the interior surfaces with cone shaped radiation absorbent material.

Rotation of the antenna Polarization



Antenna Polarization: Horizontal

Antenna Polarization: Vertical

This slide illustrates the rotation of the antenna by 90 degrees to change the electromagnetic polarization.

Radiated Immunity Test Limits and Conditions (IEC 61000-4-3)

Test Level	Field Strength V/m
1	1
2	3
3	10
4	30

Criteria	Description
A	Normal performance within specified limits
B	Temporary performance loss which can recover after disturbance ends
C	Temporary function or performance loss which can recover with user's intervention
D	Permanent function or performance loss due to damage or loss of data

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The test results for radiated immunity relate to how the EUT performance is impacted by the RF interference. The best case scenario is that under all levels and all frequencies of interference, the performance of the EUT is unaffected. The worst case scenario is that the EUT is permanently damaged by the applied interference. The "Test Criteria" listed assigns a letter grade to a range of different test outcomes. Passing criteria "A" indicates that the EUT had "Normal performance within specified limits". The limits in this case are set by the EUTs manufacture according to what they believe is an acceptable deviation in the products operation from their customer's perspective. Criteria "B" allows for a temporary loss of performance, but after the interference is removed the device resumes normal operation. For criteria “C”, the EUT functionality is lost with out resetting the device or cycling power. Once reset, the device resumes normal operation. And finally, for criteria D the EUT is permanently damaged by the applied interference. These same Criterion are can be applied to many of the IEC and CISPR test standards.

The “Test Level” for IEC 61000-4-3 defines the field strength of the applied interference signal. Test level 1 is the weakest applied field strength at only 1V/m and level 4 is the strongest applied field strength at 30V/m. In some cases a non-standard test level is applied according to customer requirements or test equipment capability.

Radiated Immunity Test Results (IEC 61000-4-3)

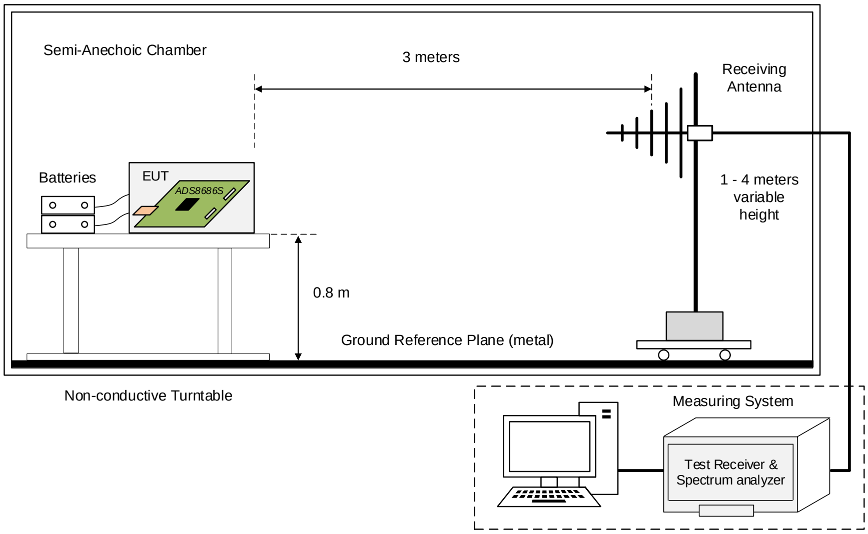
Table 3-5. Radiated Immunity Test Result

Test	IEC Standard	Test Signal			Test Level	Criterion	Test Result
		Field Strength	Frequency	Antenna Polarization			
Radiated Immunity (RI)	IEC 61000-4-3	10 V/m	80–1000 MHz	Horizontal	3	A	Pass
				Vertical		A	Pass
			1–2.7 GHz	Horizontal		A	Pass
				Vertical		A	Pass
		18 V/m	80–1000 MHz	Horizontal	> 3	A	Pass
				Vertical		A	Pass
			1–2.7 GHz	Horizontal		A	Pass
				Vertical		A	Pass

Link to EMC Compliance Test Example for ADC Systems
http://www.ti.com/lit/pdf/SBAA548

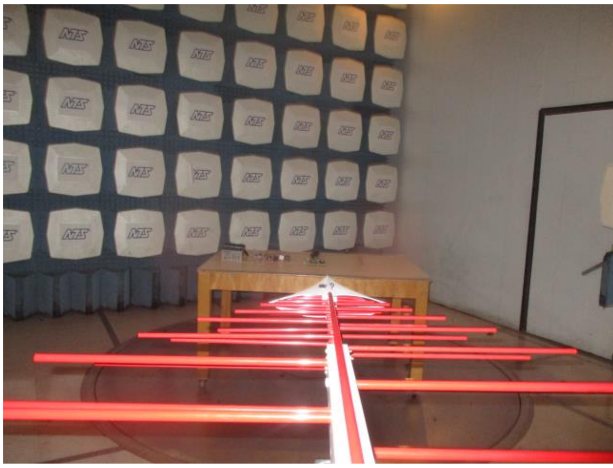
This shows example test results where the EUT was an Analog to Digital System. A link to the full document with all the different EMC tests is give a the bottom of the page. Notice that two different field strengths of 10 V/m and 18V/m were used for the testing. 10V/m corresponds to the IEC test level 3, but 18V/m does not have a corresponding defined IEC test level, so it is just listed as greater than 3. For all the immunity tests here, the device passed criterion A. This means that the EUT continued to operate under the presence of the interference signal within some predetermined limits. Technically, this means that the device may show some impact from the RF interference, but the impact was minimal and inside limits set by the EUT manufacturer. Also, the test was done over a range of frequencies and with different antenna polarization.

Radiated Emissions (CISPR 11)



The CISPR 11 test standard defines the maximum allowed radiated emissions for different types of equipment. The test setup looks very similar to the Radiated Immunity setup, but the antenna receives RF signals radiated from the EUT rather than transmitting them. The RF pickup from the antenna is then measured by a spectrum analyzer which is external to the anechoic chamber. As with the radiated immunity setup, the antenna will be rotated 90 degrees to measure the different polarity of the RF emissions. Furthermore, the table will be rotated to check if emissions are stronger in different physical orientations.

Radiated Emissions CISPR 11

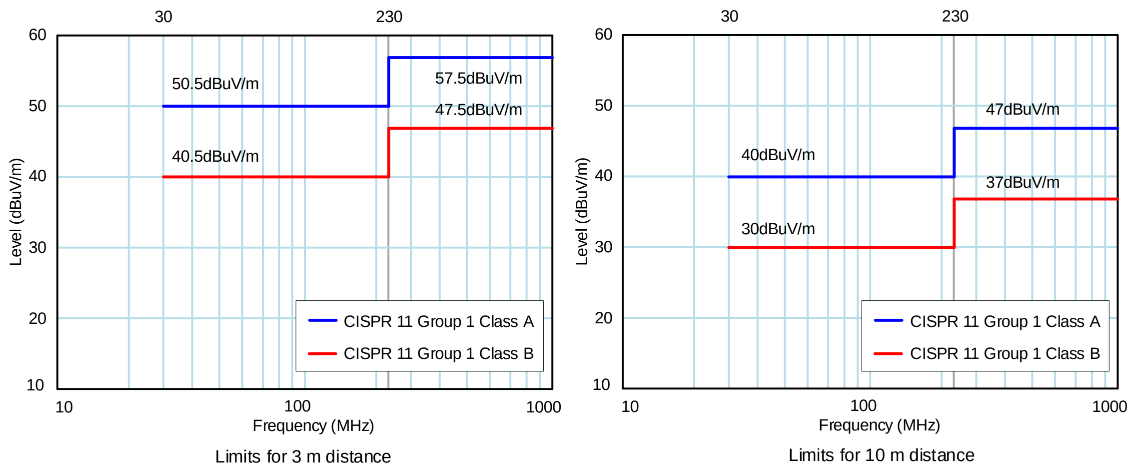


Antenna Polarization: Horizontal

Antenna Polarization: Vertical

This slide shows the test chamber used for the Radiated Emissions testing. Generally, the same chamber and antenna are used for this test as was used in the Radiated Immunity test. The difference is that the antenna is connected to a spectrum analyzer here as opposed to the signal generator that was used in the immunity test. Again, the product is placed on a non-conductive rotating table at a defined distance from the antenna.

Radiated Emissions CISPR 11



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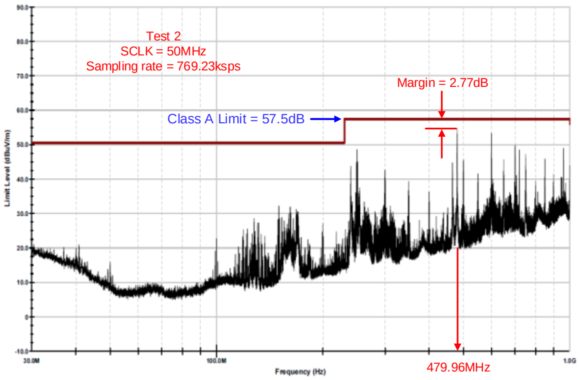
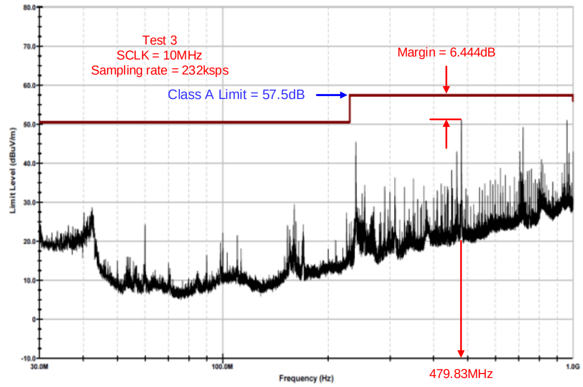
This slide shows the maximum RF Emissions limits defined by CISPR 11. Class "B" is for is used for residential buildings, and Class "A" is for all other types of uses. Residential requirements are more restrictive. The example covered in this presentation will use the Class A limits as it is a type of test equipment and is not used in residential environments. Notice that there is two set of limits depending on how close the measurement antenna is to the EUT. Also notice that the limit is less restrictive at higher frequencies. The objective of the emissions test is to make sure that all emissions stay below the specified limit.

Radiated Emissions CISPR 11

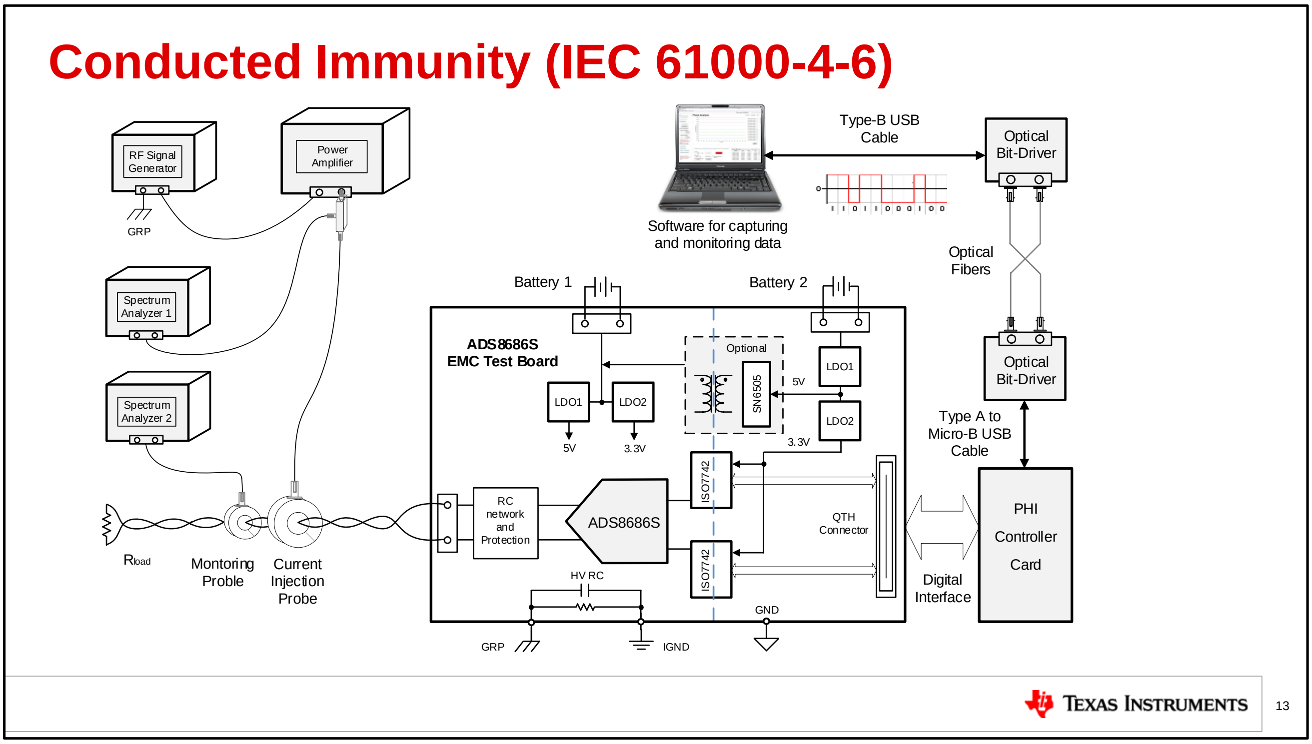


Horizontal Antenna Polarization
SCLK = 50MHz
Margin = 2.77dB



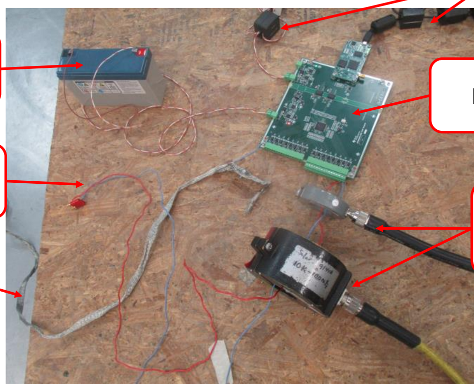
Vertical Antenna Polarization
SCLK = 10MHz
Margin = 6.4dB

This slide shows the measured radiated emissions for our example system. In these two example measurements, the antenna polarization was adjusted, and the data clock rate was adjusted. Both examples pass here, but the margin for the case with the 50MHz clock is fairly low. To thoroughly test a product, it may be important to run the test in many different modes of operation and to physically orient the product differently. For test results that don't pass compliance, or have very low margin it may be necessary to do a new PCB revision and apply the principles discussed in the other videos in this series.



The IEC 61000-4-6 standard, specifies the details about the conducted immunity test. The test is to verify the EUT immunity to conducted electromagnetic disturbances induced onto the EMC board input terminals. The test signal is generated from an RF signal generator and RF power amplifier is used to amplify the test signal to a specified level. The test signal is injected to the EMC board input with an injection probe. Spectrum analyzer #1 is used to monitor the output of the power amplifier, and the spectrum analyzer #2 is used to monitor and verify the injected signal with a monitoring probe. The signal frequency is swept from 150 kHz to 80 MHz with a disturbance signal of 80% amplitude that is modulated with a 1-kHz sinusoidal signal. Two field strength levels applied are: 3 V/m and 10 V/m.

Conducted immunity



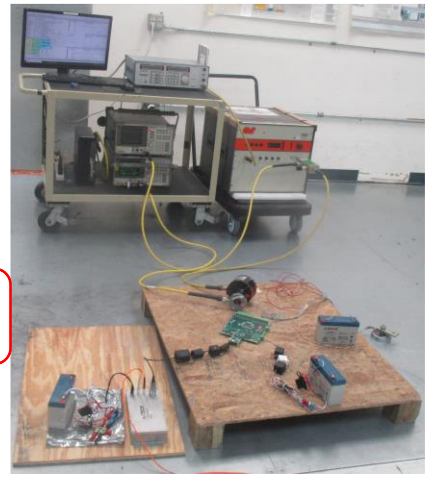


Table 3-4. Conducted Immunity Test Result

Test	IEC Standard	Test Signal		Test Level	Criterion	Test Result
		Field Strength	Frequency			
Conducted Immunity (CI)	IEC 61000-4-6	3 V/m	150 kHz–80 MHz	2	A	Pass
		10 V/m	150 kHz–80 MHz	3	A	Pass

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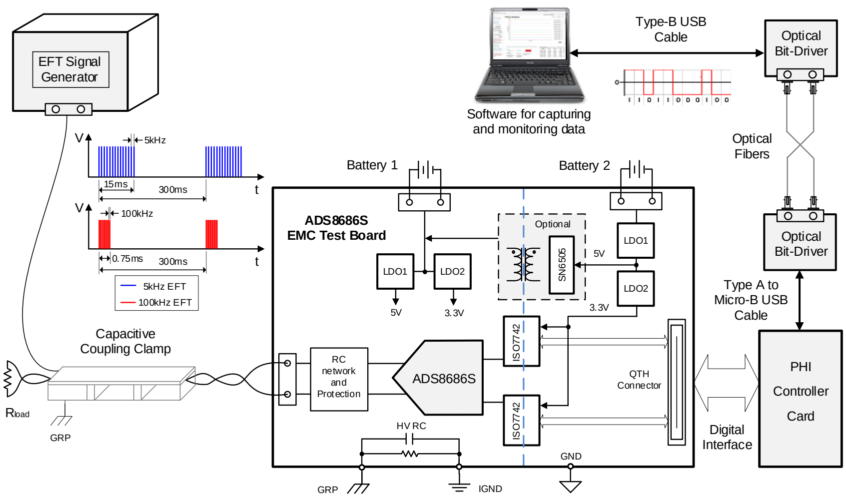
This slide shows the conducted immunity test setup and the test results for our example test. For the test results, note that the field strength applied is the standard field strength corresponding to test level 2 and 3 according to IEC 61000-4-6. The test criterion is also defined by the IEC specification as discussed previously.   Passing criterion A indicates that normal operation within specified limits was observed when the conducted immunity signal was applied. Notice that in this example, the system passed criterion A for both test levels. The pictures shows the different elements involved in the physical setup. Note that ferrite beads are used on the supply and USB cable to minimize the impact of the EMC signal on the computer and power supply. Again, one of the goals of EMC testing is to test only the EUT and to attempt to minimize the impact of the EMC signals on test equipment.

Electrical Fast Transients (EFT), (IEC 61000-4-4)



Electrical fast transients (abbreviated EFT) is an overstress robustness test that emulates real world transient events such as relay and motor switching. These transients are often introduced on AC power lines, but can couple to sensitive signal connections if they run near switching sources. The EFT signal is coupled into input signal lines capacitively. The IEC 61000-4-4 standard specifies the details about the EFT test in terms of the test signals and the requirements. The EFT signal is a series of rapid high voltage test pulses ranging from 250V to 2kV. The pules are sent in groups of 75 fast pulses that are repeated every 300ms. The total test time for each test is approximately one minute. Note that a special EFT signal generator is used to create the rapid high voltage pulses.

Passing EFT and other overstress type tests normally involves adding overstress protection devices at the input and output connections of the EUT. The ADC Precision labs series on electrical overstress covers theses kinds of protection circuits in detail. Common circuits include usage of TVS diodes, Schottky diodes, PTC fuses, gas discharge tubes, and simple RC circuits. Tight layout methods near the PCB entry points helps minimize parasitic inductance and improves the effectiveness of these circuit. It is not unusual to cause permanent damage to the EUT during the EFT test, so it is a good idea to bring multiple copies of the EUT when doing a series of EMC tests.

Electrical Fast Transients (EFT), (IEC 61000-4-4)

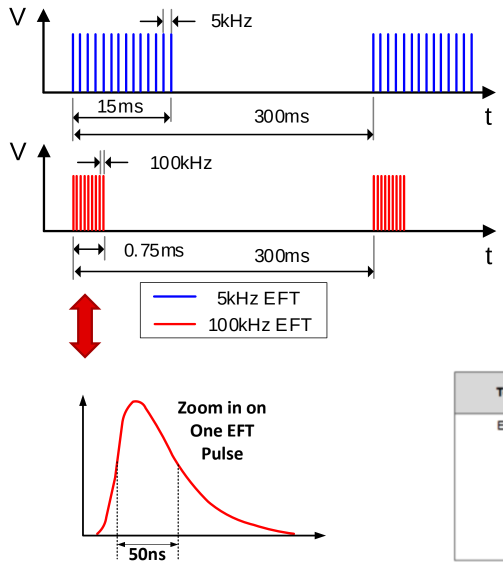


Table 3-1. EFT Test Result

Test	IEC Standard	Test Signal		Test Level	Criterion	Test Result
		Voltage	Frequency			
EFT	IEC 61000-4-4	±1 kV	5 kHz	2	A	Pass
		±2 kV		3	B	Pass
		±4 kV		4	B	Pass
		±1 kV	100 kHz	2	A	Pass
		±2 kV		3	B	Pass
		±4 kV		4	B	Pass

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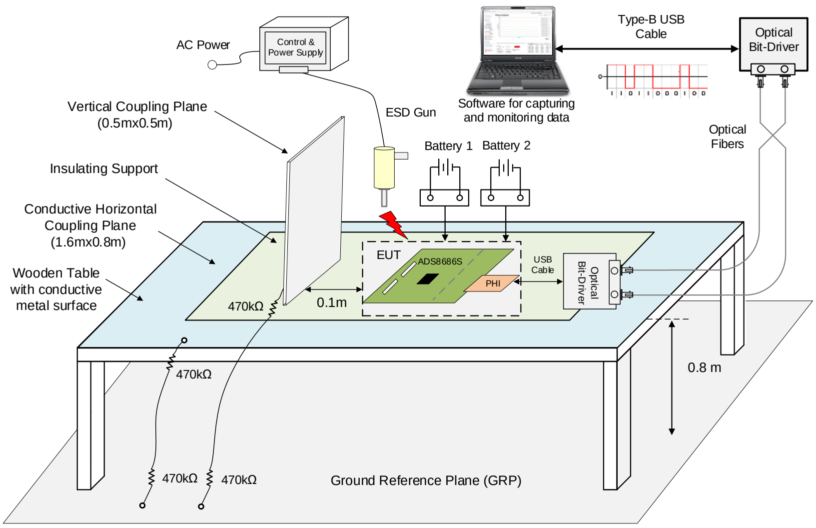
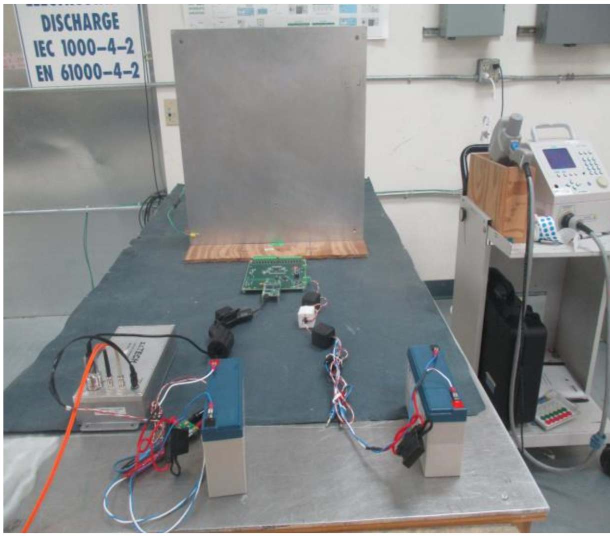
This slide shows a closer look at the EFT test signal. For both signals shown the pulse groups are repeated every 300ms. The top EFT signal has a 5kHz pulse frequency for a pulse group length of 15ms. The bottom signal has a 100kHz pulse frequency for a pulse group length of 0.75ms. The actual shape and width of an individual EFT pulse is shown at the bottom of the page. For our example EFT test, test levels 2, 3, and 4 were used which corresponds to ±1kV, 2kV, and 4kV according to the IEC 61000-4-4 test standard. Notice in the example test results, for some cases criterion A passed and for others criterion B passed. Criterion A indicates that the EUT had “Normal performance within specified limits” and criteria “B” allows for a temporary loss of performance, but after the interference is removed the device resumes normal operation. Thus, the devices that pass criterion B did not pass criterion A. In other words, for EUT that passed criterion B, there was a temporary loss of performance but after EFT was complete the equipment resumed normal operation.

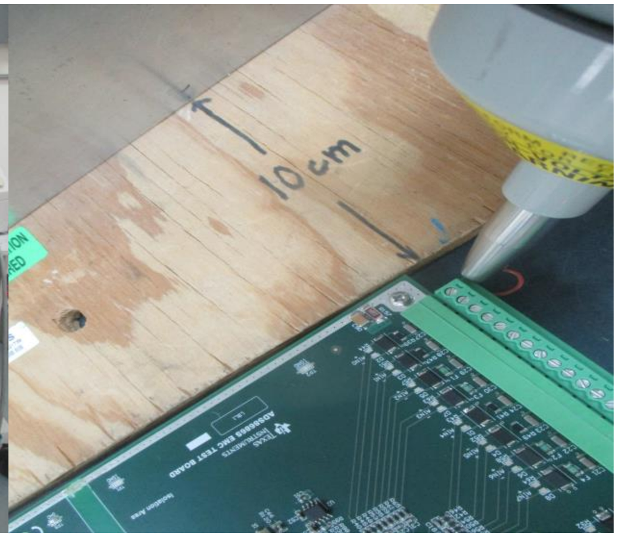
Electrostatic Discharge (ESD), (IEC 61000-4-2)



The electrostatic discharge test, or ESD, is another example of an electrical overstress test. This test simulates the impact of direct contact and air discharge types of ESD events. The contact discharge test is the most aggressive test. In this case, the tip of the ESD gun is placed on conductive screws of the input terminal blocks on the EUT. Air discharge tests are run three different ways: direct air gap discharge, indirect discharge to the horizontal coupling plane (abbreviated HCP), and indirect discharge to a vertical coupling plane (abbreviated VCP). In the air gap discharge test, the tip of the ESD gun is placed near insulating surfaces of the input terminal blocks of the EUT. Using the good PCB layout principles discussed in this series can help make the equipment more robust against ESD. Also, using input protection circuitry such as Schottky and TVS diodes is important in protecting against ESD. The TI precision labs videos series on electrical overstress covers protection circuits in detail.

Electrostatic Discharge (ESD), (IEC 61000-4-2)





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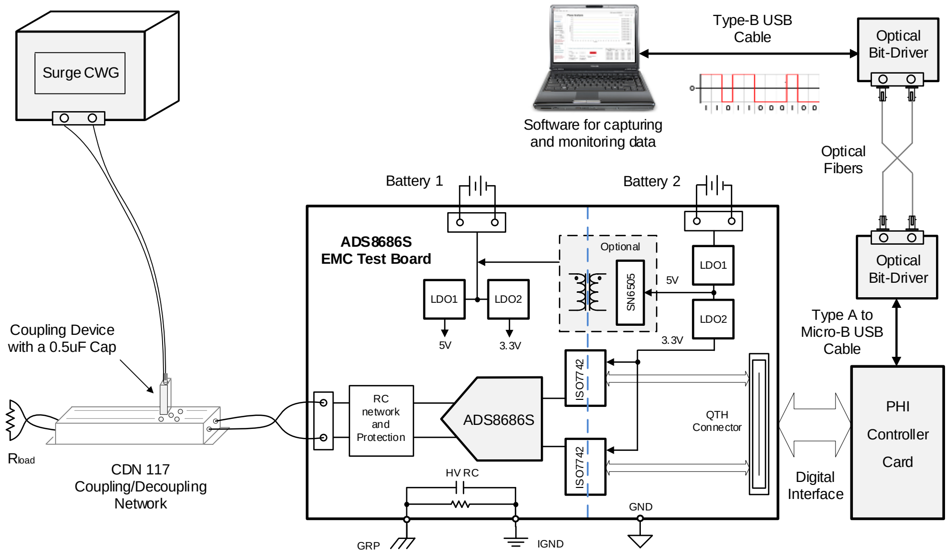
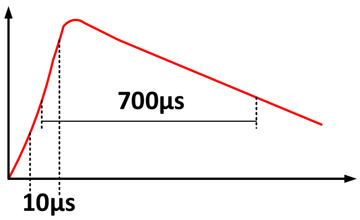
This slide shows a picture of the horizontal and vertical coupling plane used in ESD testing. The photograph on the right illustrates direct contact discharge on a screw terminal connection. The physical dimensions of the coupling plains, as well as the distance to the EUT are all defined in the IEC specification.

Surge IEC 61000-4-5



The surge test is meant to simulate high-energy surges caused by switching of power systems from load changes and short circuit faults as well as lightning strikes. IEC 61000-4-5 specifies two types of combination wave generators (abbreviated CWGs). The 10 µs / 700 µs CWG is specifically used to test the ports of symmetrical telecommunication lines. The 1.2 µs / 50 µs CWG is used for all other cases. These waveforms are shown on the next page. The EUT is subject to 5 positive and 5 negative surges at each rating. The surge is repeated at least once per minute. A coupling and decoupling network (abbreviated CDN) is required by the surge test. The IEC 61000-4-5 specification defines the impedance and capacitance used in the coupling network in different cases. In this example, the EUT was tested with the surge through a coupling / decoupling network (CDN117) with a 0.5-µF capacitor and a twisted cable.

Surge Test Results



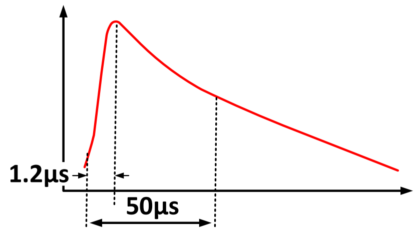


Table 3-3. Surge Test Result

Test	Standard	Type	Impedance	Test Voltage	Test Level	Criterion	Test Result
Surge	IEC 61000-4-5	Line-to-Line	42 Ω (2-Ω source impedance + 40 Ω from coupling network)	500 V	1	A	Pass
		Line-to-Ground	42 Ω (2-Ω source impedance + 40 Ω from coupling network)			B	Pass
		Line-to-Line	42 Ω (2-Ω source impedance + 40 Ω from coupling network)	1 kV	2	A	Pass
			2-Ω source impedance only(1)			B	Pass
		Line-to-Ground	42 Ω (2-Ω source impedance + 40 Ω from coupling network)			B	Pass
			2-Ω source impedance only(1)			B	Pass

(1) The test has a higher peak current (250 A for level 1 and 500 A for level 2) and is more aggressive than other tests in the table.

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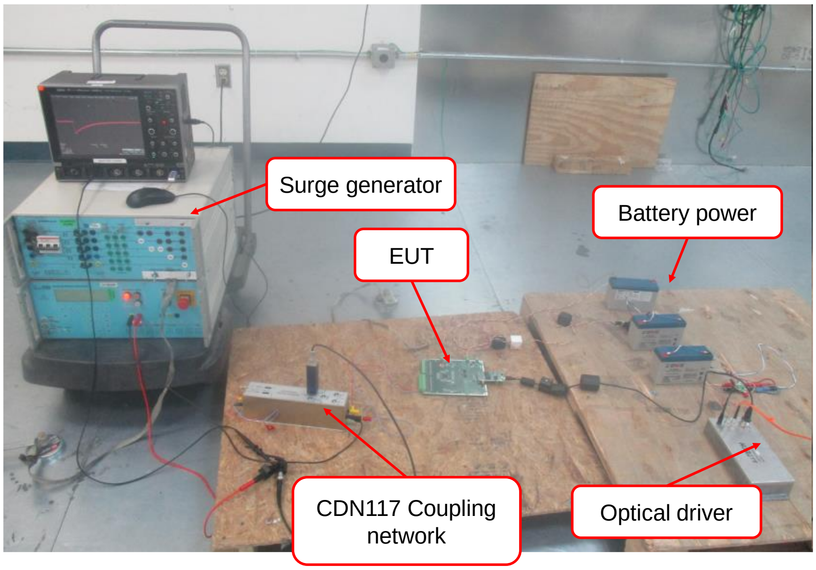
This slide shows the test result table and the surge waveform shape. Notice that the source impedance in the coupling network can be adjusted to make the test more aggressive. In this example, the 2 ohm source impedance corresponds to a 500A surge when the 1kV pulse is applied. As compared to EFT transient, the duration of the surge pulse is much longer. That is, it lasts hundreds of microseconds as opposed to nanoseconds. As with the other tests, the criterion and test levels are defined in the IEC specification. The test level corresponds to the test voltage and the criterion defines the operational behavior during the test.

Surge IEC 61000-4-5



This slide shows the physical setup for the surge testing. In the picture you can see the coupling network, surge generator, EUT, and other support circuity. The oscilloscope monitors the surge waveform during the test for confirmation .

Thanks for your time! Please try the quiz.

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That concludes this video – thank you for watching! Please try the quiz to check your understanding of this video's content.

Quiz: EMC Compliance Testing

1. (True/False) The pulse duration for surge is longer than the pulse used in EFT, and surge emulates a lightning strike.
   a) True
   b) False

2. (True/False) TVS diodes, Schottky diodes, and gas discharge tubes are used to minimize the effects of radiated emissions.
   a) True
   b) False

Question 1, (True/False) The pulse duration for surge is longer than the pulse used in EFT, and surge emulates a lightning strike.

The correct answer is a, True.

Question 2, (True/False) TVS diodes, Schottky diodes, and gas discharge tubes are used to minimize the effects of radiated emissions.

The correct answer is b, False. These devices are used for overstress tests such as EFT and Surge.

Quiz: EMC Compliance Testing

3. Why is it common practice in EMC testing to use batteries for power, fiber optic communications, and ferrite beads on cables?
   a) These are requirements according to the IEC specifications.
   b) This helps protect the test equipment from damage and performance impact.

4. (True/False) The radiated emissions and radiated immunity test can use the same anechoic chamber, and antenna. The main difference is that the immunity test requires a signal generator and the emissions test requires a spectrum analyzer.
   a) True
   b) False

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Question 3, Why is it common practice in EMC testing to use batteries for power, fiber optic communications, and ferrite beads on cables?

The correct answer is b, This helps protect the test equipment from damage and performance impact. One objective in EMC testing is to make sure that the overstress and interference signal do not damage or impact the performance of the support and measurement circuitry.

Question 4, (True/False) The radiated emissions and radiated immunity test can use the same anechoic chamber, and antenna. The main difference is that the immunity test requires a signal generator and the emissions test requires a spectrum analyzer.

The correct answer is a, true. Through the principle of reciprocity, an antenna that works well as a transmitter will work equally well as a receiver.

That’s all for todays video. Thanks for watching.