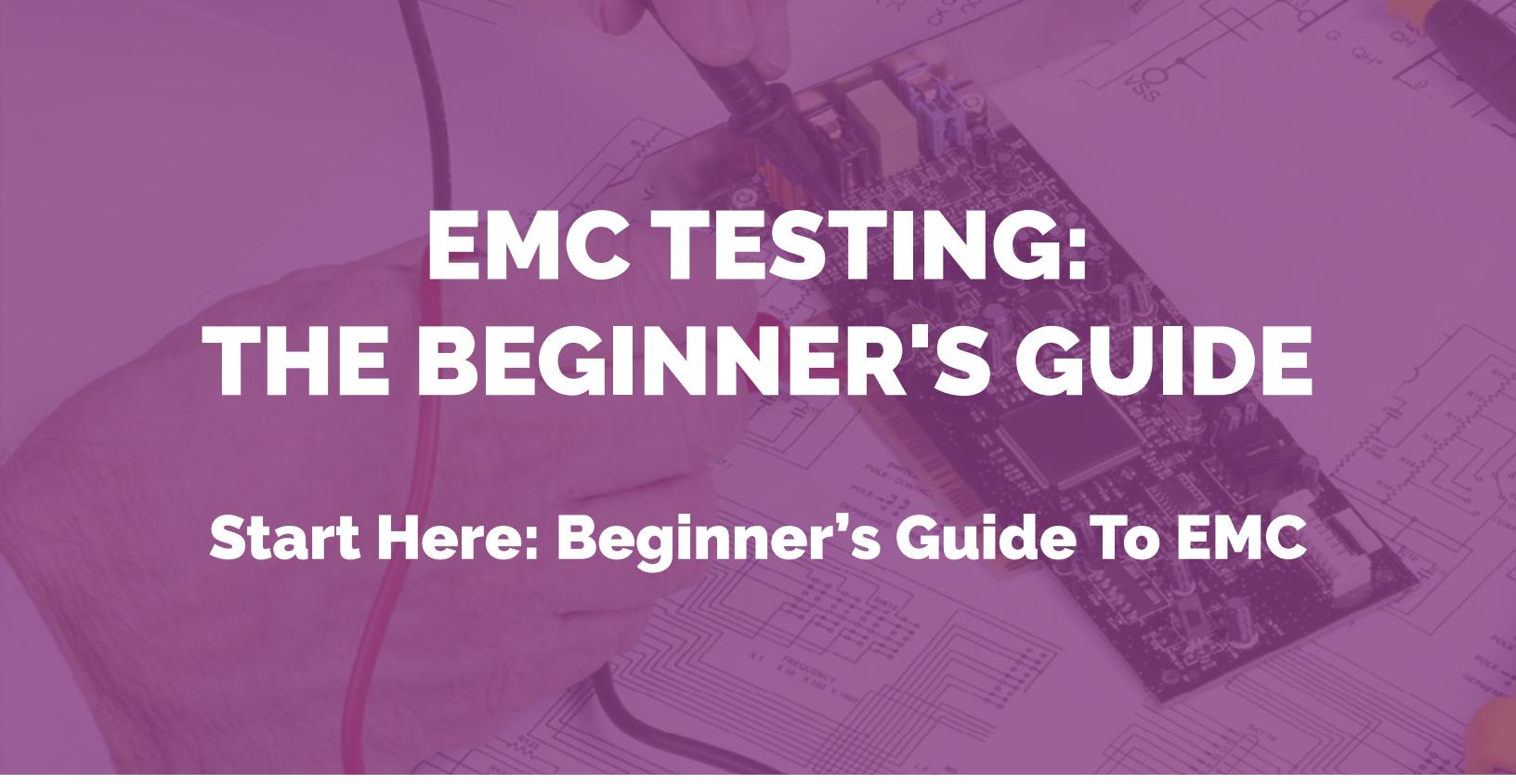


EMC TESTING: THE BEGINNER'S GUIDE

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EMC TESTING: THE BEGINNER'S GUIDE

Start Here: Beginner's Guide To EMC

New to EMC (electromagnetic compatibility) testing? Need to polish up your knowledge? This beginner's guide to EMC gives the concise information you need to identify, prepare for and ultimately pass EMC testing.

In this guide, you'll learn how to find the EMC standards that apply to your product, what the emissions and immunity tests are that you'll need to pass, how to prepare for testing, how to find good EMC test labs, typical pricing and much more.

The beginner's guide to EMC is an in-depth tutorial on all aspects of EMC testing. This guide covers the fundamentals of everything you need to know to be able to navigate, prepare for and pass EMC testing.

Here's what we'll cover in this chapter:

- ✓ Learn what electromagnetic compatibility (EMC) testing is
- ✓ Discover the poor first time pass rate average
- ✓ The 5 reasons manufacturers care about EMC testing
- ✓ The history and future of EMC testing

Read on below!

What is Electromagnetic Compatibility (EMC) Testing?

EMC (ElectroMagnetic Compatibility) testing exists to ensure that your electronic or electrical device doesn't emit a large amount of electromagnetic interference (known as radiated and conducted emissions) and that your device continues to function as intended in the presence of several electromagnetic phenomena.

Regulatory bodies around the world have placed limits on the levels of emissions that electronic and electrical products can generate.

Also, electromagnetic immunity testing is mandated for some areas and some product types. In the first chapter of this guide, we'll be digging into the applicability of emissions and immunity tests to your product, as well as determining exactly which standards apply.

What is the Average EMC Testing Pass Rate?

EMC testing guide Statistics on this subject are few and far between, because EMC test labs and governments are not required to collate the information. However, one of the largest studies available, by Intertek Labs puts the first time pass rate at only 50%! A

5 Reasons To Care About EMC Testing

Do I need to care about EMC Testing?

Although a [few exemptions exist](#), if you design, manufacture or import products with electronics inside, then it's almost definite that you're going to need to care about EMC.

1. Protection of the electromagnetic spectrum

We only have a finite amount of electromagnetic spectrum that we can use for things like radio transmission, microwave communication, x-ray machines and a huge number of other products.

Unfortunately, even electronic devices without transmitters emit electromagnetic radiation, just as a byproduct of switching currents and voltages inherent to electronic circuitry. Without limits to the amount of unintended electromagnetic radiation from electronic products, the electromagnetic spectrum could be adversely affected and frequency bands reserved for radio transmission could become compromised.

As the number of non-wireless and wireless electronic products continues to explode, the already packed electromagnetic spectrum is going to become even more crowded. Protection of this essential resource is critical to ensuring that devices continue to be able to function properly in the future.

2. Safety

For many products and industries, EMC performance can mean the difference between life and death. Many medical, military, industrial, aerospace and automotive products (and others) have safety critical applications.

If the function of those products fail due to electromagnetic phenomena such as power supply surges, ESD or radiated electric fields, then lives can certainly be at risk. Imagine 300 cellphones all transmitting 7 Watts of power on an aircraft at 36,000 feet - it's rigorous EMC testing that ensures that the electrical systems can withstand those sorts of electromagnetic environments.

3. Product performance (quality)

The function and performance an electronic product can easily be affected by external and internally generated EMC phenomena. As an example, if your internal power supply regulation is too noisy, that can adversely affect sensitive analog measurements (for sensor products), or lower the performance of a radio transmitter (for wireless products). Those are both examples of internal EMC problems.

Externally, applied EMC phenomena can negatively affect products in a virtually unlimited number of ways, from data corruption to measurement accuracy to RF performance to frying ICs. EMC testing helps to ensure that your device will continue to function as expected in the presence of a typical EMC environment and (hopefully) reduce the amount of product returns to poor EMC performance.

4. To keep test labs and government employees busy

Given the [well documented variability of lab to lab EMC testing results](#), the large testing price tag that applies regardless of the quantity of sales or size of the company and the shear volume of non-compliant devices that enter the market every year, it's easy to see how manufacturers can get cynical about the whole process.

AN OFFICIAL 2013 REPORT OF NON-COMPLIANCE ACROSS EUROPE STATED: >35% TECHNICAL REQUIREMENTS NON-COMPLIANCE AND >60% DOCUMENTATION NON-COMPLIANCE.

It's true that EMC testing can be a huge burden to small and large manufacturers alike and its effectiveness can sometimes be questionable. But the rules did emerge as a result of real problems (see history below) and the government and private infrastructure grew to accommodate and enforce those rules.

5. Fines

EMC testing finesIf you're caught with a non-compliant device on the market, the fines and actions can vary from insignificant to horrendous.

Legal firm Fish & Richardson published a summary of the [FCC's legal proceedings over the last few years](#) and the results were interesting. Most fines were related to issues with wireless transmitters, rather than unintentional radiators.

PENALTIES VARIED FROM 'ADMONISHMENT ONLY' TO \$2.2M.

Enforcement seems to be fairly minimal, as evidenced by a non-compliance rate of approximately [>60% in parts of Europe on a sample size of 10,000 products](#).

However, there are several risk areas relating to non-compliant devices covering both civil and criminal law. You can find a good presentation on the legal aspects of compliance [here](#).

The most likely ways to be caught with a non-compliant device on the market include competitors notifying authorities, market surveillance and finally customer complaints due to interference with other devices.

History of EMC Testing

One of the first EMC regulations were originally formed way back at the turn of the 20th century in Europe in response to specific problems that arose from usage of electrical devices. Defective electric lamps caused other lights in the neighbourhood to 'flicker'. This was back in the days when electric power grids were new to London, England and some other wealthy places. To curb this problem, probably the first EMC legislation was enacted, called "The Lighting Clauses Act" of 1899!

Germany may have beaten the UK to the post with their 1892 "Law of the Telegraph in the German Empire" which dealt with influences of EMC disturbances on products and installations in the field of telegraph communications. This was a result of the discovery that communication cables could negatively affect each other.

The [FCC has had limits on transmitter emissions since 1938](#) and has continued to expand its rules in response to the explosion of transmitters and electronic devices over the following decades. The rules were getting a little sprawling and uhh.. unruly, so in 1989 the FCC standardized emission limits for general applications.

The EMC directive was introduced in the EU in 1992 which was designed to standardize requirements across the EU member countries and free up the movement and electronic goods.

So that was a quick look at the history of EMC. Now let's take a look at where it's heading....

The Future of EMC Testing

There are a few trends that are emerging in the field of EMC:

- **Standardization of Rules**

There is a concerted effort to standardize EMC testing requirements across the world, led primarily by the [IEC \(International Electrotechnical Commission\)](#). The IEC generate standards that can be transposed by countries into their local standards and in theory this standardizes the EMC requirements across all of the regions that adopt IEC standards. In the UK for instance, 85% of IEC standards are transposed to UK standards.

- **Expansion of test requirements**

In some countries, such as the US and Canada, currently only emissions testing is required (unless your product falls under the scope of an industry specific standard that calls out immunity testing). Whereas in Europe, both emissions and immunity testing are mandated.

Over the past few years, countries such as Australia and New Zealand have followed Europe's model and necessitate immunity testing as well. The push from test labs, government and international standards (discussed above) all indicate that requirements for immunity testing is increasing.

**THIS CAN EASILY DOUBLE OR TRIPLE TESTING COSTS
COMPARED TO EMISSIONS ONLY TESTING, AS WELL AS
INCREASE TIME TO MARKET BY SEVERAL DAYS OR WEEKS
IF A FAILURE IS ENCOUNTERED.**

- **Consolidation of EMC Test Labs**

Recently announced new rules for EMC test labs by the FCC mean that transmitter 'certification' testing will only be accepted from recognized and accredited test labs. Approximately 2/3 of the 1000 or so test sites registered with the FCC are currently not accredited. The extra requirements are likely going to favour larger test labs that can absorb the accreditation overhead costs and staffing and may force smaller test labs out of business. You can read an in depth analysis on this topic [here](#).

EMC TESTING: THE BEGINNER'S GUIDE

Chapter 1 - Global Rules & Regulation

Finding the right EMC standards for your product can be pretty daunting. In this section, we'll cover how to track to the right EMC rules and standards that apply to your product. Read on to get the low down....

Here's what we'll cover in this chapter:

- ✓ How to find the EMC standards that apply to your product
- ✓ Links to many global and industry standards

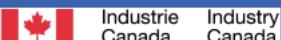
Which EMC Standards Apply to Your Product?

There are a few different options for working out which EMC standards apply to your product around the world. I'll outline some options below so that you can see what's available.

EMC Regulatory Bodies Around The World



The FCC oversees the EMC and RF test requirements for the USA.



Industry Canada is Canada's equivalent to the FCC. They oversee the electromagnetic spectrum for Canada.

Option 1 - Ask an EMC test lab

This is probably the easiest method. Just call up the sales department of a test lab that you're considering using for product approvals. They should be happy to provide a breakdown of the applicable tests and give a quote for testing services for your particular product. If they're not, choose a different test lab.

Bear in mind that sometimes test labs get it wrong. They do their best, but occasionally they will give you some incorrect information. I've seen several product datasheets where they claim compliance with the wrong standard. It's not the end of the world, but it's worth getting right.

If you need a legally correct interpretation of the standards that apply to your product, ask a TCB (Telecommunications Certification Body) in the case of the FCC, or an NB (Notified Body) in the case of CE Mark for Europe.



One thing to note is that test labs can spend a decent amount of time researching the standards that apply to a given product. If it's a simple job for FCC or CE testing, then they'll probably be able to tell you which standards apply to your product off the top of their head.

However, if your product is a wireless device (RF testing) that will be fitted to a bus (automotive testing) in South America (complex regulations on a per country basis), then they're probably going to have to do a fair amount of legwork.

My point is: don't go asking a lab if there's no possibility that you'll use their services. The exception to that is when it's a lab's responsibility to give advice - in Europe for instance, if you need a concise answer on exactly which tests apply to your product, you can hire an NB (Notified Body) to interpret the regulations for you.

At my lab, I was happy to give advice for existing customers or if I had a shot at securing a new client. I drew the line at providing advice to customers that were using labs in China but asked for free support here because of the language barrier.

Option 2 - Check your competitor's datasheet

If any of your competitors claim compliance for the same target markets as you're aiming for, they often cite the standards that they've tested to in their product datasheets. Search Google for identical products and look for the compliance and regulations section of their datasheet. Very often you'll find the answer you're looking for.

For example, search terms like "Audio power amplifier +'declaration of conformity'" are useful for Europe, or "Audio power amplifier +'FCC test report'" for the US. They'll usually turn up some good candidates. This will also usually turn up the right safety standards too!

Option 3 - Find them yourself

Manually tracking down the EMC standards is no easy task. It varies between geographic region and product type. Read on below to find links to several to the EMC standards of several countries and industries.

Where To Get or Buy EMC Standards

Here are some resources for sourcing EMC standards:

EMC Standards By Country:

United States: [FCC Part 15 Rules Online](#) (Free)

Canada: [Industry Canada ICES Rules](#) (Free)

Europe: [European standards](#) (Free or low cost)

Australia & New Zealand: [EMC standards list](#)

Most are similar or identical to European standards. Recommend using European link above to get European standards.

Japan: [VCCI](#)

China: [CNCA](#)

Russia: [EASC \(GOST\)](#)

EMC Standards by Industry:

Medical: [IEC 60601-1-2](#)

Automotive

SAE

[ISO7637](#)

[IEC CISPR-25](#)

Automotive Directive ("E-mark" for Europe).

[ISO1145-1](#)

[ISO1145-2](#)

Military

[MIL-STD-461](#)

[DEF STAN 59/411](#) (common in NATO)

[MIL-STD-704](#) (for aircraft)

[MIL-STD-1275](#) (for land vehicles)

[MIL-STD-1399](#) (for ships)

If you'd like me to add some others to this list to make it more comprehensive, please [email me](#).



The RCM is the single compliance mark for Australia, covering EMC, RF and safety testing. It indicates compliance with ACMA technical standards.



VCCI oversees EMC and RF compliance for Japan.



CCC is China's compliance mark for EMC and safety requirements.

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Chapter 2 - Radiated & Conducted Emissions

In this chapter of the guide, we're gonna cover the most common emissions tests. It's important to note that not all of them may apply to your product - this is just a comprehensive list of emissions tests that EMC test labs often perform on electronic products.

Here's what we'll cover in this chapter:

- ✓ Learn about radiated emissions tests
- ✓ Learn about conducted emissions tests
- ✓ Learn about flicker & harmonic tests

You can think of this chapter as the 'problem definition' chapter. We'll define the hurdles that you'll need to get over to be able to pass emissions (EMI) testing. In the later chapters, we'll address how we're going to pass these tests.

Radiated Emissions Testing

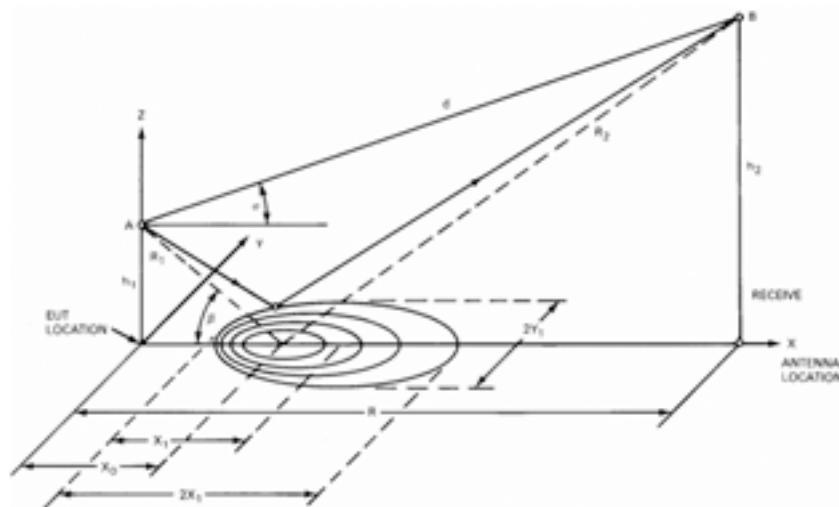
This is by far the most common EMC test undertaken around the world. There are radiated emission limits in every major market in the world and they apply regardless of product type or industry. There are a few different types of radiated emissions testing facilities that test labs use. Read on to get the low down on each of these sites.

What is Radiated Emissions (or EMI) Testing?

Radiated emissions testing involves measuring the electromagnetic field strength of the emissions that are unintentionally generated by your product. Emissions are inherent to the switching voltages and currents within any digital circuit, the only question is: how large are the emissions and do they comply with the emissions limits?

So how do EMC test labs measure radiated emissions?

Radiated Emissions Test Method



The electromagnetic waves don't extend out from your product in a nice spherical pattern.

The emissions tend to be pretty directional, so a test lab has to vary the height of the receiving antenna between 1 and 4 meters as well as rotate a turntable.

The receiving antenna picks up both the signal direct from the EUT, as well as a bounce off the ground. To increase measurement accuracy, the ground is covered with an electromagnetically reflective surface (aluminum, steel, wire mesh etc..) and this ground plane must be relatively flat.

The test lab will scan the frequency band of interest and look for emissions that are close to the limits. Using a process called 'maximization' (described below), the test lab focuses in on each of these emissions, and quantifies the amplitude of the field strength.

Types of Radiated Emissions Test Sites

There are two primary types of test sites that are used for measuring radiated emissions from electronic products. The goal of these test sites is to accurately measure the

emissions that come from your product and ensure that they comply with the relevant limits.

There are over 1000 FCC listed/accredited EMC test sites around the world, each of which contains at least one of the test sites described below. And that number doesn't include any EMC test sites that are not registered with the FCC.

Read on below for a description of the test sites so that you know what to expect....

Open Area Test Site (OATS)



An "OATS" or an open area test site is the most common radiated emissions test site.

They are most commonly constructed to comply with the requirements of ANSI C63.4 (for North America and elsewhere) and CISPR 16-1-x (for Europe and elsewhere).

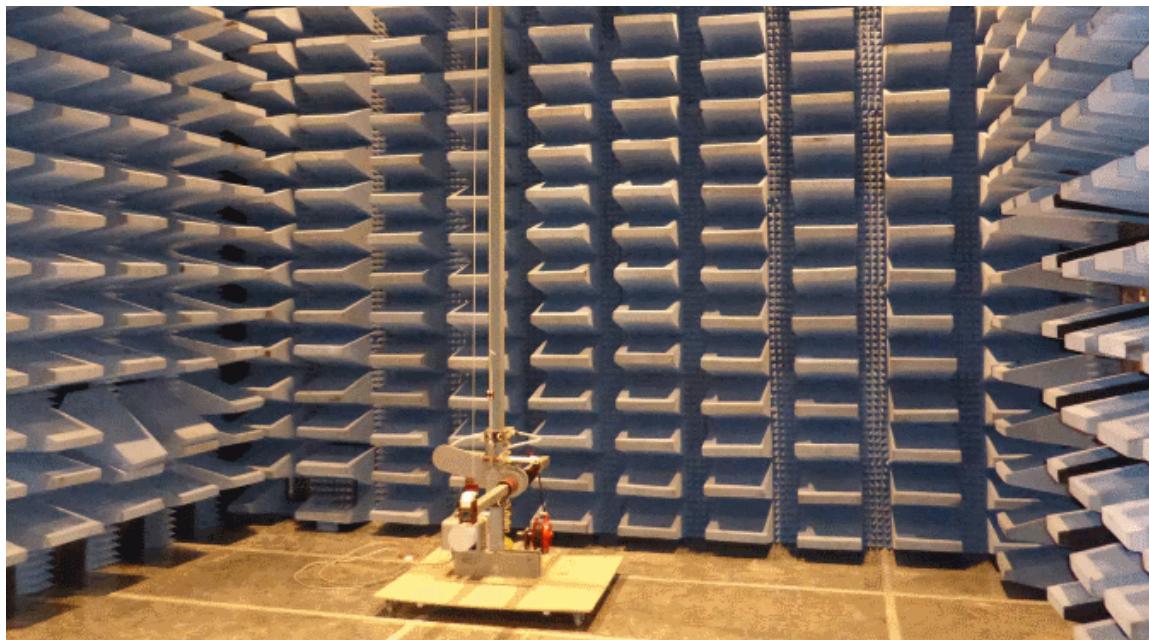
The distance between the antenna and the equipment under test (EUT) is typically 3m, 10m or 30m. The measurement distance is important because you want to ensure that you are measuring the field strength in the **far field as opposed to near field**.

At 30 MHz, the wavelength is 10m. As you approach the near field or fresnel region (region between near and far field), the electric field may not yet be stable and the measurements will be less accurate.

Some standards mandate a specific separation, while others allow the use of 2 or more different separations. Because the strength of the electromagnetic field varies with distance, the limits are re-calculated at each measurement separation.

Although it is usually acceptable for test measurements to be compared between different measurement distances by factoring in an extrapolation factor of [approximately 20dB/decade](#), in reality [there are issues](#) that make comparisons of measurements at different types of facilities problematic.

Semi Anechoic Chamber



A semi-anechoic chamber (or SAC for short), is just like an OATS, only it's housed within a shielded (metal) room.

This is really helpful because it attenuates the background (ambient) radio signals, so it's much easier to distinguish what's coming from your product vs. the background signals.

The inside of a SAC is lined with RF absorber material so that reflected signals are kept to a minimum.

Without these absorbers, the measurement antenna would receive an unquantifiable signal contribution from wall and ceiling reflections, making the measurements quite inaccurate.

Chambers are quite expensive (>\$100k), but they are a good solution to measuring EMI in a noisy environment.

Related Post: [The Anechoic Chamber Guide For Emissions, Immunity and RF \(Wireless\) Testing](#)

Spectrum Analyzer

A spectrum analyzer (or alternatively an EMI receiver) is the backbone of an EMC test lab's emissions measurement equipment. Their specifications and costs vary wildly. If you're looking to invest in a spectrum analyzer for compliance testing, here are a few qualities that you want to look for:



- Low noise floor
- Wide frequency range (ideally it covers down to the lower end of conducted emissions up to the upper end of radiated emissions)
- Peak, AVG and QP detectors
- Common EMI bandwidths: 9kHz,

10kHz, 100kHz, 120kHz, 1MHz

- GPIB or other computer interface port
- Software for adding/subtracting transducers + applying limit lines

What Are The Emission Limits And Frequency Ranges?

The limits for radiated emissions vary by geographical region and by product type. Europe and North America's limits are very similar, although Europe's limits are slightly stricter in certain frequency bands.

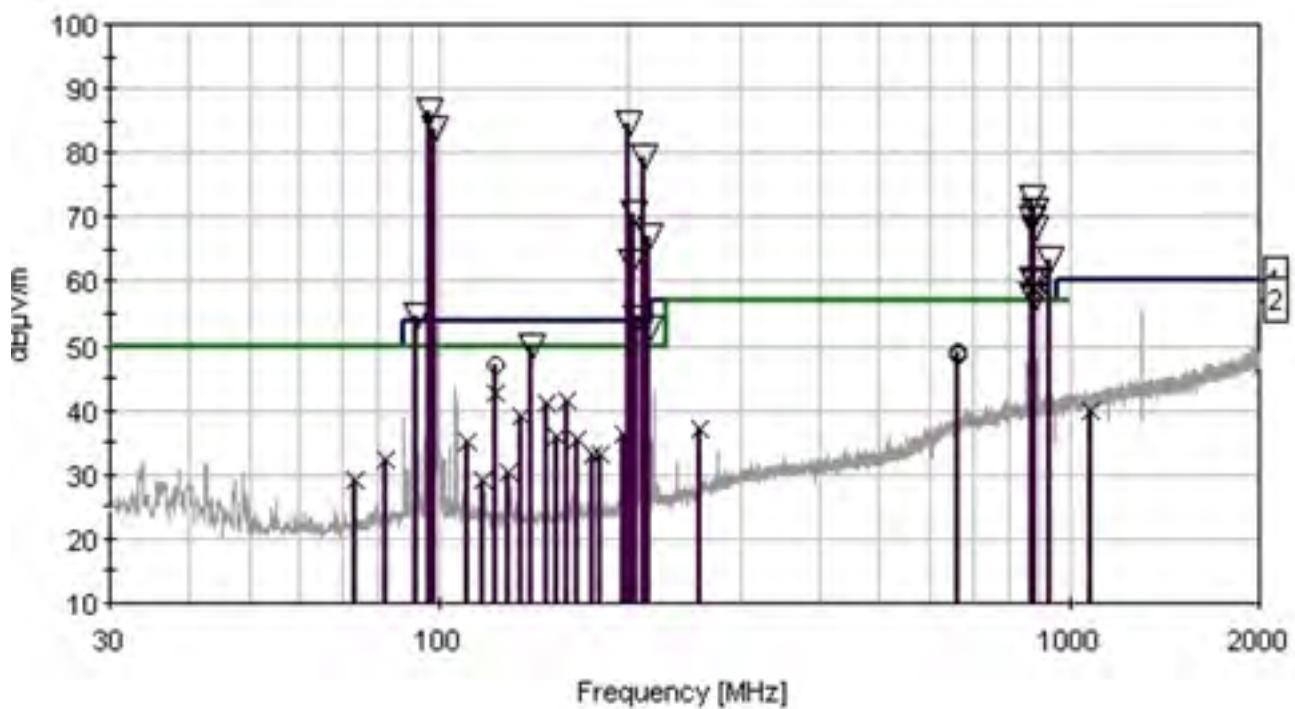
If your product has an industry specific standard such as military, automotive or aerospace, the limits are usually much stricter and harder to pass.

Radiated Emission Limits

Below you can see a sample radiated emissions plot from an EMC test lab. The green line is the limit line for Europe and the blue line is for the FCC.

You can see that they're very similar, but there are subtle differences. It's possible to pass FCC but fail CE emissions limits, but not vice versa!

You can tell that this plot is from an OATS because you can see several large ambient signals in the FM and cell phone bands. What Frequency Range is Measured?



What Frequency Range is Measured?

The frequency range that a test lab needs to investigate usually varies with the highest speed clock rate present in the device. For some industry and product specific standards, the frequency range is fixed, but for the FCC you can see how the upper frequency range of measurement relates to the highest clock frequency in your design.

Upper limit:

| Highest frequency generated or used in the device or on which the device operates or tunes (MHz) | Upper frequency of measurement range (MHz) |
|--|--|
| Below 1.705 | 30. |
| 1.705–108 | 1000. |
| 108–500 | 2000. |
| 500–1000 | 5000. |
| Above 1000 | 5th harmonic of the highest frequency or 40 GHz, whichever is lower. |

FCC Part 15.33

The lower frequency range is defined by the lowest frequency clock used in your design. For example, if you're using a 16 kHz crystal for timing, the lab should measure down to that frequency.

Measuring frequencies below 30 MHz usually necessitates the use of a loop antenna which picks up magnetic fields. Magnetic fields tend to be dominant at lower frequencies.

Measurement Transducers

With radiated emissions testing, everything that interacts with the RF signal has some effect on that signal.

Just as a resistor will drop a voltage across it if current flows at DC; a cable, attenuator, connector or adapter will similarly cause the amplitude of an RF signal to drop. Equally as important is the fact that the amount of attenuation varies with the frequency of the RF signal.

The gain of antennas and amplifiers also vary with the frequency of an RF signal.

For an EMC test lab to get repeatable, accurate results, it's crucial to have calibrations of all transducers used in the measurements. The transducers include:

- RF cables
- Attenuators
- Antennas
- RF amplifiers
- Connector adapters

Measurement Antennas

To cover the entire frequency range of interest, test labs often need to use several different antennas.

This is because different antennas have different gain profiles across different frequency ranges. Ideally you want a high, flat gain response across your measurement band of interest. Without a reasonable amount of gain, the measured signal fed into a spectrum analyzer or EMI receiver could be too small and fall below the noise floor of the measurement instrument.

For high frequency measurements (> 1 GHz), an RF amplifier is sometimes required to boost the signal.

Check out the most common types below.



Loop



Biconical



Log Periodic



Horn

Freq: 10kHz-30MHz

Freq: 30MHz ~ 300MHz

Freq: 300 MHz ~ 1 GHz

Freq: 1 GHz ~ 26 GHz

How Hard is it to Pass?

This is the \$64,000 dollar question and the answer really depends on what your product is, how it's been designed and how strict the limits are. I've seen radiated emissions failures from products as simple as a 25 MHz, single microprocessor unit (mostly due to the 2 layer construction which made return paths very segmented), and I've seen multi-gigahertz computers sail through emissions testing on the first pass.

Passing EMC testing first time around comes down to good understanding of the problem, proper preparation and the skill of the design engineers.

The chapter on "EMC testing preparation" in this guide will give you a full breakdown of the process large multinational companies use to consistently pass EMC testing.

What Are The Typical Failure Modes?

There are a virtually unlimited number of ways that you can fail a radiated emissions test. Here is a small sample of the classic design issues:

- Noise on the cabling
- Poor board grounding
- Non-optimized layer stack
- Ineffective board decoupling
- Poor cable termination
- Non-compliant auxiliary equipment
- High PDN impedance
- Poor signal integrity
- Choosing wrong class of power supply

- Poor component placement
- Cuts in return paths
- Large current loops
- Lack of grounding for crystals, heat-sinks and LCDs
- Stubs
- Segmented ground fills
- Critical nets change reference planes
- Signals close to edge of reference plane
- Poor decoupling capacitor placement
- Poor decoupling capacitor routing

Conducted Emissions Testing

What is Conducted Emissions Testing?

Your device creates electromagnetic energy and a certain portion of it will be conducted onto the power supply cord.

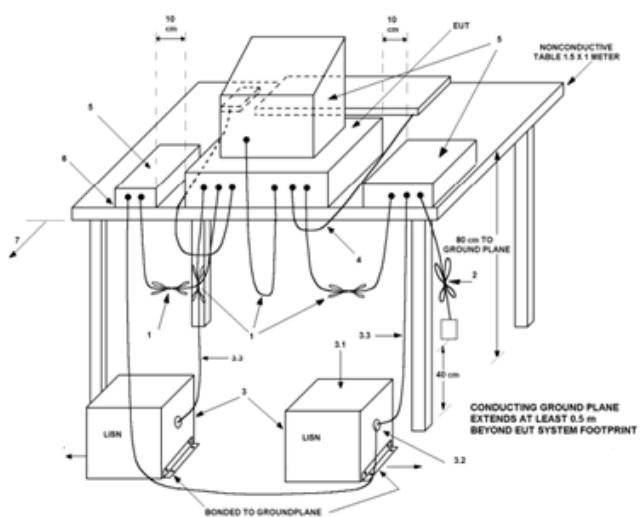
In order to restrict the amount of interference your device can couple back onto a power supply, test labs measure these emissions (usually from 150 kHz - 30 MHz, and verify that they comply with specified limits.

This helps to ensure that the local power supply remains relatively 'clean' and nearby devices won't be affected by your device.

Conducted Emissions Test Setup

Above, you can see a diagram of a typical conducted emissions test setup, according to ANSI C63.4. The LISN (or LISNs) sit on the ground, while your product sits on a table (or remains floor standing if the equipment is large).

The RF port of a LISN connects directly to a spectrum analyzer (or via a transient limiter to prevent damage from voltage spikes).



Conducted Emissions Applicability

Conducted emissions testing is usually performed on devices that connect to an AC power supply. That is regardless of whether you're using a pre-certified AC-DC power supply adapter.

For some standards, there are also limits placed on devices that operate from a DC power supply.

What Are The Frequency Ranges and Limits?

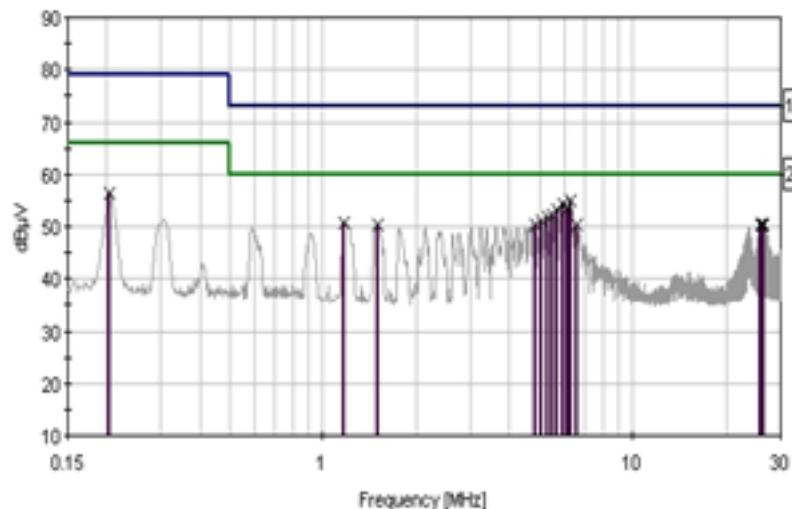
Frequency Range

A very common frequency range called out by conducted emissions standards is 150 kHz to 30 MHz. But that range may be higher or lower for specific standards.

Different standards call for different frequency ranges and different impedances, so LISN manufacturers usually carry a line of products to satisfy all of these requirements.

Conducted Emission Limits

Below you can see the FCC's conducted emission limits for class A and class B devices. You'll notice that class B limits (for domestic environments) are more strict, probably because the number of devices expected in a household is large, and users want to be sure that devices won't interfere with each other through conducted noise on the AC power supply.



| Frequency of emission (MHz) | Conducted Limit (dBuV) | |
|-----------------------------|------------------------|---------|
| | Quasi-Peak | Average |
| 0.15-0.5 | 66-56* | 56-46* |
| 0.5-5 | 56 | 46 |
| 5-30 | 60 | 50 |

TABLE 4 - LIMITS FOR CLASS B, DEVICES

*Decreases with logarithm of frequency

| Frequency of emission (MHz) | Conducted Limit (dBuV) | |
|-----------------------------|------------------------|---------|
| | Quasi-Peak | Average |
| 0.15-0.5 | 79 | 66 |
| 0.5-30 | 73 | 60 |

TABLE 5 - LIMITS FOR CLASS A DEVICES

LISN

A LISN is a low-pass filter typically placed between an ac or dc power source and the EUT (Equipment Under Test) to create a known impedance and to provide an RF noise measurement port which connects to a spectrum analyzer or oscilloscope.

You need a known impedance because otherwise the measurements won't



be repeatable. The impedance of AC power supplies vary from outlet to outlet, so a LISN standardizes this impedance between labs.

A LISN also filters and isolates unwanted RF signals from the power supply source. This is helpful for the case when the power supply of the test lab is noisy - the filtering in the LISN minimizes this noise and (ideally) allows the lab to measure only the noise due to the EUT.

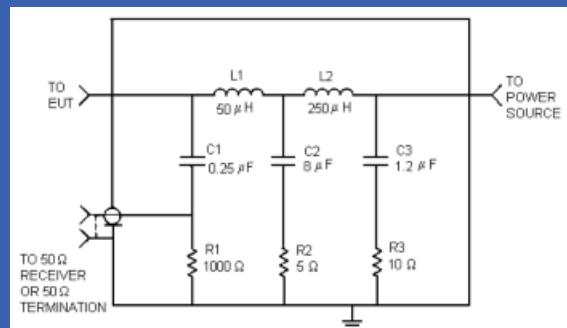
What's in a LISN?

The circuit inside a LISN is relatively simple. It just consists of some filtering, a power supply input and output, and a port that connects to a spectrum analyzer.

For AC LISNs, there are often 2 identical circuits inside so that you can measure the noise on the line and neutral signals without needing a separate LISN.

There are many types of LISN to satisfy the specifications of different standards. Here are some of the properties that vary:

- Maximum current/phase
- Impedance presented to EUT
- No. of phases
- AC or DC
- Frequency range



What Are The Risks of Conducted Emissions Testing?

It's really common for devices to fail conducted emissions testing. Even if your equipment uses a pre-certified external AC-DC power adapter, that doesn't guarantee a pass. There are a couple of reasons for this:

- The power supply may be non-compliant.

It is not uncommon to see power supplies that are supposedly compliant, but when re-tested, they are actually non-compliant. That could be due to a number of reasons including batch to batch variations, flaws with the original testing or hardware changes since the original testing.

- The original power adapter was tested using a DC load

Typically, OEMs who have their power supply adapters tested, do so with a DC load attached to the output, with the value selected to correspond to the highest rated current draw. Your equipment will pull both a DC and AC/RF current, so the emissions profile of the adapter will be different than when originally tested.

Conducted Emissions Recommendations

Without going into huge detail on circuit design for conducted emissions compliance, there are a few simple ways that you can minimize the risk of failing conducted emissions testing:

- Always source a power supply that is rated for the limits that you need to pass
If your device is a 'class B' device, then make sure to source a class B adapter. An adapter that has only passed class A limits, is unlikely to result in a pass for you. A class B adapter doesn't guarantee a class B conducted emissions pass, but it will certainly help.

Similarly for stricter military, medical, automotive or aerospace limits, always source a supply who's specification claims compliance with the relevant limit.

- Bring at least 3 different power supplies to the test lab

If your device uses an external AC-DC power adapter, bring equivalents from different manufacturers just in case. If you fail, you can swap it out and see if the other supplies result in a pass.

- Check your power supply rails for ripple

If you have nice clean power supplies, the chances are that your PDN and decoupling are in good shape. If you see excessive ripple or spikes from switching power supplies, this noise may well be present at the AC side of your power supply.

Ethernet Conducted Emissions

Did you know that in some geographical regions (e.g. Europe), testing of the noise on Ethernet ports is also usually required?

Your device can inject noise back onto an Ethernet network and in some standards, there is a limit to the amplitude of that noise.

Flicker & Harmonics Testing

What is Flicker & Harmonics Testing?

Flicker and harmonics testing are another form of emissions testing. These EMC tests are usually performed to the EN61000-3-2 and EN61000-3-3 standards respectively.

In Europe, these are considered to be 'horizontal' standards, which means that they apply to almost all types of electronic or electrical equipment that enter the EU.

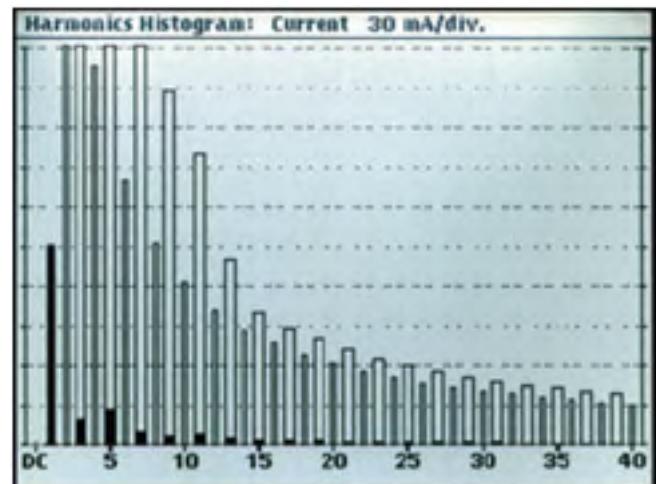
There are many caveats to this, but you can use our EMC testing standards finder tool to see if these standards might apply to you!

Harmonic Current Testing (61000-3-2)

This test is designed to measure the harmonic current requirements of an EUT.

It's usually associated with switch mode power converters and other non-linear loads such as motors, transformers and lamp dimmers/ballasts.

By limiting the harmonic current draw requirements, the harmonic load on local power supplies is reduced, which helps to avoid overheating and increases efficiency. It's an important piece of the puzzle for power companies to maintain the quality of AC distribution systems.



Voltage Flicker Testing (61000-3-3)

One of the first EMC tests ever - with limits specified back in the 1890s in London, England. Degrading electric lamps would cause arcing between contacts which in turn would cause nearby lamps sharing the same power supply to 'flicker'.

The impedance of the power supply cabling was much higher than it is today. The non-linear current draw of an arcing lamp induced voltage variations on the power supply, thus affecting nearby lamps.

The flicker limits today actually still relate back to the amount of visually perceivable flickering on an incandescent light bulb.



Flicker & Harmonics Test Equipment

There are some fairly low cost test equipment solutions for measuring flicker and harmonics current.

This one shown to the right is from TTI and it covers both flicker and harmonic current test requirements. Rated up to 16 A @ 230V, it suits a wide range of relatively low power products.

The bottom section of the equipment is a very clean power supply and it presents a known impedance to the analyzer (the top section).

Read on below to see what the analyzer is actually doing...



Inrush Current Limits

The voltage variation limit in EN61000-3-3 effectively creates an inrush current limit for devices when you first switch them on.

The maximum inrush current limit varies depending on the voltage variation limit (d_{max}) selected for your equipment, but it can be in the range 20A-30A averaged over the first 10ms of on time.

The inrush current at power on is measured by turning the power on and off to your product 24 times. The highest and lowest recorded values are thrown away and the middle 22 are averaged to get the final inrush current value which is then compared with the limit.

Class Definitions

The limits for the harmonic current testing depends on the class of the EUT. Here are the class definitions:

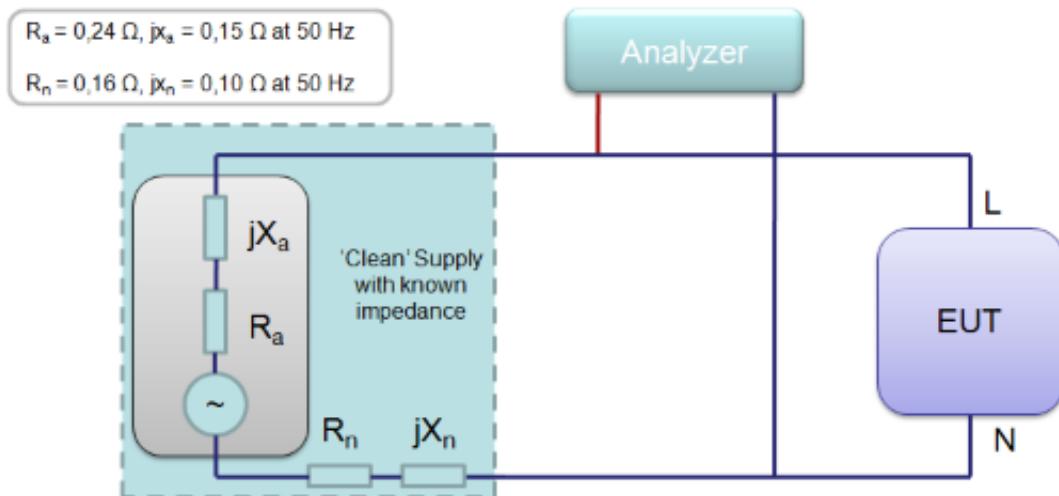
A: Balanced three-phase equipment, and all other equipment except that stated in one of the remaining three classes

B: Portable electrical tools, which are hand held during normal operation and used for a short time (a few minutes) only

C: Lighting equipment, including dimming devices

D: Equipment having an input current with a "special wave shape" e.g. Personal computers and personal computer monitors, Television receivers. Note: Equipment must have power level 75W up to and not exceeding 600W

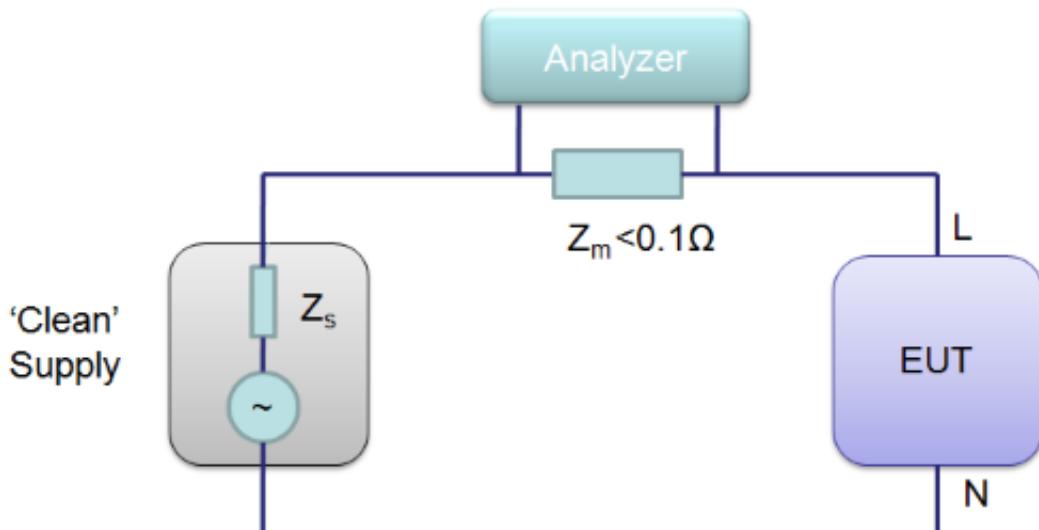
Flicker Measurement Circuit



As you can see, the simplified diagram of this measurement circuit isn't very complex.

All the analyzer is doing is measuring the voltage across the EUT. There is a calibrated complex source impedance, so the analyzer can work out the voltage fluctuations across a range of frequencies.

Harmonic Current Measurement Circuit



The test setup for measuring harmonic currents is very similar, only a sense resistor is added in series.

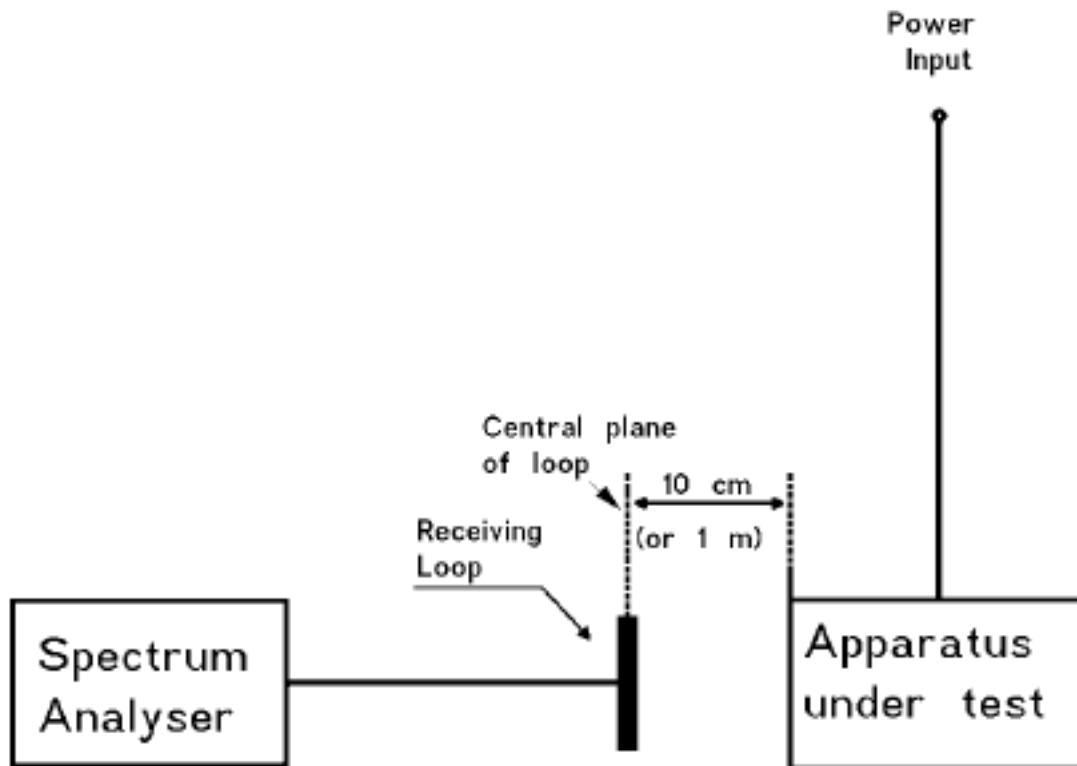
By measuring the dynamic current consumption across the frequency range of interest, the analyzer is able to calculate the current consumption of the power supply harmonics.

Magnetic Field Testing

Magnetic field testing is a pretty uncommon test, but some standards do mandate it. Magnetic fields are predominantly present at lower frequencies and measurements are usually made with a large loop antenna that is placed very close to the EUT.

You can see a sample test setup specified below, which is taken from the professional audio product family standard (EN55103).

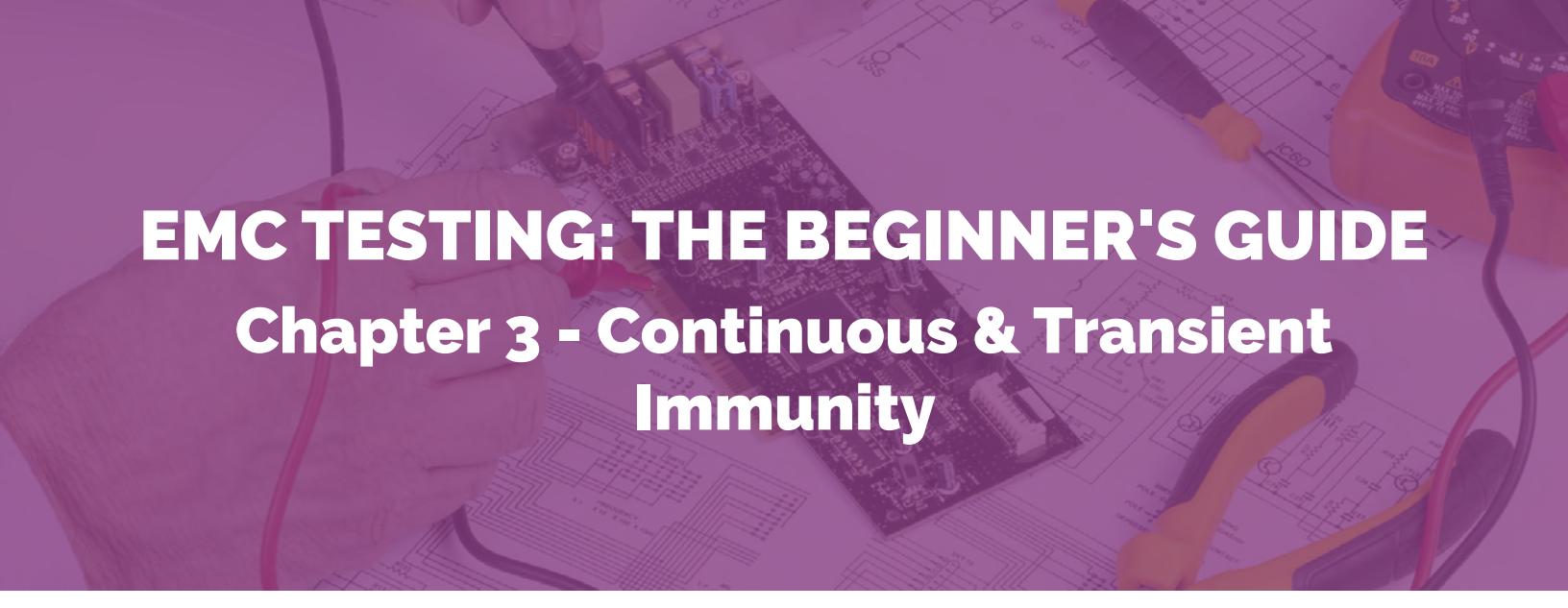
We're also going to take a look at magnetic field immunity testing in the next chapter.



Conclusions

If you've read this far, you now have a great idea of every single emissions test that your product may have to comply with!

Now you know the 'problem definition', i.e. this is the hurdle you have to jump over. In the following chapters, we'll begin to dig into the 'problem-solutions' so that you can increase your chances of passing these tests.



EMC TESTING: THE BEGINNER'S GUIDE

Chapter 3 - Continuous & Transient Immunity

You're going to need to consider immunity test requirements under lots of circumstances: If you're shipping to Europe or Australia (and many other specific regions), if you're using international product standards (published by IEC) or if your product is designed for a specific industry that mandates immunity testing (such as medical, military, aerospace and automotive to name a few).

In this chapter, we're going to cover what each of the main immunity test requirements are and how they may affect your product.

Here's what we'll cover in this chapter:

- ✓ What is EMC Immunity Testing?
- ✓ Transient tests (ESD, EFT, Surge, Power Quality)
- ✓ Continuous Tests (Conducted, Radiated and MagneticField)
- ✓ Typical Failure Modes for Each Test
- ✓ Pass Criteria
- ✓ Links to Low Cost Standards

What is EMC Immunity Testing?

Immunity testing is just the application of some electromagnetic phenomena to your product. So you can think of it as the opposite of emissions testing. Instead of measuring what's coming from your product, immunity testing involves subjecting your product to EM phenomena.

Continuous vs. Transient EMC phenomena

Of the several EMC immunity tests, some are continuous (usually modulated) waves and others are very short bursts (transient) phenomena. The continuous tests are applied to your product over a period of time (minutes to hours). The transient phenomena may have come and gone in a matter of microseconds.

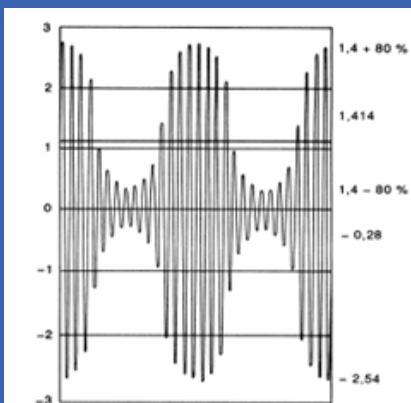
Here is a top level breakdown of the most common immunity phenomena:

What are the EMC Immunity Tests?

Despite the huge number of individual product and family standards covering many geographic areas and many industries, all of them come back to these base EMC immunity tests (or close variations of them) that I'm going to describe below.

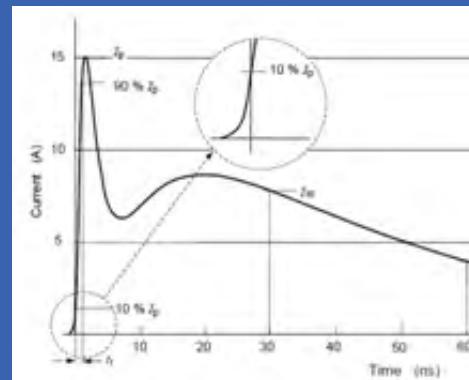
Related Post: [The In-House EMC Test Equipment Guide](#)

Continuous

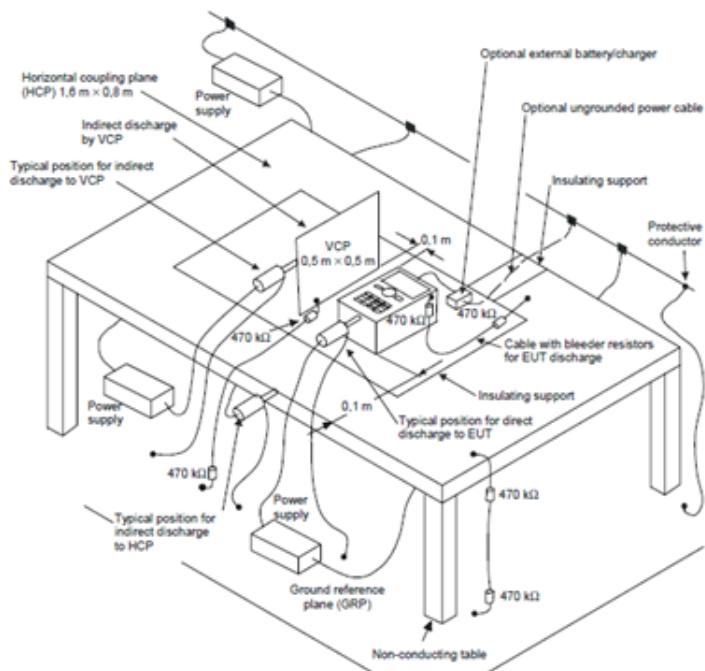


Continuous EMC phenomena are applied to your product over a period of seconds to minutes via a transducer.

Transient



Transient EMC phenomena are very short duration (ns to us) bursts of energy (voltage and current).



ESD testing is a very common form of EMC immunity testing. You know that little zap you get when you step out of your car and touch the metal?

That's ESD in action - your body (or the car chassis) accumulated a large voltage and when you touched the car, this voltage differential (of several kV) causes a spark to arc between you and the car.

ESD testing involves applying electrostatic discharges to any areas of your product that are normally accessible to a human touch.

Discharge Profile

An electrostatic discharge to your product happens really quickly.

As you can see from the diagram, the bulk of the energy has dissipated within 100ns.

That means that any protection circuitry you select has to be able to react quickly to ESD events.

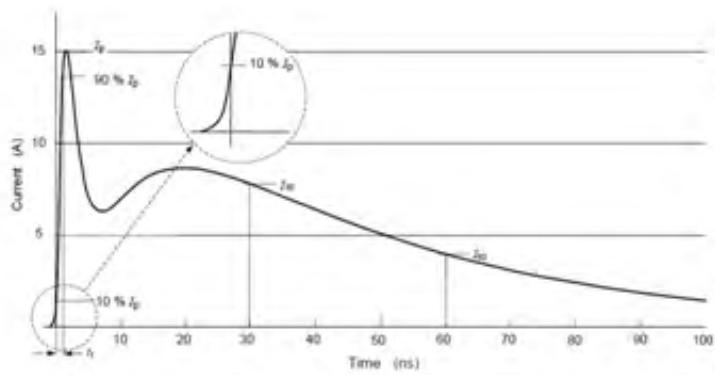


Figure 2 – Ideal contact discharge current waveform at 4 kV

Discharge Tips

There are two types of discharge tips used for ESD testing. Here they are...



This is an 'air' discharge tip. During an 'air discharge' test, the tip is charged up to full voltage, then the tip is moved closer to the EUT. When the tip gets close to a conductive surface with a sufficiently large potential difference (usually ground), a spark will arc across to the device.



This is a 'contact' discharge tip. During a 'contact discharge' test, the uncharged tip makes contact with a point on the EUT. The test engineer then engages the trigger on the ESD simulator which charges the tip up to the test voltage and discharges the energy through the EUT (if a discharge path exists).

What test levels will be applied?

Here are some common test levels that are used when testing electronic devices. The test levels will be defined for your product in your product standard.

A very common test level is 4kV contact, 8kV air, but these values could be higher or lower depending on your standard.

A test lab will start at a low voltage (say 2kV), then if your product passes the lower level, they will increase the voltage and test again. Ideally your product will pass at the specified voltages, but often products exhibit some failure modes at lower levels.

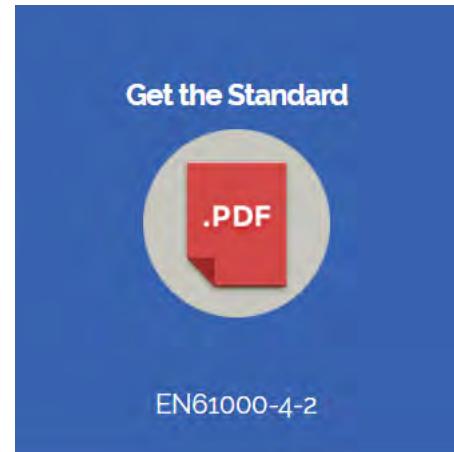
| ESD Test Levels | | | |
|-------------------|--------------------|----------------|--------------------|
| Contact discharge | | Air discharge | |
| Level | Test voltage kV | Level | Test voltage kV |
| 1 | 2 | 1 | 2 |
| 2 | 4 | 2 | 4 |
| 3 | 6 | 3 | 8 |
| 4 | 8 | 4 | 15 |
| x ^a | Special | x ^a | Special |

a) "x" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification. If higher voltages than those shown are specified, special test equipment may be needed.

What are some typical failure modes?

ESD tests can often be hard to pass. The short burst of high energy can cause lots of issues with your device. If you don't have adequate grounding and protection, here are some of the classic issues:

- Resetting
- IC port damage
- I/O communication failures
- LCD damage
- Memory corruption
- Digital logic errors

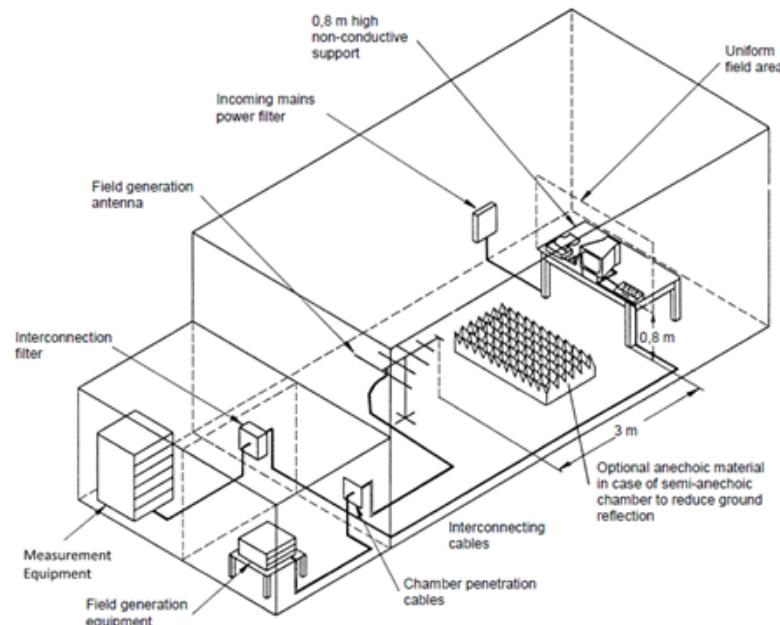


Radiated Immunity (IEC/EN61000-4-3)

The theory behind the radiated immunity test is that your device will encounter many different types of electric field disturbances in normal usage.

Someone might use a cellphone next to it; someone might operate a motor next to it. There are lots of electric field sources that may interact with your device.

This test is intended to see how well your product performs when it's subjected to an electric field of a specified amplitude (measured in volts/meter) across a range of frequencies.



Radiated Immunity

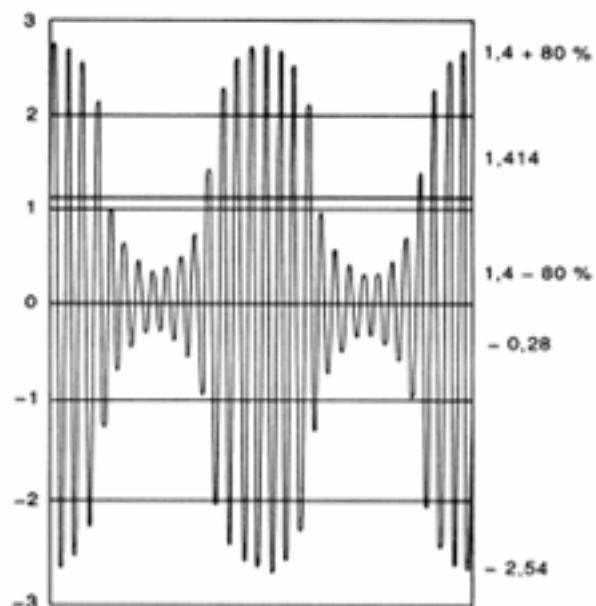
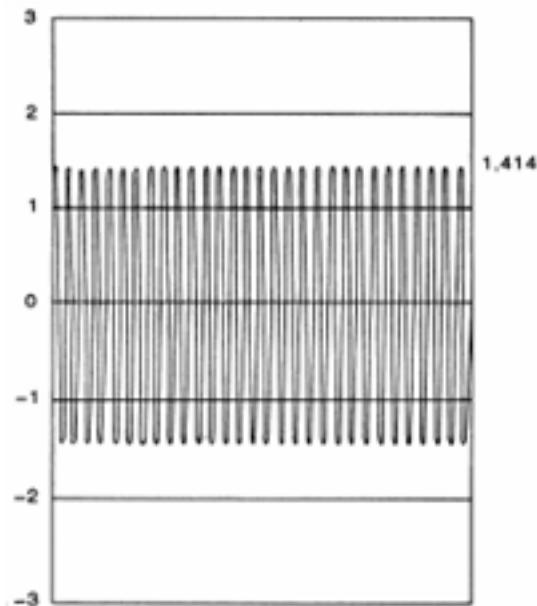
- Essential Equipment
- Semi-anechoic chamber (or GTEM)
- Signal generators (often 3 required to cover entire frequency range)
- RF broadband power amplifiers (also often 3 required)
- Automation software
- Antennas (Often need to use 2 or 3 types)
- Attenuators

Radiated Immunity Field

During this test, your equipment is going to be subjected to a uniform electric field. The test lab has calibrated the field at several points around the test area that your product will sit within.

The field is generated in this way: A signal generator feeds a modulated sine wave to a broadband RF power amplifier. The output of the amplifier is connected to a transducer (an antenna), which turns the varying conducted voltage into a varying radiated electric field.

The field is usually modulated at 80% with a 1 kHz sine wave. For some standards, the modulation frequency and depth are different.



Typical Test Levels

- 1 V/m
- 3 V/m
- 10 V/m (industrial)
- >200 V/m (military + automotive)

Typical Frequency Ranges

- 80 MHz - 1 GHz
- 1.4 - 2.0 GHz
- 2 - 2.7 GHz
- Other standards may reach higher and lower.

What are some typical failure modes?

Radiated electric fields are most often picked up by a product's external cabling. That's because at the lower end of the radiated immunity frequency range, cables of length 1-3 metres can act as really effective receiving antennas.

At the higher frequencies, traces on your PCBs begin to become more effective at receiving energy from electric fields. The field can induce voltages on both analog and digital signals, so you can imagine that there is a host of issues that this can cause.

Here are a few of the common ones:

- Measurement errors (for EUTs with analog sensing)
- Wireless interference (for EUTs with transmitters)
- 1 kHz audio (The EUT often demodulates the modulation signal)
- Digital logic errors (if your eye diagram is very small and signal integrity is poor)

Get the Standard



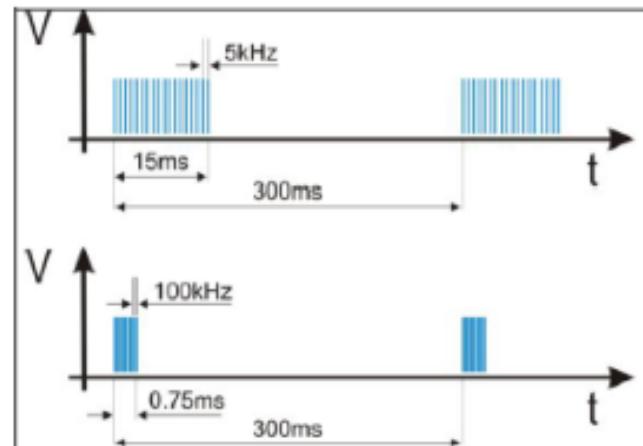
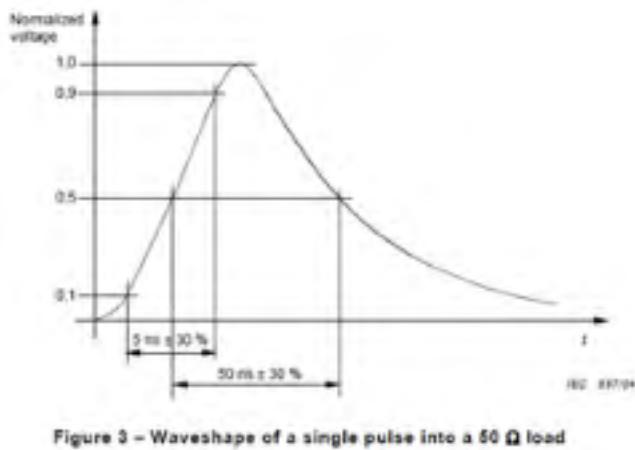
EN61000-4-3

Electrical Fast Transient (EFT) - IEC/EN61000-4-4

The EFT immunity test is an attempt to simulate switching of inductive loads in the real world. Here are a few examples of inductive load switching that could perceptibly affect your product:

- Toggling electric switch nearby
- Bundled cables can capacitively couple disturbances from switched loads other cables
- Motors and relays
- Fluorescent lamp ballasts

So what do the EFT disturbances look like?



EFT is a transient EMC immunity test, so the disturbances happen very quickly.

To the right is an example of an EFT pulse. For this particular pulse, the voltage risetime is approx 5ns with a pulse width of approximately 50ns.

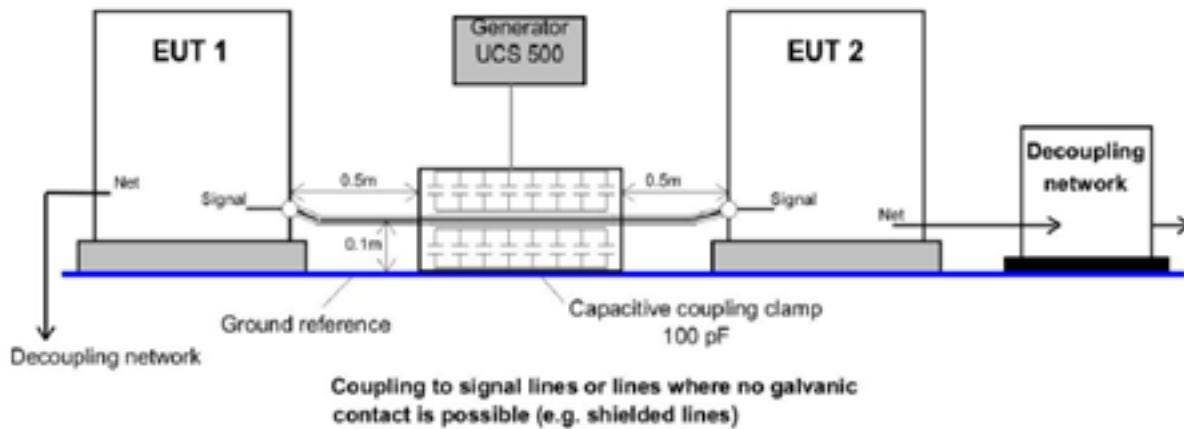
There are other profiles of EFT pulses for different standards but this is the most common for 61000-4-4 compliance.

The test involves several 'bursts' of these pulses, with a delay inbetween bursts. The length of the bursts, the frequency of the pulses and the delay between bursts varies between standards. But here you can see a couple of the most common configurations.

Where will EFT be applied to your product?

There are a couple of injection points and methods for EFT. The first and most common is via an AC power cable. Even if you're using an external AC-DC power adapter, an EMC lab will most likely still inject EFT pulses onto the line and neutral wires.

Also, EFT is normally applied capacitively to signal/control ports who's cables will be >3m in length. For capacitive coupling, the signals are simply fed through a capacitive coupling clamp, which couples the disturbance to the cables.



EFT Essential Equipment

- EFT/burst generator
- Capacitive coupling clamp



- Automation software

Direct Coupling

- For power ports, the EFT disturbances are injected directly onto the relevant signals with a carefully defined source impedance.

Capacitive Coupling

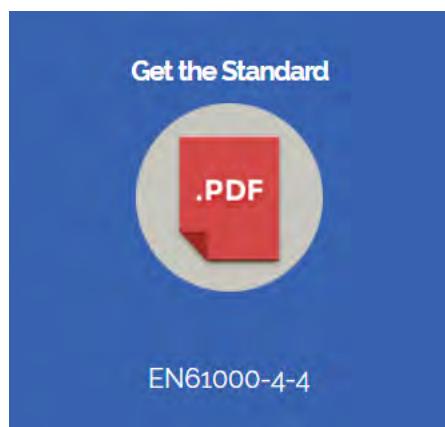
- When EFT has to be applied to signal ports (e.g. USB, ethernet), the disturbance is usually applied capacitively using a clamp (see above) rather than direct injection.

What are some typical failure modes?

Energy from EFT testing can find its way into many parts of your circuit. Entry points are via your power cable or other cables connected to your product, so without proper chassis grounding or common mode suppression, the disturbance can cause you some headaches.

Here are a few of the common issues:

- EUT resets
- Damage to ICs/hardware
- Failing auxiliary equipment
- Communications links drop out
- Temporary analog measurement errors
- Audible clicking (audio products)



Surge - IEC/EN61000-4-5

The surge immunity test is designed to simulate low frequency power surges.

Here are a few examples of places where you would expect to see surge events:

- Power switching events
- Insulations faults on the power grid
- Nearby switching reactive loads (e.g. motors)
- Fuses blowing (flyback voltage)
- Nearby (indirect) lightning strikes

A typical product plugged into a residential AC power socket can expect to see 3 x 6kV power surges per year!

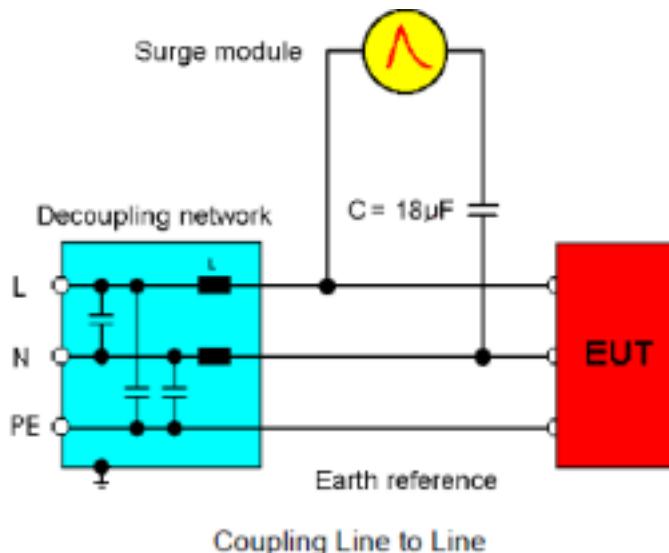


Surge Coupling Methods

Surge is usually applied to AC (or DC) power input ports, but in some standards, it is also to be applied to signal ports.

The surge pulses are usually coupled directly to the signals via a carefully defined source impedance (e.g. 2Ω , $18\mu\text{F}$ in series).

The coupling network is usually contained inside an immunity test system along with a decoupling network which helps to protect the power supply or auxiliary equipment.



What are some typical failure modes?

Surge testing involves a lot of energy. The currents involved can easily exceed 100A for a short period of time. With this amount of energy, it's really easy to do damage to your product.

Here are a few of the common issues:

- Frying ICs
- Cabling breakdown
- Thermal issues
- Arcing is common
- Damage to motor windings

Recommendations

- Use power supply with surge protection of correct rating (legitimate CE Marked supplies will have protection, but check the rating)
- Design in your own protection using protection components such as TVS diodes or MOVs etc.
- The location and routing of protection circuitry is critical to its effectiveness.

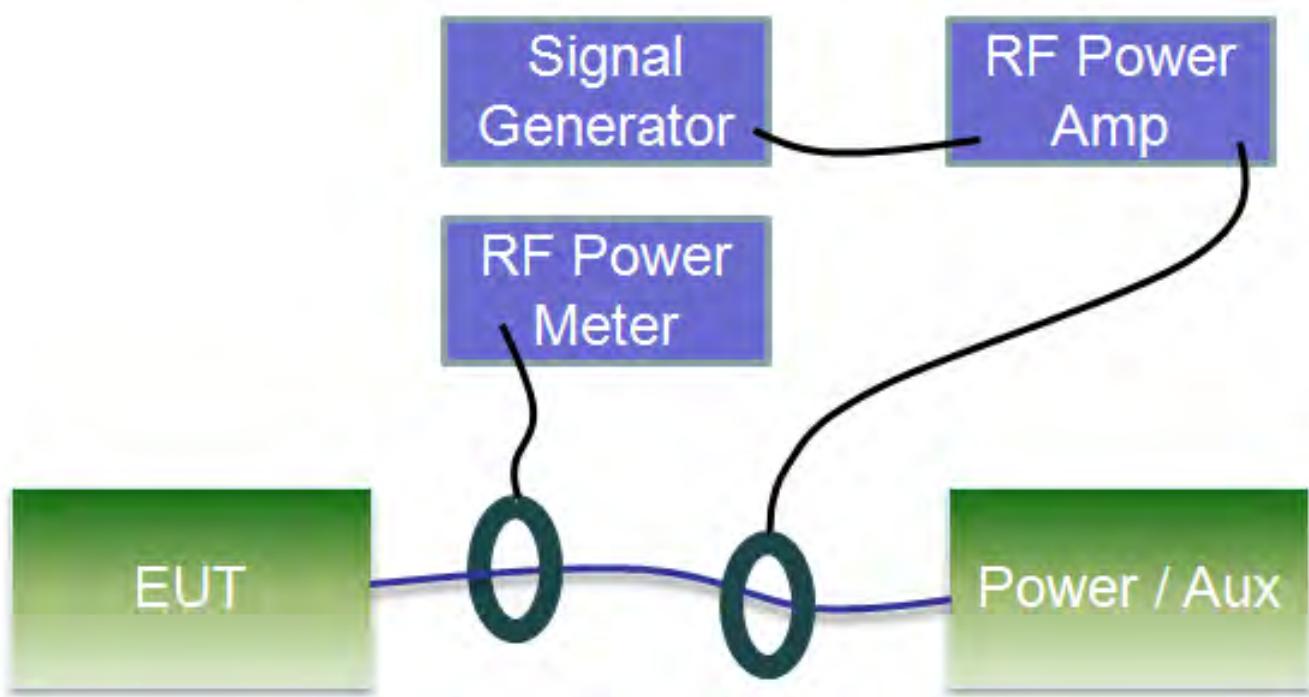
Conducted Immunity - IEC/EN61000-4-6

Conducted immunity testing is used to simulate the normal voltage and current environment of external power and signal cables.

When cables are bundled together they can have both capacitive and inductive coupling. This test simulates adjacent cabling by injecting a common mode disturbance into your cabling using a transducer.

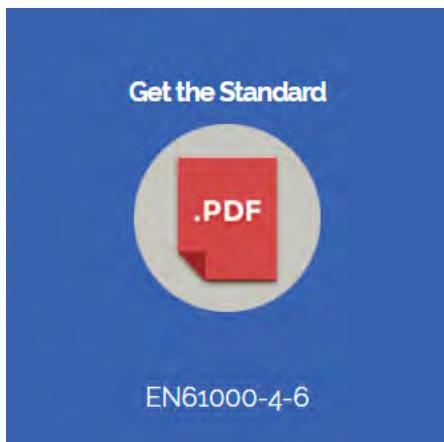
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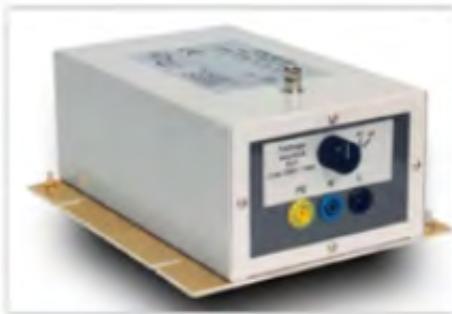
Conducted Immunity

- Essential Equipment
- Signal generator (<150 kHz to >80 MHz with AM)
- RF power amplifier (>50W)
- Transducer (4 types)
- Current monitor probe
- Attenuator
- Automation software



Conducted Immunity Transducers

CDN



CDNs are the preferred transducer. They're not always used because you need a lot of them to cover different cable types and connectors.

BCI Probe



BCI probes are very convenient but it's hard to get repeatable results due to the unknown input impedance of the EUT and auxiliary equipment.

EM Clamp



Also convenient, but again there are problems with repeatability of the tests. BCI probes are preferred over these.

Direct Voltage Injection



As a last resort, EN61000-4-6 allows the use of direct injection of the disturbance via a resistor.

What are some typical failure modes?

This test can be quite hard to pass because you usually have to meet criteria 'A' (see below for definitions).

Here are a few of the common issues:

- Audible rectification of the 1 kHz modulation frequency
- Measurement errors due to supply or signal ripple
- Resetting of ICs

Recommendations

- Apply RF common mode filtering to a cable interfaces (either low impedance capacitive filtering to chassis or high impedance common mode choke)
- Consider cable screening with an effective range up to at least 200 MHz)
- Implement bandwidth limiting on analog input cabling

Magnetic Field - IEC/EN61000-4-8

Some product standards call for magnetic field immunity testing.

The most common type of magnetic field immunity testing is what's called 'AC power line' which means that the magnetic field generating transducer will be driven with a 50/60 Hz signal to simulate the AC power supply.

This version of the test is to ensure that your product works properly in the presence of magnetic fields generated by nearby power cabling.

Some other magnetic field test variations involve sweeping a band of frequencies and also applying a modulation frequency.



Magnetic Field Immunity -Essential Equipment

- Signal generator (if not powerline magnetic field testing)
- Variac
- Current Transformer
- H-field transducer (wire loop)
- Immunity test system (optional)
- Automation software (optional)

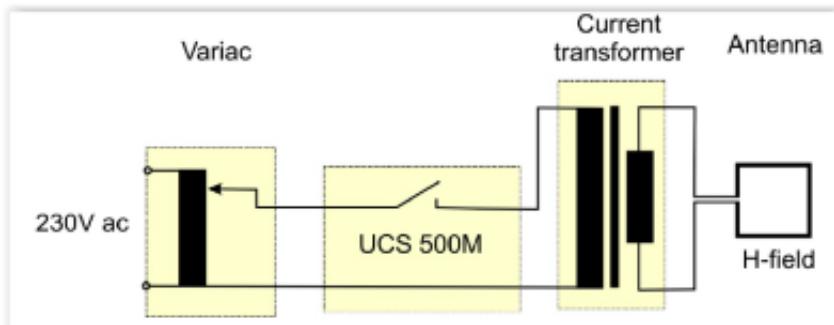
How is the magnetic field generated?

For power line magnetic field testing, the setup is pretty simple.

You can see from this diagram that a variac is connected to the mains AC voltage. The tap point of the variac define the voltage that's fed to a current transformer.

By varying the voltage, you can vary the current in the H-field antenna (the transducer) and therefore set the magnetic field strength (measured in Amps/m). The antenna just a loop or several loops of electrical wire. The varying current through these loops generates a magnetic field.

As you can see from the picture above, the EUT sits within the antenna so that it's subjected to a uniform magnetic field.



Get the Standard



EN61000-4-8

Which components are susceptible to magnetic fields?

There are a few types of components that can be particularly susceptible to magnetic fields. Often the test is exempted if your device doesn't contain any components that could perceptibly be affected by a magnetic field. But, here are some to watch out for:

- Relays
- CRT monitors
- Hall elements
- Electrodynamic microphones
- Magnetic field sensors etc..

Voltage Dips, Drops & Interruptions - IEC/EN61000-4-11/-29

This EMC test is to simulate voltage dips and short brownouts on AC or DC power supplies.

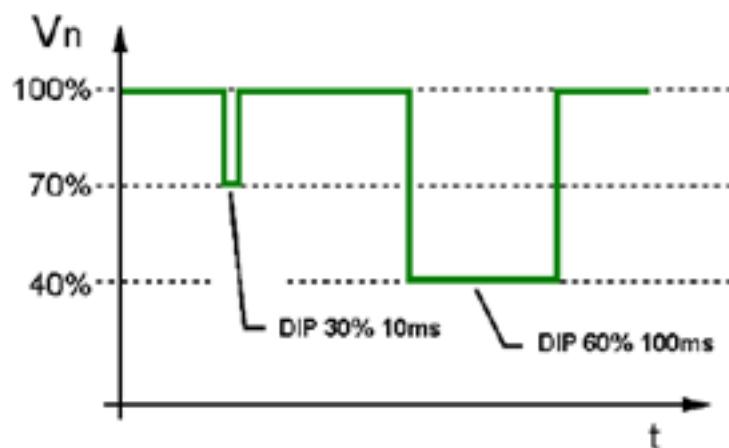
It helps to ensure that your equipment functions properly (as expected and safely) with power supply fluctuations.

The duration of the voltage dip and the depth of the dip vary and are defined in your standard.

As you can see from this diagram, the dips happen for a period in the order of milliseconds.

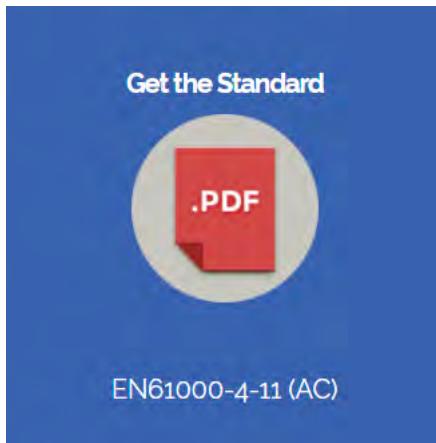
For many pieces of equipment that use external AC/DC adaptors that operate down to lower voltages, this test rarely causes issues.

But issues often turn up for equipment that is connected directly to an AC or DC power supply.



Voltage Dips/Drops

- Essential Equipment
- Immunity test system
- Auto-transformer
- Automation software

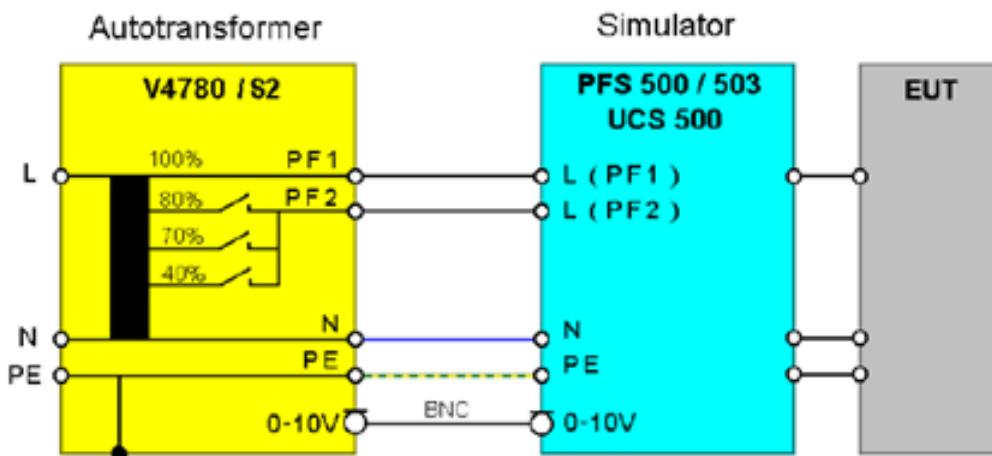


Voltage Dips Test Setup

For AC voltage dips and interruptions, the test setup will look something like this.

A tapped auto-transformer selects the dip level and an immunity test system controls the selection using an analog feed signal.

The immunity test system controls the length of the dip and switches between 100% and the dip signal to create the momentary drop in voltage.



Recommendations

- Make sure your watchdog timer works properly
- Ensure the system reboots into an acceptable mode when the device resets

Pass/Fail Criteria

To evaluate whether your product passes or fails each EMC immunity test, an EMC test lab needs to know what an acceptable degradation of performance actually is. They need to monitor your equipment during and after each test and watch for any changes to the behavior or operation.

The performance of your product usually falls into categories A,B,C and D, but this is dependent on the standard that applies to your product. The definitions below are taken from the European generic immunity standard for residential, commercial and light industrial environments (EN61000-6-1). Yours will probably look pretty similar.



Criteria A, that's considered perfect. That means your product performs normally and within specifications that you specify, usually in the product manual, during and after the test.

So essentially nothing bad happened to your product during or after the test.

Criteria B, on the other hand, the product may have had a temporary loss of function or degradation of performance which ceases after the applied disturbance ceases.

So after the test finishes, the equipment under test recovers its normal performance without operator intervention. That just means that the operator didn't have to do anything to get it back into a mode that it was in before the test started.

Criteria C, is the same as B, but you're allowed operator intervention as well.

So maybe you have to power the device back on. Maybe the EMC phenomena reset the device and you need to power it back on manually.

Criteria D, is that there's a loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software or loss of data.

So basically in some way the test has trashed your product. It might have fried some components or caused corruption of some data.

Conclusions

So those are the EMC immunity tests that your product may have to face. Now that you know what they are, you can begin to start thinking about how to prepare your designs for testing.

In the following chapters, we'll be digging into preparation and pre-compliance testing. You'll get a full view of how large companies set themselves up for success against EMC testing requirements!

EMC TESTING: THE BEGINNER'S GUIDE

Chapter 4 - EMC Testing Preparation

Looking for a step by step process to prepare for EMC testing? Look no further - in this chapter we delve into the process for EMC test preparation.

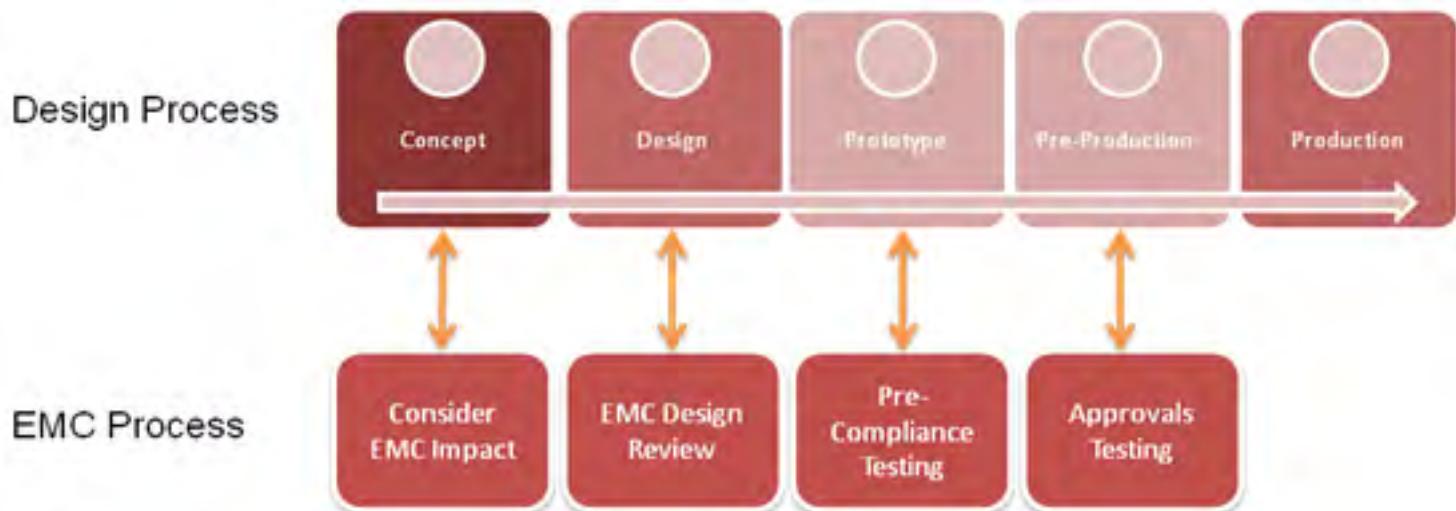
Here's what we'll cover in this chapter:

- ✓ EMC in Your Project Schedule
- ✓ How to Get/Analyze Your Test Requirements
- ✓ PCB and System Design For Compliance
- ✓ EMC Design Reviews
- ✓ Pre-Compliance Testing
- ✓ Preparing Your Hardware and Software For Testing

Let's Get You Started

This beginner's guide to EMC testing is an in-depth tutorial on all aspects of EMC testing. This guide covers the fundamentals of everything you need to know to be able to navigate, prepare and pass EMC testing.

Where Does EMC Testing Preparation Fit Into Your Schedule?



This diagram is just a different way to visualize the information already covered in this chapter of the guide.

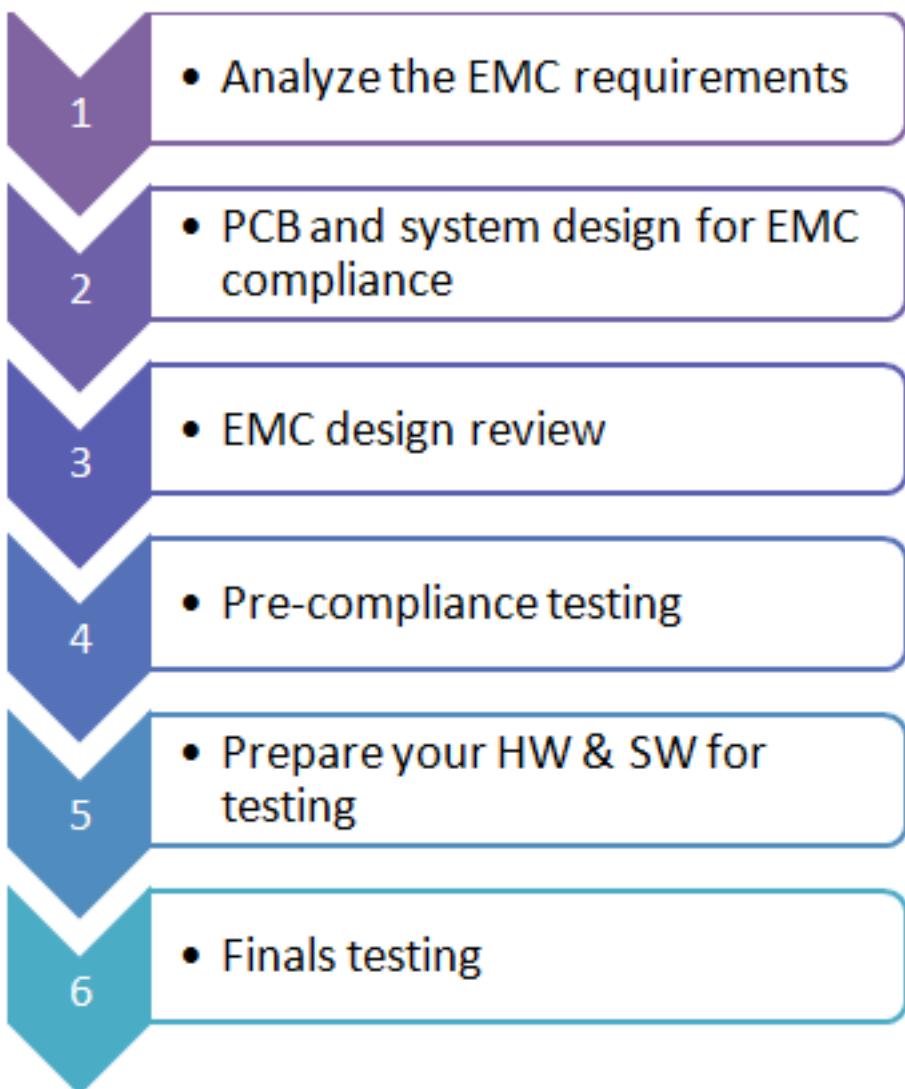
You can see how each step of EMC preparation fits into your overall product design cycle and when you should be thinking about each step.

EMC Testing Preparation - Step by Step Process

You can see a basic process flow for EMC testing preparation in the right hand sidebar. In this section, we're going to walk through several important steps in the lead up to EMC testing.

Step 1 - Analyze the requirements

First things first, you need to know what the test are that your device is going to have to pass at an EMC test lab. Do you need to pass radiated and conducted emissions only, or will your device be subjected to a suite of EMC immunity tests as well? Which ports will be tested? Which levels will be used? What limits will be used? What are the pass and fail criteria? The EMC test requirements specific to a particular product is called an "**EMC test plan**". There are a couple of ways to get a hold of this:



a) Contact your test lab

Just ask your test lab for an EMC test plan for your product. They will request details about your product on things like: power supply, signal/control ports, what is the application and things like that. With this information, they will be able to draw up a test plan which itemizes the standards, tests and levels for each port.

b) Create one yourself

If you've been through this process before with a similar product, the chances are that you know what standards are applicable and what each test is. In many cases, you may just be able to copy and past the test plan from a previous test report. If you don't have that luxury, you'll need to find the standards that apply to your product, then analyze the emissions and immunity tests that the standards call out.

Refer to the previous chapter for help with working out which standards apply and check out the in-depth webinar on how to put together your own test plan (and some other cool stuff).

Step 2 - PCB and system design for EMC compliance

Now that you've nailed down the EMC tests and requirements that you have to pass, you now need to design your product in a way that's going to meet those requirements.

Have you used the correct rating of power supply adapter? Do you need to pass class A or B emissions? Is your ESD protection implemented correctly? Will surge testing be applied to your power supply? Do you have the correct immunity protection components in place?

There are loads of textbooks on the subject of PCB design for compliance and most of them are big enough to choke a donkey.

EMC design for compliance is a vast subject because it covers so many aspects of electronic engineering.

If you want to master this discipline, it's going to take lots of learning, covering subjects including power supply design, power network analysis, decoupling, high speed design and signal integrity to name a few aspects.

I worked with several experts over a period of 6 months to create the most in-depth online course on EMC design for compliance currently available. If you're interested in mastering this subject, here is the course: [EMC design for compliance \(Emissions\)](#).

More EMC design resources:

- [EMC design for compliance \(emissions\) 24 hour online training course](#)
- [EMC design for compliance free webinar](#)
- [EMC design for compliance in-depth online training course](#)
- [Essential EMC Design Rules To Avoid The 7 Most Common EMC Failures](#)

Design For Compliance

Unfortunately design for EMC compliance is a huge subject.

It's tempting to look for simple 'EMC design rules' and quick fixes, but ultimately this is just the tip of the iceberg.

That's probably why the first time pass rate is so low, but fortunately that gives engineers and manufacturers who spend time to learn about the subject a distinct advantage over those who don't.

Step 3 - EMC Design Review

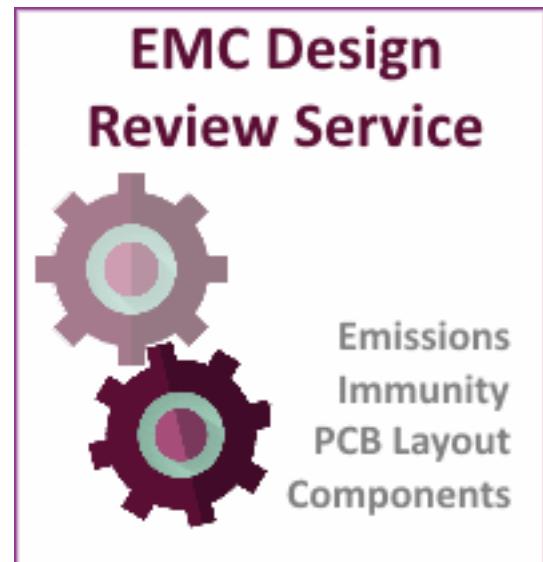
At this point, you're just about to get the first or second prototype of your product manufactured.

Before you press the big green 'GO' button on the manufacturing run, it's a great idea to do an EMC design review.

In exactly the same way that you and your team would do a PCB and schematic design review to catch hidden errors in your design, an EMC design review helps to do the same thing from an EMC perspective.

Companies like Ford and Jaguar have implemented design review procedures to help them pass first time. IBM even created a design review which [according to their own reports](#), reduced the number of PCB iterations by 1 or 2 and got them to a place where they were consistently passing EMC testing first time around.

EMC FastPass has also created and refined a design review procedure with over 150 checks. You can read more about how [we do EMC design reviews here](#).



Step 4 - Pre-compliance testing

When your design is close to being finalized, it's prudent to do some EMC pre-compliance testing.

Because emissions and immunity performance is very dependent on the way in which you've designed your product, for pre-compliance testing results to be indicative of how the final testing will go, it's important that your device doesn't change much between pre-compliance testing and finals testing.

There are lots of options for emissions and immunity pre-compliance options available. We'll be digging into those options in the upcoming chapters, but you can also check out the [emissions pre-compliance guide](#) from EMC FastPass which highlights some of the most popular options.

The "[In-House EMC Testing Equipment Guide](#)" also covers a good overview of immunity pre-compliance test equipment.

If your pre-compliance testing is accurate and comprehensive enough then you're going to have addressed the majority of EMC emissions and immunity issues before you get to final testing.

In the following chapters I'll be digging into what makes pre-compliance test equipment accurate and what the cost vs performance trade offs are.

Step 5 - Prepare your hardware and software for testing

One of the best ways to lose 1-2 weeks time to market is to forget to send some items that are crucial for EMC final testing.

Here is an EMC preparation checklist of items that you should include with your product when you send it to an EMC test lab:

- Your product along with any peripheral equipment that constitutes the complete system
- Include any auxiliary/optional equipment that may be needed for testing. e.g. if your device has a USB port, provide a USB peripheral that would typically be used for that port. If you don't ship a device with a USB peripheral, provide a 'typical' unit. Make sure that unit is compliant so that it doesn't cause you to fail a test.
- If it isn't possible to provide functional auxiliary equipment for a particular port, often dummy loads are acceptable. When you can't provide auxiliary equipment, provide a dummy load that exercises a port to its fullest extent. E.g. Load a power supply output port with a load resistor with a value that ensures the highest rated current draw from the power supply.
- Provide all cables that are needed to exercise your equipment to the fullest extent. Cables should be of a typical length used in normal operation.
- Provide a firmware/software test mode that exercises your equipment to the fullest extent. Regulatory agencies want to know what 'worst case scenario' emissions and immunity performance is. This usually involves exercising all moving parts, all communication interfaces and all memory interfaces at the highest speed.
- Provide 2 or 3 alternative 'backup' power supply units. This can be useful if you fail conducted emissions testing. Swapping out an external power adapter with a better performing adapter can often cure conducted emissions problems. More adapters can also be useful if you're doing surge testing, which can be destructive to power supplies.

- Supply proper documentation for the test engineers. If they don't know how to operate your product or set it up into the correct test mode, then the test schedule will be delayed.
- Supply a monitoring method. For immunity testing, a lab needs to monitor the performance of your product. It is helpful for EMC test labs if you clearly define the method by which you would like your product to be monitored.

If the test lab has all of the equipment, all of the cabling and auxiliary equipment as well as firmware that fully exercises your product, then the EMC test schedule is likely to go a lot more smoothly, and thus you'll avoid delays.

Step 6 - EMC Finals Testing



When you've got your final production units in your hands, it's time for final testing.

This is where an EMC test lab will put your product through the full range of tests outlined earlier in the EMC test plan.

Hopefully based on your diligent EMC design review and EMC pre-compliance testing, there are no surprises when it comes to final testing!

Conclusion

In this chapter we covered how to prepare for EMC testing. I hope that this step by step process can help to guide you through the EMC minefield!

EMC TESTING: THE BEGINNER'S GUIDE

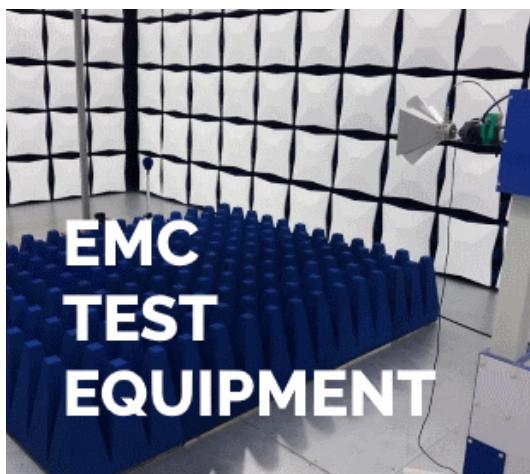
Chapter 5 - Pre-Compliance - EMI

In this section of the guide, we're going to dig into an important part of preparing for EMI/EMC testing: emissions (EMI) pre-compliance testing and equipment.

You'll learn about various options for test equipment, what an ideal test site looks like and what you'll want to avoid with test equipment purchases.

Here's what we'll cover in this chapter:

- ✓ What is the Difference Between EMC Troubleshooting and EMC Pre-Compliance Test Equipment?
- ✓ Near-Field vs. Far-Field Measurements
- ✓ What Makes a Full Compliance Test Site Accurate?
- ✓ What to Buy on a \$1k, \$10k – \$15k or \$100k budget?



Visit EMC FastPass's online test equipment store

EMC Pre-Compliance vs. EMC Troubleshooting Equipment

Let's keep in mind that the main goal of emissions pre-compliance testing is to work out whether your device is going to pass or fail at an EMC lab. It isn't whether your device is emitting radiation - in fact we know it definitely is - we just want to know whether those emissions are within the limits.

Some EMC test equipment claims to be 'pre-compliance' equipment when it's actually only useful for EMC troubleshooting. As an example, a near field probe is good for tracking down an emission source and isolating the frequency of the emission, but it's next to useless for telling you whether that emission will be a problem at an EMC test lab.

EMC TEST LABS GO TO GREAT LENGTHS TO CREATE A TEST SITE THAT PROVIDES ACCURATE FIELD STRENGTH MEASUREMENTS. DESPITE THEIR INVESTMENT OF TENS OR HUNDREDS OF THOUSANDS OF DOLLARS IN TEST EQUIPMENT AND FACILITIES, THEY CAN STILL ONLY BARELY MEET THE ACCEPTABLE ERROR BUDGET, WHICH IS +/- 4dB FROM AN 'IDEAL' TEST SITE.

Often FCC registered test sites struggle to even meet this error budget as outlined in this 'elephants in the test room' webinar.

You typically won't be able to get anywhere near +/- 4 dB of an ideal measurement using troubleshooting EMC equipment. The error may be closer to +/- 40 dB which is no good for working out whether you're going to pass or fail at an EMC test lab.

So when we're choosing emissions pre-compliance test equipment and making emissions measurements, we need to keep this error budget in mind. If we can be within +/- 4 dB of an ideal site, then we're doing as well as a full compliance EMC test lab. To do that, you're going to need a full compliance setup, which we'll get into below.

Without investing in a full compliance setup, a more modest goal might be to get within +/- 10dB of an ideal site.

IF WE FACTOR IN A MARGIN OF 10 DB WITH OUR PRE-COMPLIANCE MEASUREMENTS, WE COULD GET A VERY GOOD IDEA OF WHETHER WE'LL PASS OR FAIL AT A TEST LAB.

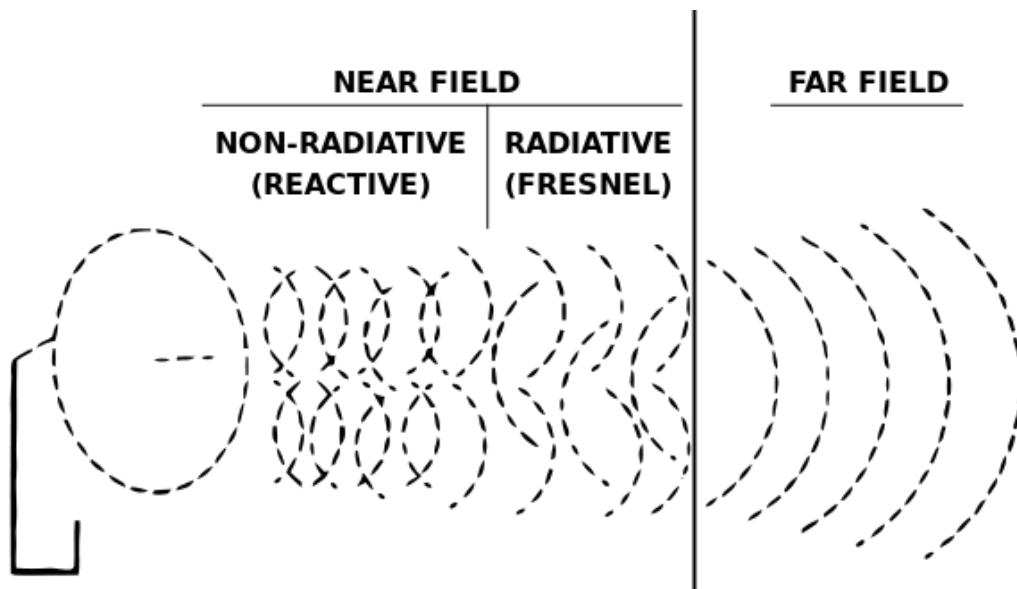
EMC Troubleshooting

EMC troubleshooting equipment like near field probes are good for isolating RF sources and frequencies. You can make reasonable 'relative' measurements, but not so good 'absolute' measurements.

EMC Pre-Compliance Equipment

Good EMC pre-compliance equipment is able to either measure directly or extrapolate to 'absolute' field strength values in the far field (at 3m or 10m measurement distances typically).

Near Field vs Far Field Measurements



With near field probes, you're typically measuring an electric or magnetic field in the near field (within 1 wavelength) as opposed to the far field.

When you're measuring in the near field, it's almost impossible to accurately extrapolate to an absolute field strength value in the far field because the relationship between the E (electric) and H (magnetic) fields are complex.

In the near field, there are strong inductive and capacitive effects from the PCB/system structures that are behaving like antennas, which causes the fields to behave unlike far field radiation fields.

Antenna Separation

At an FCC listed/accredited measurement facility, the separation between the equipment under test (EUT) and the measurement antenna is typically a minimum of 3 meters, but preferably 10 meters.

Measuring at 10 meters means that you're measuring at least 1 wavelength away (some people's rule of thumb definition of the beginning of the far field region) at a frequency of 30 MHz which is often the lower end of the measurement range. This means that for the most part, they're measuring the electric field strength of a stable wave in the far field.

Absolute vs. Relative Measurements

Making relative measurements with equipment like near field probes can be useful for EMC troubleshooting, but it doesn't give us a decent idea of whether our product will pass at a lab.

At a full compliance facility the measurements are absolute field strength values measured at a particular separation between the EUT and antenna.

FULL COMPLIANCE EMC TEST LABS CAN SPEND
HUNDREDS OF THOUSANDS OF DOLLARS ON EMC
TEST EQUIPMENT TO BE ABLE TO GET ACCURATE AND
REPEATABLE MEASUREMENTS AS WELL AS CREATE
ACCURATE AND REPEATABLE IMMUNITY TEST LEVELS.

What Makes a Full Emissions Compliance Test Site Accurate?



If we want to make accurate pre-compliance emissions measurements, we need to know what an ideal test site looks like and what the characteristics are that we ideally want to copy.

Here is an outline of the main equipment and facilities of a full compliance lab that help them to meet the +/- 4 dB error budget.

EMI Test Site/Area

The way in which an emissions test site is constructed has a huge bearing on the potential accuracy of the measurements. Below I'll go into the important factors of designing an accurate test site.

Open Area Test Site (OATS)

The properties of an open area test site that allow it to meet the +/- 4dB error budget are:

- Minimal RF reflective objects close to the measurement area

It's important to keep a large clearance between test area and RF reflective (metallic) objects to ensure that the contribution of reflections received by the antenna are negligible.

- Large and flat RF reflective ground plane

The measurement antenna actually receives a field directly from the EUT plus a reflection off the ground plane. It's important that this ground plane is flat so that the reflection is predictable and we can account for it when making measurements.

- At least 3m separation between the EUT and the measurement antenna

As mentioned above, it's important to be in the far field, or close to it, to make accurate repeatable measurements. At 30 MHz, one wavelength is 10m and at 100 MHz one wavelength is 3m. At closer measurement distances, you enter the near field and measurements get much less accurate.

Semi-Anechoic Chamber (SAC)

When you're using a semi-anechoic chamber, there are a few important factors to consider.

A chamber essentially a sealed metal room with RF absorbers lining the inside.



The dimensions of the chamber itself can affect the measurement and the dimensions are influenced by the standards that you want to comply with. You would want to look for the size of chamber called out in the standard that applies most commonly to your product.

Here are some more variables of semi anechoic chambers that influence measurement accuracy:

- The type of absorber material (this needs to be selected carefully to make sure you get adequate attenuation across a wide frequency band, otherwise you could get reflections or standing waves).
- Antenna separation - generally 3m, 5m or 10m but smaller chambers exist. Due to the near field effects and limited absorber performance, chambers

smaller than 3m would struggle to meet +/- 4dB measurement accuracy across 30 MHz - 2 GHz. If you're just testing high frequency transmitters, the wavelength is much smaller and you can still be measuring in the far field at closer separations.

"[The Anechoic Chamber Guide For EMC and RF \(Wireless\) Testing](#)" goes into much more detail on the subject.

Full Compliance Test Equipment

As well as a well designed measurement area, to meet the +/- 4 dB error budget EMC test labs also have to invest in accurate measurement devices and transducers.

Spectrum Analyzer/EMI Receiver

Every test lab needs either a spectrum analyzer or EMI receiver to make accurate RF measurements. The performance of these can vary over time and it's important that they're properly calibrated using a high accuracy source periodically. As well as covering the entire frequency range that you need to investigate for your product (e.g. 30 MHz - 5 GHz), the spectrum analyzer also needs to have the correct 'detectors' which match those specified in the standards. Standards typically dictate 'peak', 'average' and 'quasi-peak' detectors. While most spectrum analyzers are able to perform 'peak' and 'average'



measurements, a 'quasi-peak' detector is usually an optional extra. Resolution bandwidths (RBW) are another important factor of spectrum analyzers/EMI receivers. Standard EMI bandwidths are 9 kHz, 10 kHz, 100 kHz, 120 kHz and 1 MHz. These bandwidths are defined in the standards that apply to your product.

IF YOUR SPECTRUM ANALYZER DOESN'T HAVE ALL OF THE BANDWIDTH OPTIONS THAT ARE CALLED OUT IN THE APPLICABLE STANDARDS, THIS IS LIKELY GOING TO ADD A FEW DB TO YOUR ERROR BUDGET.

Antenna(s)

Of course the measurement antenna plays a key role in measurement accuracy. The gain of antennas varies with frequency, so you need to know what the gain is at many points across the spectrum of interest. Antennas must be individually calibrated to get the exact antenna factors needed to extrapolate from the raw measurement values to an accurate field strength measurement. Otherwise the raw data you see on your spectrum analyzer is virtually meaningless.



Turtable

Every FCC OATS or SAC has a turntable. This is required because the emissions from the EUT are usually directional. That is, the emissions don't usually extend in a nice uniform sphere from the EUT - there tends to be an orientation of EUT that produces the highest field strength. The turntable revolves the EUT 360 degrees to present every angle of the EUT to the measurement antenna. When you rotate the EUT you can often see variations in the measurement of +/- 20 dB. If your pre-compliance test setup doesn't revolve the EUT, then your error budget will be vastly increased.



Antenna Mast

In the same way, the maximum field strength at the antenna will be at some particular height. A full compliance test lab needs to move the antenna up and down a 4 or 6 meter antenna mast to make sure it has found the point where the field strength is at a maximum. Again, moving the antenna up and down can easily see measurement difference of several 10's of dBs. If your pre-compliance test setup does not have a movable antenna mast, that's also going to increase your error budget significantly.



Cable

The cable from the measurement antenna to the spectrum analyzer/receiver is also a 'transducer'. The attenuation of the cable varies with frequency and can easily attenuate your signal by several dB at higher frequencies. It's important to calibrate your cables so that you know how much signal is being lost at every point across the band of interest. For your pre-compliance setup, I'd recommend buying a cable that comes with calibration data, or calibrating it yourself with a network analyzer (or signal generator + spectrum analyzer).



What's Your Budget?

The options available really depend on your budget. If you only want to spend \$1k then you're going to have 'significant challenges' recreating the measurements that an accredited EMC testing lab will make.

I'm going to outline some purchases you can make at 3 price points below: **\$1k, \$10k-\$15k and \$100k.**



\$1k Budget

With a \$1k budget, you're going to have a hard time getting accurate RF pre-compliance measurements. On this budget, the measurement error (or more specifically, the error associated with an extrapolation to a far field absolute field strength measurement) will probably be so large that the measurements will typically just be useful for EMC troubleshooting or getting an extremely loose idea of what the emissions sources and frequencies are.

You won't be able to (at least to my knowledge) be able to get anywhere near +/- 10 dB of an idealized far field measurement across the frequency range 30 MHz - 2 GHz.

With that said, here is the equipment I would buy on a \$1k budget:

Spectrum Analyzer (\$150-\$800)

On this budget you're going to have to get creative when you're purchasing a measurement instrument.

Follow my methods in the "[How to Find Test Equipment Bargains](#)" guide and pick up a cheap spectrum analyzer such as a 'pocket RF explorer' or perhaps a USB spectrum analyzer dongle.

These won't have great performance, sensitivity or amplitude accuracy and will probably lack some of the RBW settings required for EMI testing. But they will at least give you the ability to measure radiated fields with a degree of accuracy.

Near Field Probes (\$10-\$350)

Couple your USB spectrum analyzer with a cheap or homemade set of near field probes and you'll have a decent EMC troubleshooting kit. As I mentioned before though, measuring in the near field won't give you a great extrapolation to a far field measurement that you're really looking for.

These are available for [sale in our online store](#).

For slightly more accurate far field measurements, you'll want to get an antenna instead.



Tekbox Near Field Probes

Cheap Antenna (\$10 - \$700)

Getting an antenna that will give you usable RF measurements on this budget is tricky but possible.

The first thing to do is identify the frequency range of interest. For most unintentional radiators, that would be 30 MHz - X GHz where X is anywhere between 1 GHz and 40 GHz (in the case of the FCC). 30 MHz - 2 GHz will cover the majority of issues for unintentional radiators with internal clock frequencies <500 MHz.

You can buy cheap off the shelf antennas covering the UHF and VHF bands (check ebay) for \$10 - \$150. The key is to find antennas that cover the whole band you want to investigate AND come with some sort of calibration or gain data.

TO GET MEASUREMENT DATA THAT'S USEFUL FOR COMPARING WITH A TEST LAB, YOU NEED TO KNOW THE GAIN OF THE ANTENNAS. OTHERWISE AGAIN, YOU'RE JUST GOING TO HAVE AN EMC TROUBLESHOOTING SETUP.

If you're diligent and a bit lucky, you'll be able to pick up a used measurement antenna on ebay for a few hundred dollars. Look for bi-conical antennas for the 30 MHz - 200 MHz range and log-period antennas for the 200 MHz - 2 GHz range.

Above 1 or 2 GHz, you'll need a horn antenna which can start getting pricey.

Current Clamps/Monitor Probe (\$10-\$1000)

Current clamps (aka current monitors) can give you a very good idea of the emissions problems you'll see at a test lab due to common mode currents on external cabling. The extrapolation to a far field measurement is actually pretty good for common mode emissions up to around 200 MHz.

Some standards, such as CISPR 14 even call for the use of cable current clamps for use up to 1000 MHz.

However for pre-compliance measurements above 200 MHz, where wavelengths become small enough that features of a circuit board and enclosure can become effective radiators, the emissions from cabling aren't all we need to worry about.

A measurement of common mode current of around 5 uA on all external cables corresponds to a 'class B' pass/fail limit, whereas 15 uA corresponds to the lower 'class A' limit (very roughly). See [Henry Ott's guide](#) for more information.

You can either buy new calibrated current clamps, or make your own.



Antenna Mast and Turntable (\$0 - \$500)

Assuming you've bought a USB spectrum analyzer and antennas with gain data, you're doing well. To reduce the error budget more and get closer to the measurements of a full compliance lab, you'll want to move the antenna up and down and also rotate the EUT.

To rotate the EUT, you can just manually turn it in 90 degree (or less if you want) increments. The EUT should be sitting on a non-conductive table to avoid reflections. This will multiply your test time because you'll need to do a full sweep in each orientation.

If you want to level up and go with a fancy turntable, just go and buy a '[lazy susan bearing](#)' for your non-conductive table to sit on. You can manually swivel the table during measurements, or even better, buy a brushless DC motor (to avoid noise issues) to turn the turntable remotely.

To mimic an antenna mast, you can use an adjustable tripod [like this one](#), or the cheapest method would be to have a non-conductive support that you could set to a few different positions. Repeating the measurements at 2 or 3 height increments would at least help you to minimize this part of the error budget.

For most manufacturers who make more than 1 product per year, investing only \$1k in pre-compliance test equipment doesn't make much financial sense. A failure can cost you as much in re-testing costs, not to mention the delay to market.

Leveling up to a modest \$10k investment will get you much closer to a full compliance setup.

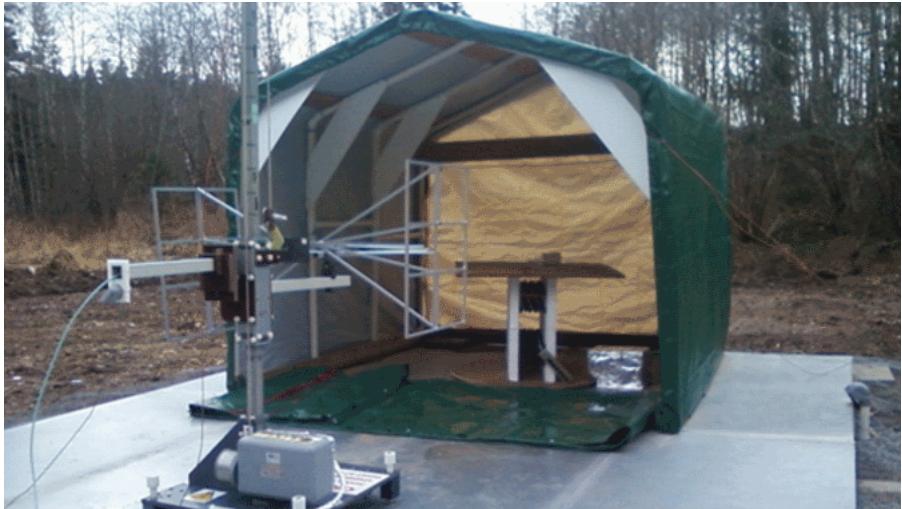


\$10k - \$15k Budget

1. Build a Low Cost OATS (Option 1)

With a \$10k budget, you're close to being able to afford a full compliance OATS. Fully compliant OATS are usually constructed according to [ANSI C63.7 \(Guide for Construction of Open-AreaTest Sites for Performing Radiated Emission Measurements\)](#) and/or [CISPR 16-1-4](#).

Your ability to construct an OATS on this budget will depend on the availability of a large open site with utilities and a building/cabin. You could set this up in a large indoor loading bay or on a rooftop, but keep in mind that you want to minimize reflections off nearby walls, cables and metallic objects.



Here's what you need to buy with your \$10k:

- Low cost spectrum analyzer (\$1k - \$5k)

At this price point, EMI receivers are not going to be within budget. I would look at a good, calibrated spectrum analyzer with frequency range 10 kHz (so you can do conducted emission measurements too) up to 3 - 6 GHz. A few good options under \$5k are the HP8560A, HP8563E and Agilent E4403B.

Buy them with a fresh calibration from a reputable cal lab (stickering without proper calibration is apparently rife).

- One or two calibrated antennas (\$500-\$3k)

A good broadband EMC (hybrid) antenna will get you from 30 MHz - 2 GHz which will cover many applications. They're a combination of a biconical and logarithmic antennas which may be called hybrid, bi-log, bicon-log etc.. depending on the manufacturer.

If you want more accuracy, split this job up into 2 antennas and buy both a bi-conical and a logarithmic antenna.

- Ground plane (\$200 - \$2500)

Your ground plane should be nice and flat and electrically contiguous (bonded at no more than every 1 inch). Chicken fence wire laid on top of flattened soil will be adequate in a pinch. A higher end solution is galvanized aluminum or steel with a minimum 16 gauge (otherwise welding gets very tricky and the plates bend in direct sunlight).

The size of this will depend on the antenna separation, but the smallest you would want to go is 8m x 10m. At smaller sizes, you'll have problems meeting the +/- 4 dB error budget.

- Manual or automated mast (\$500- \$5,000)

For maximizing the emissions, you'll need to vary the mast height between 1 meter at 4 meters. The mast needs to be non-conductive. If you're on a tight budget you could make one yourself or look out for used one on ebay.

- Manual or automated turntable (\$10-\$1k)

Again, for maximization, you need to be able to rotate the EUT 360 degrees. Ideally you'll have control of the turntable when you're standing next to the spectrum analyzer, so a motor controlled by remotely would be required. I bought a DC motor and variable speed controller from Ebay for under \$500. If you're determined to cut costs, you can have someone else manually rotate the EUT.

- Software for creating plots and including transducer data (\$0-\$2,000)

To be able to include the transducer data (the antenna gain, cable attenuation and possibly an amplifier), labs normally use automation software. You could do it manually in a spreadsheet, but it would get laborious and would be more open to human error.

There are a couple of good options here: [KE5FX](#) - a free toolkit that lets you grab data across GPIB ports. With a bit of programming you could set this up to rip the spectrum analyzer data into a spreadsheet.

Probably the best option at the moment, if your spectrum analyzer is supported, is the [EMCWare software](#) from Amplifier Research. It's free and looks to be really comprehensive for emissions and immunity automated testing (I haven't personally used it).

Finally, some spectrum analyzers let you input the transducer data manually and the readings on the screen are compensated.

GTEM + Current Clamps (\$7k-25k) (Option 2)

An alternative to a low cost OATS solution is to use a GTEM + current clamp.

GTEMs are not as accurate below 200 MHZ and great above 200 MHz (roughly).

Current clamps are not as useful above 200 MHZ and great below 200 MHz (roughly). See where I'm going with this?

York EMC have investigated the GTEM thoroughly and produced a [great app note](#) on the subject.



Basically they have good correlation to an OATS down to about 200 MHz, then at the lower frequency range, the correlation drops right off.

Luckily for us, at the lower frequencies cable radiation starts to dominate. We can fill in the GTEM's deficiency by using a current clamp.

Now cable radiation isn't the only source of radiation at frequencies below 200 MHz, but it current_probedoes account for a large proportion of failures below 200 MHz (I don't know what percentage, but at a guess >50%).

So with these two products, we can probably get to within +/- 10 dB of a full compliance test site.

GTEMs vary greatly in size and price. To meet the budget, you're going to need to watch ebay and test equipment auctions. I've seen used models as low as \$5k and as high as \$50k.



**Update: We now offer benchtop TEM cells for under \$1k.
Check them out here.**

\$100k Budget

If you've got \$100k to spend on an emissions pre-compliance test setup, you're in good shape. You're going to be able to meet the +/- 4 dB error budget and essentially do the same measurements as a full compliance lab.

You may want to think about registering your site with the FCC so that your own measurements are acceptable.

Full OATS (\$20,000- \$50,000)

The main differences from a 'cheap OATS' described above would be:

- Automated turntable and mast

You could invest in automated equipment so that you can accurately control the mast and turntable from beside the spectrum analyzer. Good automated equipment will have GPIB ports which feed the height and orientation data to a PC so that it is recorded in the measurement reports.

Some automated masts also have the capability to remotely change the antenna orientation from horizontal to vertical, which is a good feature if you're doing a lot of testing and every second counts.

On this budget you can just purchase automated equipment directly from the manufacturers. Modern automated equipment tends to be fiber optically controlled to avoid cable noise (and minimizes the antenna picking up noise from the automation equipment).

- EMI Receiver

You can also go high end with your measurement instrument. EMI receivers have a lower noise floor than their spectrum analyzer equivalents, they're faster and more importantly, they are usually CISPR 16 compliant (measurement bandwidths and detectors) which most spectrum analyzers are not.

- Weatherproof enclosure

If your OATS is outside (as opposed to a large loading bay), then it's open to the elements. Investing in a good non-conductive weatherproof enclosure will protect the EUTs and potentially the antennas and mast.

Some weather proof enclosures only cover the turntable, while preferably you cover both the turntable and the antenna. While some labs use wood for this, fiberglass is preferable. Wood can absorb moisture which can attenuate electric fields whereas fiberglass is pretty RF transparent.

Semi-Anechoic Chamber

Unless you find an amazing deal on a SAC, \$100k will only just cover the cost of a used chamber.

You would want to make sure that the chamber is of dimensions that are capable of meeting NSA requirements (+/- 4 dB) and make sure that the absorbers/ferrites are still good.

The attenuation of these can degrade over time, so used chambers are susceptible to excessive reflections.

In terms of antenna separation, you should go for a minimum of 3 meters. 10 meter chambers are available and their price increases accordingly (>\$1m).

The same advice applies as before to your choice of antennas, mast, turntable and automation.

Conducted Emissions Pre-Compliance

Conducted emissions pre-compliance is a lot simpler than radiated emissions pre-compliance because the test equipment requirements are so much smaller. There are not as many factors in play and everything is a lot less complicated. Basically a conducted emissions test setup only needs a low end spectrum analyzer and a line impedance stabilization network. We looked at the typical conducted emissions test setup in [chapter 1](#) of this guide. Assuming you picked up a spectrum analyzer for radiated emissions compliance according to the specs above, then all you need to purchase is a LISN.



LISN

Line Impedance Stabilization Network

The type of LISN you need to buy really depends on the standard(s) that apply to your product. They vary in terms of frequency range, current rating and impedance (presented to the EUT). I haven't come across many low cost sources of LISN other than eBay. Keep an eye on there for used LISNs. Otherwise there are plenty of LISN manufacturers to choose from.

A full compliance LISN will typically cost less than \$3k brand new, so it isn't hard to re-create a full compliance setup in your own office.

IF YOU BUY ONE OF THESE AND YOU HAVE A CALIBRATED LOW END SPECTRUM ANALYZER, THERE WOULD BE NO REASON TO EVER FAIL CONDUCTED EMISSIONS AT A 3RD PARTY TEST LAB AGAIN.

You could conceivably create your own LISN because the circuit isn't very complex, but you're working with line voltages and high currents so there is a significant safety risk.

**UPDATE: WE NOW OFFER BRAND NEW LISNS FOR SALE
FOR UNDER \$1000 IN OUR ONLINE STORE. VIEW OUR
LISNS HERE.**

Conclusions

Hopefully this article outlines exactly what emissions pre-compliance equipment you should be thinking about purchasing for whatever level of budget you have available.

If you have any questions or you think there's something I've missed, please let me know in the comments section below.

EMC TESTING: THE BEGINNER'S GUIDE

Chapter 6 - Pre-Compliance Testing - Immunity

Immunity compliance testing can be really costly and time consuming at a full compliance lab.

In this chapter of the guide, I'll guide you through some cost effective tools and techniques for immunity pre-compliance testing.

Here's what we'll cover in this chapter:

- ✓ Which Test Setups to Invest In First
- ✓ ESD Test Equipment
- ✓ Radiated Immunity Test Equipment
- ✓ EFT Test Equipment
- ✓ Surge Test Equipment
- ✓ Conducted Immunity Test Equipment
- ✓ Magnetic Field Test Equipment
- ✓ Voltage Dips, Drops and Interruptions Test Equipment

Before you dive into immunity pre-compliance testing, it's important to know what the 'ideal' compliance setup is. That's really what we're trying to achieve with a pre-compliance test setup.

In [chapter 3](#) we covered all of the main [EMC immunity tests](#). If you're rusty on what the tests are or what equipment EMC test labs use for each test, then head over and read that first. The test setups described in chapter 3 are really the 'gold standard' of what you're aiming for with pre-compliance testing.

When you're doing EMC pre-compliance testing, you really want to know whether you're going to pass or fail at a full compliance lab. So the closer the results are with your pre-compliance test equipment to the equipment at a full compliance lab the better.

In this chapter, we'll dig into immunity pre-compliance testing tools and options on different budgets and how the various solutions compare in terms of cost and accuracy.

EMC Immunity Pre-Compliance Testing

Which Immunity Test Setups to Invest In First?

If your company develops lots of variations of one type of product, it's often the case that each variation struggles to pass one specific test. For example a high power switch mode power supply manufacturer may struggle to pass class B conducted emissions. Whereas a high performance graphics card manufacturer may struggle to pass radiated emissions testing.

If that's the case for your company, it makes sense to purchase the equipment to re-create that test in your office so you can verify the performance earlier in the design cycle.

If you don't have that information available, start by investing in perceived high risk areas first.

Often the first dip of the toe into the water of immunity testing is to get an ESD simulator, but read on below for some more ideas.



Ken Wyatt's EMC
Troubleshooting Kit

ESD Pre-Compliance Testing

IEC/EN 61000-4-2

ESD testing is a really common test to fail. It also won't break the bank for most hardware manufacturers to invest in an ESD pre-compliance test setup, so it's often one of the first pieces of EMC test equipment to get.

Here are some options in **ascending** order of cost.

BBQ Igniter

Cost: \$, Accuracy 1/10

At the cheapest end of the spectrum, you can find an extremely cost effective 'ESD generator' in your camping kit.

A simple BBQ igniter is nothing more than a voltage source that can generate several hundred or thousand volts - enough to generate a spark between the igniter and a conductive surface.

The upside of this solution is of course the cost. They are extremely cheap. The downside is that you really have minimal idea of what the peak voltage, how much charge there is or what the source impedance is. You could be several hundreds or thousands of volts (plus or minus) away from the level called out in your applicable test specifications.

So this option really has limited use as a pre-compliance tool. At best, it could be useful for ESD troubleshooting if you're attempting to recreate and fix a failure mode that was discovered using a calibrated ESD simulator.



Cheap ESD Generator

Cost: \$\$, Accuracy: 3/10

A step up from the BBQ igniter method is this 'ESD generator' from [Bartek](#).

Again, this is no match for a calibrated ESD simulator, but it does have a few advantages compared to the BBQ method I just described.

- It has had some qualitative testing performed on the output by the manufacturer, so you have a slightly better idea of the output waveform (Approx +/- 3 to 15 kV, 20ns rise time)
- A ground lead is provided, so the loop impedance is more repeatable



Still, this should really be viewed as a glorified BBQ igniter and only used for ESD troubleshooting and very rough ESD pre-compliance testing.

Make Your Own ESD Simulator

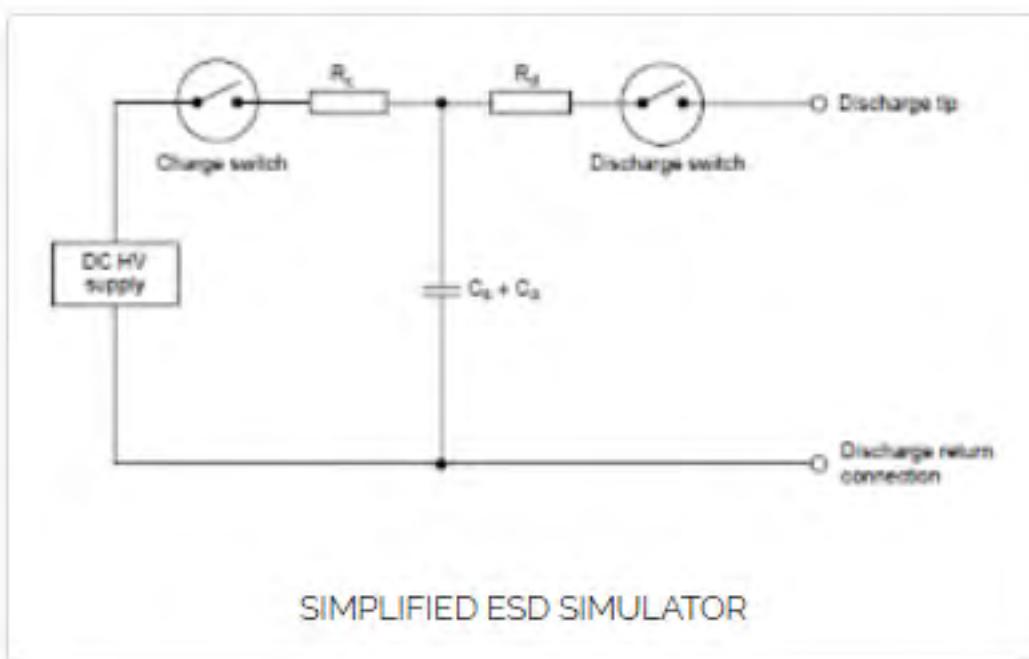
Cost: \$\$, Accuracy: 5/10

The insides of an ESD simulator aren't rocket science. Here's a diagram from one of the ESD root standards (61000-4-2) that shows a block diagram of an ESD generator.

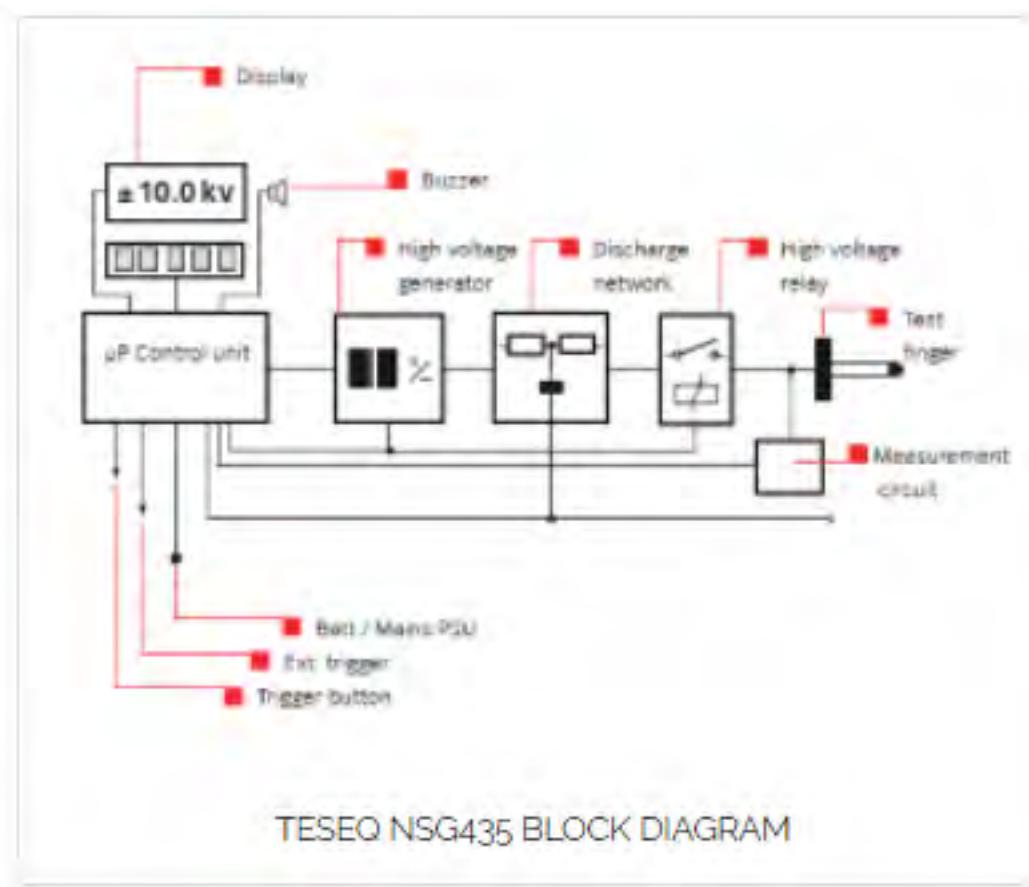
Essentially all ESD simulators consists of:

1. A tuneable high voltage supply (e.g. 500 V-16 kV)
2. A resistor/capacitor discharge network
3. A switch (must not 'chatter' back and forth when switching on/off)
4. A discharge tip (dimensions of these are important. See 61000-4-2 standard for precise measurements for air and contact discharge tips)

Any additional functions/circuitry in an off the shelf ESD simulator are typically related to usability, such as battery, LCD, pulse repetition rate etc.



SIMPLIFIED ESD SIMULATOR



TESEQ NSG435 BLOCK DIAGRAM

This diagram on the left for example is taken from the Teseq NSG 435 ESD simulator user manual.

I haven't come across a good app note from an engineer who has created their own accurate ESD simulator yet, but if you have one, please let me know.

Full Compliance ESD Simulator

Cost: \$\$\$, Accuracy: 10/10

Buying a calibrated ESD simulator can be a really good investment. At current market rates you can expect to pay \$3k to \$7k USD for used models and \$8k+ for new models.

Follow the tips in my "[How to find test equipment bargains](#)" post to learn how to secure the best deals.

With your own unit in-house, you can not only avoid paying test lab fees, but you can also de-risk project timelines by testing early prototype units for potential failures.

To get repeatable results, you'll also need to spend a few dollars on a test bench and an indirect discharge metallic panel designed according to the specifications in the 61000-4-2 standard.



Radiated Immunity Pre-Compliance Testing

EN/IEC 61000-4-3

If you're lucky enough to have a full compliance chamber with antennas and RF amplifiers to do radiated immunity pre-compliance testing, then you're set.

For the rest of us without a \$100k budget, let's see what's available.

These options are ordered in ascending levels of price and accuracy.

Option 1: Handheld Transmitters

Cost: \$\$, Accuracy: 2/10

By using devices that intentionally generate RF energy near to your equipment, you can spot check a few frequencies to get an idea of radiated immunity performance. Examples of these include:

- CB Radios (usually 27 MHz)
- FM 2-way radio (~465 MHz)
- Cell phone (~850 MHz/1800 MHz)

At their maximum power output (usually in the order of 500mW - 5W), these should be able to generate field strengths of 3-10 V/m at a distance of 1 meter.

Using a combination of these transmitters, you will be able to subject your product to electric fields at a few spot frequencies.



Limitations

There are lots of downsides to this method of radiated immunity testing. Here are a few:

- Relatively unknown field strength will not give you a good idea of whether you're going to pass or fail at a full compliance lab.
- Limited power output means you won't get much more than 10 V/m which may not meet the strength called out in the standard that applies to your product.
- There may be failure modes in bands in-between these spot frequencies. The chances of the transmit frequencies overlapping with your equipment's problem frequencies are very low.
- Subjecting your product to a field generated only 1 meter away will mean that your device is sat within the near field for at least a portion of the band. This will make the field level even less stable/calibrated.
- Modulation method is different from proper test. Usually 80% AM is required. You won't have the luxury of selecting the modulation scheme on a hand held radio, so it almost definitely won't have the same modulation scheme as required in your immunity standard. This will likely mean you'll get different results than a full compliance test lab, even at the same spot frequencies and same power levels.

Option 2: USB Signal Generator + Near Field Probes

Cost: \$\$\$, Accuracy: 5/10

There are some pretty cool new products that have come out in recent years that will be able to help you to do some radiated immunity pre-compliance testing.

Small, portable USB powered signal generators such as the [Windfreak Technologies Synth NV](#) (lots of similar devices available on eBay) come with a little built in amplifier. They can usually cover the whole frequency band of interest (typically 80 MHz - 2.7 GHz) and allow you to modulate the signal with 80% AM, just like a test lab setup.

You can connect the output of this signal generator to either another RF amplifier to get some more gain, or connect directly to passive near field probes.

Using this method, you should be able to generate RF fields across the band of interest with levels of 3-10 V/m. Kenneth Wyatt, an EMC trainer and consultant wrote a good article outlining the test setup in detail here including measurements of the generator field strength levels.

Limitations

- It's entirely possible to generate radiated fields that totally break limits set around the world. Since you'll be sweeping frequencies not just in unlicensed bands, it's very important to be aware that it's illegal to broadcast on many frequencies without a license. Some frequencies are reserved for emergency beacons for instance, so you could inadvertently call emergency



USB SIGNAL GENERATOR FOR RADIATED IMMUNITY PRE-COMPLIANCE TESTING



NEAR FIELD PROBES

services to your office. You could solve this problem by doing the testing in a sealed chamber or faraday cage.

- Again, you'll be operating in the near field for much of the band of interest, so you'll likely get different results from a full compliance lab.

We have low-cost near field probes and RF probe amplifiers for sale in our online store. [Click here](#) for more details.

Option 3: Signal Generator + Amplifier + Antenna (Upgrades)

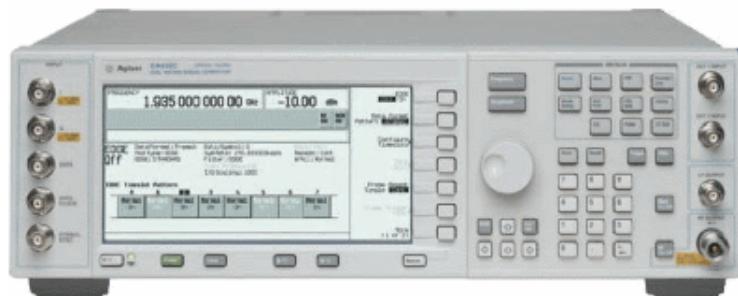
Cost: \$\$\$, Accuracy: 7/10

Compared to 'Option 2' above, there are a few incremental upgrade options, namely the type of signal generator, the strength of the amplifier and the type of transducer.

Signal Generator Upgrade

By investing in a bench-top signal generator as opposed to a small USB generator, you get a few advantages:

- Better frequency stability, phase noise performance and harmonic amplitude levels. Of these, harmonics amplitudes are probably the most important because you could end up over-testing your product with significant fields generated by harmonics rather than the fundamental.
- GPIB control. If you want to write your own test software to control a test setup, GPIB control is often the way to go. The Windfreak generator does provide open source software, so you could potentially modify it for your application, but other low cost signal generators may not be so kind in terms of giving low level control to your custom application.



Amplifier Upgrade

Another upgrade you could consider is to replace the small amplifier (e.g around 100mW in Broadband RF amplifier for radiated immunity testing the Windfreak device) with a more powerful external broadband RF power amplifier. By doing that, you could generate much larger field strengths OR generate the same field strength but allow your whole product to be in the far field rather than the near field.



Transducer Upgrade

In the case of 'option 2' above, the 'transducer' is the near field probe. It turns conducted electrical energy into an electric and magnetic field. By changing this transducer, we can alter some field characteristics such as strength and field uniformity. When test labs do full compliance testing in a semi-anechoic chamber, the antenna separation is typically 3 meters or 10 meters. This allows for the equipment under test (EUT) to be fully enveloped in a fairly uniform field of a given strength. This is not possible with near field probes - only a small area of your product will be subjected to the required field strength.

Near Field Probes vs. Antennas

You can fix this issue by replacing the near field probes with an antenna. The type of antenna log_periodic_antenna you choose depends on the frequency range.

Typically you'll use a broadband hybrid (biconical/logarithmic hybrid) to cover the range 30 MHz to 2 GHz or so. Higher than that and you'll usually need a horn antenna.

For lower frequencies, get a loop antenna. The problem is that you'll need a lot more juice to drive the antenna at a reasonable separation from the EUT (perhaps 1 meter or 3 meters). Your cheap 100 mW amplifier suddenly may need to become a \$10,000 30W broadband RF amplifier.



See chapter 3 for details on antenna selection.

Option 4: Signal Generator + Amplifier + GTEM

Cost: \$\$\$, Accuracy: 8/10

If I wanted to create a radiated immunity pre-compliance test setup for under \$1500, this is the method I'd use.

A really nice solution that sits between near field probes and a full compliance test setup is to use a TEM cell or GTEM. Radiated emissions and immunity testing Your Windfreak signal generator can potentially drive a TEM cell directly without needing a separate amplifier.

For example, Tekbox offer 3 different open TEM cells.



The table below shows the required input power levels to generate a given field strength in their smallest model.GTEM TEM cell RF power amplifier

As you can see, a 20 dBm amp (around the Windfreak maximum power levels) can

| TBTC1, applied RF power | Maximum field strength between septum and wall |
|-------------------------|--|
| 10W (40 dBm) | 447 V/m |
| 1 W (30 dBm) | 141 V/m |
| 0.1 W (20 dBm) | 44 V/m |
| 0.01 W (10dBm) | 14 V/m |

Table 1 – BTC1, field strength vs. RF power

generate up to 44 V/m in the TEM - quite a high field strength for many products.

Don't know what field strength your product will be subjected to at a lab? Look at your old test reports, ask a lab, or [learn how to create your own test plan](#).

The larger the TEM, the more juice you'll need to produce a given field strength but the larger the products are that you can test.

The main benefit of a TEM over using near field probes is that the field is reasonably uniform over your whole product.

Also, larger GTEMs are fully enclosed and therefore you don't need to worry about illegally broadcasting across restricted bands.

[Click here](#) to see our stock of TEM cells.

Accessories

Shielded rooms/tents

WARNING: The FCC (and potentially equivalent regulatory bodies around the world) can issue fines and have the power to imprison you if you're found to be illegally transmitting RF energy. Pumping RF power, even in the mW range, into near field probes, antennas and open TEM cells will most likely exceed the limits for emissions.

To minimize the risk of getting fined, you can use things like:

- RF shielded 'tents'
- RF shielded enclosures
- Shielded rooms
- Semi-anechoic chambers
- Enclosed GTEM cells

Check out the "[Anechoic Chamber Guide for Emissions, Immunity and RF Testing](#)" for more info.

Isotropic field probes

If you want to verify the field strength that your near field probes, antennas or GTEM are generating, you'll need an isotropic field probe.

GPIB readable models are available (although expensive). Cheaper models are available on ebay, but make sure the frequency range and accuracy are adequate for your application.



Automation software

Radiated immunity testing involves sweeping through a band of frequencies.

Because antenna/probe/TEM gain and amplifier gain vary across a given frequency band, every frequency point needs to have a corresponding signal generator gain setting. In that way, your test setup can maintain a fixed and stable field strength from the lowest

frequency to the highest frequency of interest.

Using an isotropic field probe (described above), you can (manually or automatically depending on your probe) tune your signal generator to the levels required to maintain the required field strength across the band of interest. This table of frequency vs. signal generator gain is then stored and played back in the future to generate the same sweep.

Some options for radiated immunity automation software are:

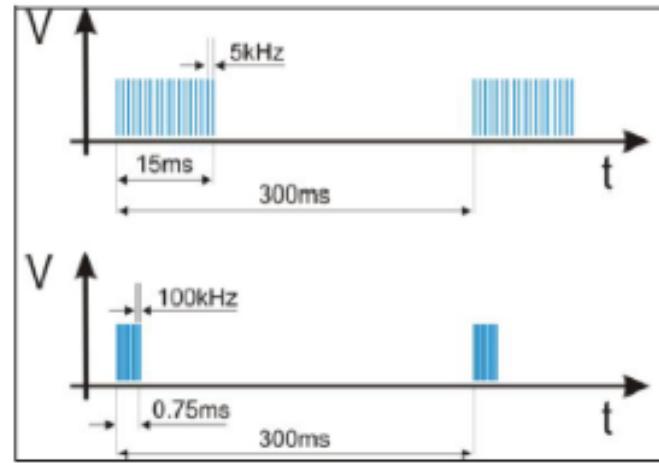
1. Write your own in LabVIEW (Control signal generator via GPIB or USB)
2. Get [EMC Ware](#) from Amplifier Research (free at time of writing)

Electrical Fast Transient (EFT) Pre-Compliance Testing

IEC/EN61000-4-4

The challenge with EFT pre-compliance testing without a fully compliant test generator is how can you accurately re-create the precisely timed transient waveforms?

The 'spikes' need to be in the order of several kV in amplitude, but only microseconds in duration and are applied through a carefully defined source impedance which is called out in the applicable standards.



Presumably a fully compliant test generator produces these waveforms in a similar way to an ESD simulator in that there is a tuneable high voltage source which charges a storage capacitor. Discharges are controlled with carefully timed relays.

The capacitors need to be capable not only of withstanding high voltages, but also high discharge currents of tens or in some cases hundreds of Amps for very short periods of time.

I learned recently through refurbishing a couple of my CE Master combination immunity test generators that these caps are expensive (hundreds of dollars) and are referred to as 'pulse capacitors'.

But, there are a couple of options that you could look into if you wanted to re-create this test on a budget.

Option 1: ESD Simulator into Cabling

Cost: \$, Accuracy: 3/10

An ESD simulator produces similar waveforms to EFT, albeit not as quickly.

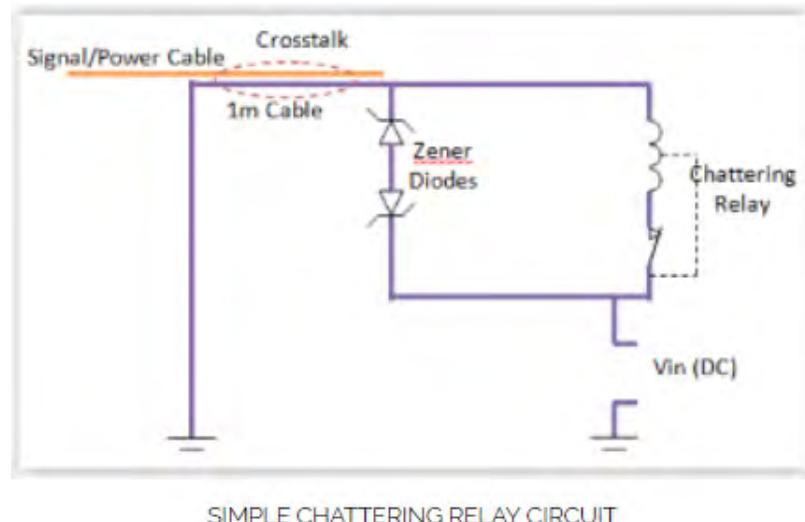
But what you can do is discharge the ESD pulse into one end of a cable (with the other end connected to ground) and tape that cable to your signal and power cables (one at a time).

The ESD pulse will cause a high current to momentarily flow down the cable and that's going to produce a magnetic field. Through inductive and capacitive coupling, the fields will induce a current in the signal and power cables of your product, mimicking the behaviour of a capacitive coupling clamp in a full compliance test setup.

Option 2: 'Chattering' Relay

This is kind of neat option if you can make or get your hands on a high voltage DC power supply.

Similar to the ESD option above, you can tape a cable carrying the 'disturbance' to signal and power cables. Instead of injecting a signal using an ESD simulator, you can supply a DC voltage and allow a relay to chatter ON and OFF by including protection diodes (back to back Zener diodes as shown).



You'll need to buy different diodes to test with different breakdown voltages and these will limit the maximum voltage injected onto the cable.

Due to the back EMF generated inductively when the relay turns off (according to $V = -L(dI/dt)$), the transient voltage can be tens or hundreds of times larger than the DC power supply you provided.

The trick will be to choose (through trial and error) the diodes with the right breakdown voltages to correspond roughly to the required EFT waveform specifications.

Option 3: Used EFT Generator

Cost: \$\$, Accuracy: 8/10

A really good option to consider is to keep an eye on eBay for used test generators. Fairly regularly you'll find used EFT burst generators selling for a couple of thousand dollars upwards.

Standards change from time to time and occasionally this will mean that old test generators are no longer fully compliant with the rules. They may be fully functional, but don't strictly meet some timing or voltage parameters. If you're willing to deal with a little less than perfect waveforms, this can be a great way to secure in-house EFT pre-compliance capabilities.

The main things to watch out for are:

- If the unit is sold 'as-is', expect that the storage caps could potentially need replacing. Consider asking the seller to send directly to a calibration lab for verification before purchasing. Alternatively verify at your office using HV probes on an oscilloscope.
- You will need to purchase a separate capacitive clamp (see below) for testing signal cables.
- Verify that the repetition rate and voltage levels the generator produces is acceptably close to that called out in the standard that applies to your product.

Accessories

Capacitive Clamp

A capacitive clamp is one of the main ways to inject the disturbance signal into your signal cables (as opposed to your power cable where the disturbance is injected conductively within the test generator).

These are few and far between on the used market, but if you're determined to save a few dollars, consider making your own.



The 61000-4-4 standard (download link provided in chapter 3) provides the specification for this simple mechanical device.

Alternatively taping the disturbance cable to the signal cable as I described above will do a similar, albeit less calibrated job.

Surge EMC Pre-Compliance Testing

EN/IEC 61000-4-5



Surge testing involves pretty large voltages and currents (kV and hundreds of Amps for a period of tens or hundreds of milliseconds).

Plenty enough to kill you if it happens to pass through the wrong part of your body.

For this reason I can't really recommend trying to hack together your own pre-compliance test setup.

EFT burst generatorIf you see surge testing as a risk area for your product, which it is for lots and lots of products, I'd recommend buying either:

- A new/used combination immunity test generator. These can typically cover several tests including EFT, surge, dips/drops/interruptions, magnetic field, ringwave oscillations etc. Sometimes you'll find combination generators that have only one or two modules installed but could be expanded in the future. Some manufacturers include: Thermo-Fischer, Haefely and EM Test.
- A new/used surge generator. These are standalone units that cover only one test.

The good thing about these options are that when they're properly grounded, you're unlikely to have a unscheduled hospital visit.

Conducted Immunity Pre-Compliance Testing

EN/IEC 61000-4-6

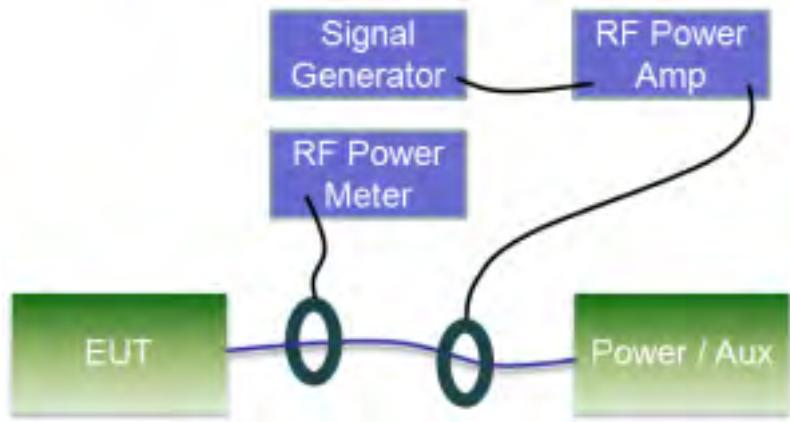
Again, this test is a real challenge to make a lower cost test setup.

The main reason being that a powerful broadband RF amplifier in the order of tens of Watts is required to generate typical test levels of 3 Vrms or 10 Vrms across typical frequency ranges of 150 kHz to >200 MHz.

Essentially you're going to need:

- A signal generator
- An amplifier
- A transducer (CDN, BCI probe or EM clamp)
- A calibration jig (optional)

Some publications I've read recommend things like the chattering relay method again or bringing licensed high power transmitters like CB radios into close proximity to your cables to inject a modulated signal in.



But in reality these will yield practically no information as to how your product will perform during final compliance testing. Accredited test labs even have repeatability issues with this test because different injection transducers are often considered to be equally valid whilst their behaviour is completely different (e.g. a CDN vs. a BCI probe).

Magnetic Field EMC Pre-Compliance Testing

EN/IEC 61000-4-8

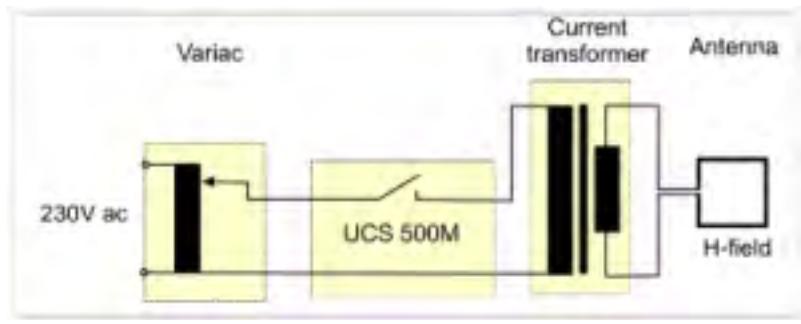
First thing to note here is that there are at least two variations to this test:

1. Power-line magnetic field testing (i.e. at 50/60 Hz)
2. Swept frequency magnetic field testing (e.g. 50 Hz to 10 kHz)

Power-Line Magnetic Field

The first is a lot easier to re-create, the second, not so much.

Magnetic Field Test Setup If you recall back to chapter 3, a typical magnetic field test setup looks like this.



In this case, the combination immunity test machine isn't doing a whole lot other than switching the current on and off to the transformer.

It's also controlling the variac tap, but you can also do that manually with whatever variac you can get your hands on.

So here's a list of what you'll need to create this test setup for pre-compliance testing:

- Variac (make sure it's sized to carry enough current to drive the antenna)
- Current transformer
- Loop antenna

To construct the loop antenna, you can use easy to find materials like wood and PVC piping. Follow the instructions [here](#).

To calculate the required current to generate a magnetic field strength defined in your standard keep in mind that for a 1 meter diameter single loop, the field in the middle will equal the loop current (Bio-Savart Law). So with 1 loop, the field will be 1 A/m. With 2 loops, the field will be 2 A/m.

For a square loop, you'll need to use a correction factor which reduces the magnetic field by approximately 10%.

Swept Frequency Magnetic Field Testing

The swept frequency magnetic field test, called out in certain circumstances in some standards (such as professional audio equipment), you'll need some different equipment:

- Signal generator (covering a frequency range e.g. 50 Hz to 10 kHz)
- Audio amplifier (not-coincidentally audio amps cover the frequency range of interest)
- Loop antenna (see details above)

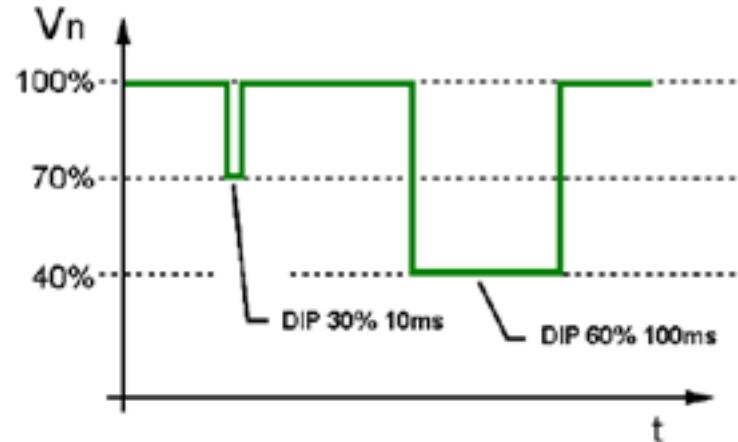
Get full details on how to make this test setup [here](#).

Voltage Dips, Drops and Interruptions Pre-Compliance Testing

EN/IEC 61000-4-11(AC)/-29(DC)

The main issues with creating a simple pre-compliance version of this test are:

- How do you dip the AC or DC voltage by a given percentage? (e.g. 40% and 70%)
- How do you dip the voltage for a specific period of time? (e.g. 20ms, 100ms)
- How do you synchronize the dips to start and finish at specific phases of the AC power waveform?



Function (1) above is typically taken care of by a manual OR automatically controlled variac (also known as variable auto-transformers).

Functions (2) and (3) are typically taken care of by a combination immunity test generator such as the UCS500N5 from EM Test.

Variacs are widely available of course, which leaves functions 2 and 3 to take care of.

Depending on how much your time is worth, it could be worth your while making a timed relay circuit to switch between the two required voltage levels (100% and the dipped value) rather than purchase a fully compliant immunity test generator.

I haven't personally done this, but I don't see why you couldn't do it fairly easily with a small micro or even a 555 timer.

Another option is to just dial down the voltage on your bench top power supply.

The main scenario you're trying to avoid is unexpected or unrecoverable product behaviour during a power brownout event.

So even if you don't have the equipment to perform this test, here are a few suggestions for mitigation:

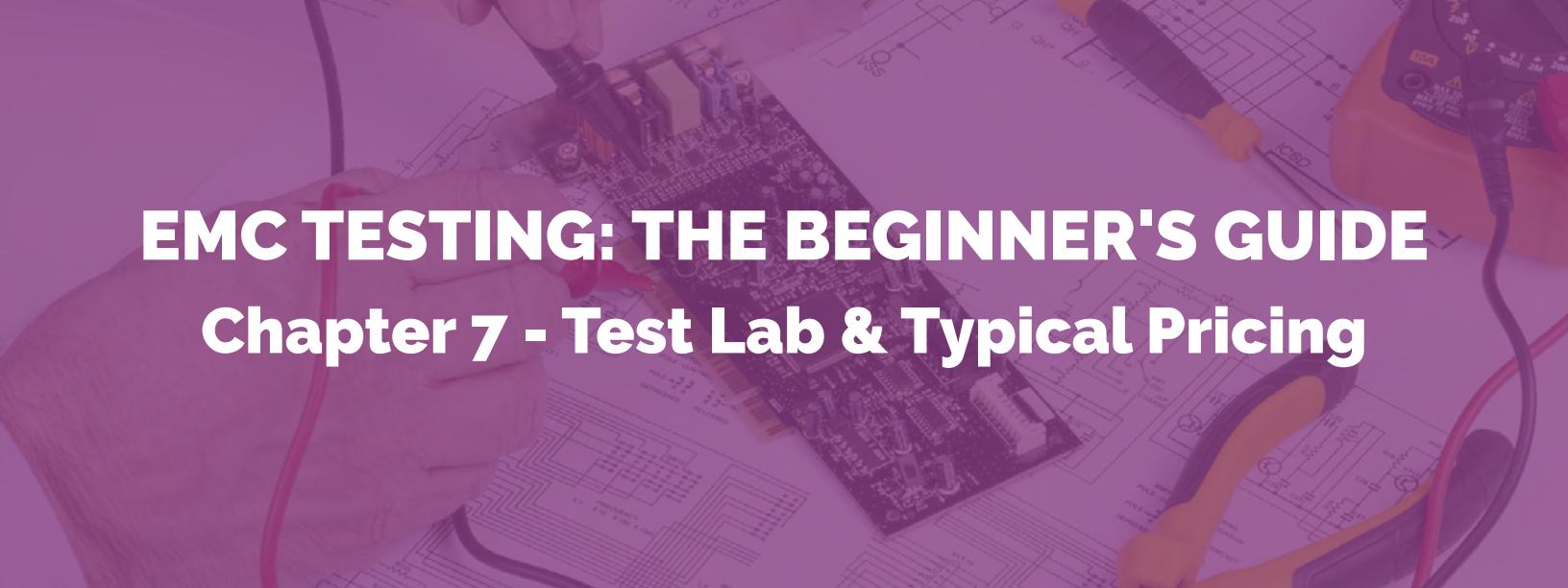
- Ensure you have a simple power brownout detector and watchdog timer in your design.

- Ensure your product software/firmware recovers to a usable state after a brownout. Ideally the user would not have to interact with the product for it to recover to the same state as before the brownout (criteria A pass).
- Flick the power supply on and off to your unit several times at high speed to see if you can get the product to behave erratically. If it does, figure out why and fix it before final testing.

Conclusions

Armed with this knowledge, I hope you go forth and begin to invest in some EMC pre-compliance test equipment, it might just save you from debugging EMC problems over the weekend!

That's it for the first part of the beginner's guide to EMC. Remember to share this with any friends or colleagues that will find it valuable. Also leave any comments or questions below!



EMC TESTING: THE BEGINNER'S GUIDE

Chapter 7 - Test Lab & Typical Pricing

Choosing the right EMC test lab can make a huge difference. It can directly affect your time to market, your budget and also your potential liability in the future. So it's important to choose wisely.

In this part of the guide we'll cover some criteria that are worth thinking about when choosing your 3rd party lab.

Here's what we'll cover in this chapter:

- ✓ 8 criteria to consider when choosing an EMC test lab
- ✓ How to save 2-4 weeks on wireless (RF) compliance testing
- ✓ Typical testing timelines
- ✓ EMC test lab budgetary/typical pricing
- ✓ List of EMC test lab directories

Read on to get the low down...

How To Choose The Best EMC Test Lab

For engineers new to EMC testing, it would be easy to get several quotes from 3rd party test labs and just choose which one to go with based on price alone.

But if you've been caught off guard by the wrong test lab in the past, you'll know that EMC test lab selection can cause:

- Delays to market of several weeks
- Inability to sell your product in specific countries
- Reduced client base due to non-acceptance of test reports
- Inefficient compliance process

So rather than consider the EMC test lab industry to be 'commoditized', it's really worth your while to chose the right one.

8 Criteria to Consider When Choosing an EMC Test Lab

Accreditation

One of the largest distinctions between test labs is whether or not they have been 'accredited'. This just means that an approved 3rd party organization such as the Standards Council of Canada (SCC) or A2LA have actually traveled on site to evaluate things like processes, documentation, calibration and staff competency amongst other things.

Accreditation does not absolutely guarantee the quality of a test lab. In many cases, the final test results are still a function of the competency and ethics of specific engineers doing the testing.

There are also claims that some accreditation bodies are far easier on test labs than others, leading to different qualities of accreditation. And in fact, the FCC only recognizes test results from labs inspected by their approved list of accrediting agencies.

But choosing an accredited lab as opposed to a non-accredited lab will at least give you some confidence that the lab knows what they're doing.

The main reasons for not choosing an accredited lab are typically cost (cheaper) and location (non-accredited lab nearby).

If you choose to go the accredited route, make sure that the test lab is accredited for each specific test that you need them to do.

One Stop Shops

Many manufacturers prefer to use a test lab that can handle every test the product needs to pass - and understandably so.

That may include a whole barrage of tests, such as EMC, safety, SAR, wireless, environmental and more.

But this isn't always the best route to go. Specific labs may have higher degrees of expertise in specific areas or with specific product types. You might like to work with a particular EMC engineer from one company for EMC tests and a test engineer from a different company for safety tests.

You'll also need to make sure that the certificates or reports that each test lab generates are acceptable to your end customer, or for a particular geographic region. Often you'll be forced to not use a one-stop-shop for these reasons.

But, if you find one that ticks all of your boxes, then one-stop-shops can help to speed up time to market and also cut down on administrative overhead.

Lead Time

Lead times of EMC test labs also vary wildly. They can vary from same day bookings, to several weeks or months, depending on the lab and their schedule.

If the lead time is huge, it can be super inconvenient. Firstly, you'll need to book far in advance and the time-slot may not coincide with your ideal test time. Secondly, if your product fails, it could take weeks for them to fit you in again.

Large test labs also have a tendency to 'bump' smaller customers in favor of large repeat clients. So watch out for them moving your time-slot to accommodate someone else!

Make sure to ask EMC test labs that you're evaluating what their lead time is.

Which Countries Can They Service?

EMC test labs often (but not always) have to be registered with the governing body of a

country for their test reports to be valid for importing products into that country.

So if you happened to use a test lab that wasn't registered with the VCCI (Japanese governing body), if you want to import your products into Japan, you're going to need to have your product re-tested at a different lab (=unhappy day at work).

For some stubborn countries such as China, they won't even let test labs outside their borders test products destined for China. This is probably more of a measure of trade protection than it is for quality control, but whatever it is, the end effect is that if you're designing products for the Chinese market, you'll need to have them tested at a test lab within China.

Make sure that you confirm with your test lab that the test reports will be valid for X country before you have them tested!

Technical Expertise

The technical expertise of EMC test lab staff can vary wildly. You might get unlucky and get a button monkey who's sole job is to follow precise instructions and can't offer any further advice on top of that.

You really want to go with a place that has very experienced staff, not just from the testing perspective, but also from the design perspective, so when the inevitable happens, they can offer more in-depth advice than just adding chokes and copper tape.

If you go with a place with relatively inexperienced staff or with minimal design knowledge, you're either going to be on your own when it comes to debugging (which might be fine if you're experienced), or you'll need to hire an expensive consultant to help.

The final thing to point out here is that it's very easy to screw up an EMC test by using incorrect test equipment or selecting the wrong settings. An inexperienced engineer might use a cable adapter or attenuator not rated for the correct frequency range which could potentially attenuate emissions at higher frequencies. Or perhaps they forgot to include the attenuation factors in software for a specific cable. You could end up with incorrect test results.

This is why it's important to go with a lab that has very experienced and well trained staff.

Facilities

What facilities does an EMC test lab have? For radiated emissions testing, do they have:

- An open area test site (OATS)

- A semi-anechoic chamber (what size, frequency range and accuracy do they claim?)
- GTEM (Cheaper per hour and useful for fast pre-compliance testing)



PARTIALLY DISMANTLED 10M SEMI-ANECHOIC CHAMBER

Check out our [chamber guide](#) and [emissions testing guide](#) for more details on the pros and cons of these.

For immunity testing, can they actually test to the levels and standards that you need them to? Does their ESD simulator generate high enough voltages? Are the 'EFT' or 'Surge' pulses high enough amplitude? Or are they hacking together test set-ups with lots of non-ideal equipment?

You can get the answers by either asking them directly or asking for their accreditation certificate which should outline each of the tests that are fully compliant.

Accessibility

For some manufacturers, it's critical to use a nearby test lab so that engineers can travel with the product to the lab.

For others, the priority is price or some other factor that makes it worthwhile using a test lab further away or even in a different country.

The main issues that come up when using a far away test lab is what happens if your product fails testing. Does the EMC test lab have competent staff on-hand to do some

simple debugging without you there or are you going to need to travel to the lab? Have you factored in the shipping times back and forth if your product has to go through several iterations to pass? Are there language barriers?

There are lots of priorities to balance when selecting the location of your test lab.

Cost

Test lab costs can vary a lot from lab to lab. Geography plays a big part (labs in the far east tend to be a lot cheaper), but even labs within the same state or country can vary +/- 50%.

In the future, we'll be doing a blog post on EMC test lab costs around the world.

In the mean time, scroll down to the section on EMC test lab pricing for more information.

How to Save 2-4 Weeks on Wireless Certifications

In North America, there's a designation of test lab that you can think of as being a level above 'accredited'. The FCC calls these 'TCBs' which stands for 'telecommunication certification bodies'.

These are the labs that have been around long enough that they're trusted to review wireless certifications for the FCC. The FCC delegated this task to the private sector many years ago when they couldn't cope with demand themselves.

For many manufacturers, the typical path to wireless certification is to have your device tested at a local lab. Often that lab happens to be 'listed' or 'accredited' rather than a TCB. If that's the case, then the listed or accredited lab must submit the test reports to a TCB for review before getting the final grant of authorization.

More often than not, a TCB will find issues with the test report or documentation so the application is bounced back to the initial test lab. This process may go back and forth over the course of a few weeks until all of the issues are resolved.

You can speed up this process significantly by just having your product tested at a TCB rather than at a listed or accredited lab. Just cut out the middle man.

The TCB would be inclined to not find fault with its own testing practices (although I'm sure the reviewer would be separate from the test lab division for conflict of interest reasons). But the upshot is that you don't have nearly as much back and forth with the test lab getting the application correct.

Their prices also tend to be slightly cheaper once all application and processing fees are included.

So if you want to save potentially several weeks time to market and some money on your next wireless certification, I recommend finding a good TCB. There's a link to a list of TCBs in the directory section below.

EMC Test Lab Directories

Here's a non-comprehensive list of EMC test lab directories around the world. If you have any to add, drop me a line (andy (at) emcfastpass (dot) com).

- [FCC EMC test lab directory](#) (listed and accredited) (Global)
- [FCC TCB directory](#)
- [UK accredited \(UKAS\) directory](#)
- [UK EMC test lab directory](#) (EMC Journal 2013)
- [Australia EMC test lab directory](#)

EMC Testing Lab Budgetary Pricing

Costs for EMC testing vary wildly. They vary depending on the product type and function as well as varying massively from lab to lab (for exactly the same test schedule).

With that caveat in mind, here is a crude breakdown of some ballpark costs that you can expect for the US (FCC) and Europe (CE):

| Unintentional Radiator | | Intentional Radiator (Wireless) | |
|------------------------|------------|---------------------------------|-------------|
| FCC | FCC +CE | FCC | FCC+CE |
| \$1k-\$2k | \$5k-\$10k | \$7k-\$15k | \$10k-\$20k |

Note that this ballpark pricing is for EMC and RF testing only. If your product needs any other types of testing, those costs will be on top of these.

For FCC and CE EMC testing, the fees above are a one-time deal i.e. there are no follow up costs associated with FCC and CE EMC testing. For many other types of testing, especially safety and medical, you may need to pay an annual fee to have an inspection of your

product and/or manufacturing facilities to ensure that there is ongoing compliance with the rules.

Unintentional Radiator Testing Timelines

Emissions Testing: 1-2 days

Immunity Testing: 1-4 days

Test Report: 3-10 days

This is if everything goes perfectly!

EMC TESTING: THE BEGINNER'S GUIDE

Chapter 8 - Resources, Books & Training

In this chapter, we'll take a look at some free and paid resources available to take the next step on your path to mastering EMC.

The application of EMC knowledge varies a lot depending on what type of electronics you're working with and also how large your company is and what resources (financial and time) you have at your disposal.

Here's what we'll cover in this chapter:

- ✓ The Many Branches of EMC
- ✓ Why The Traditional 'Learn and Burn' Technique Doesn't Work
- ✓ Over 75 Application Note Resources
- ✓ My Top 5 Recommended EMC Textbooks
- ✓ Recommended EMC Training Courses

This chapter breaks down some suggestions of further educational resources (books, app notes and online courses) that you can pick and choose from based on your own needs and finances.

Resources, Books & Training

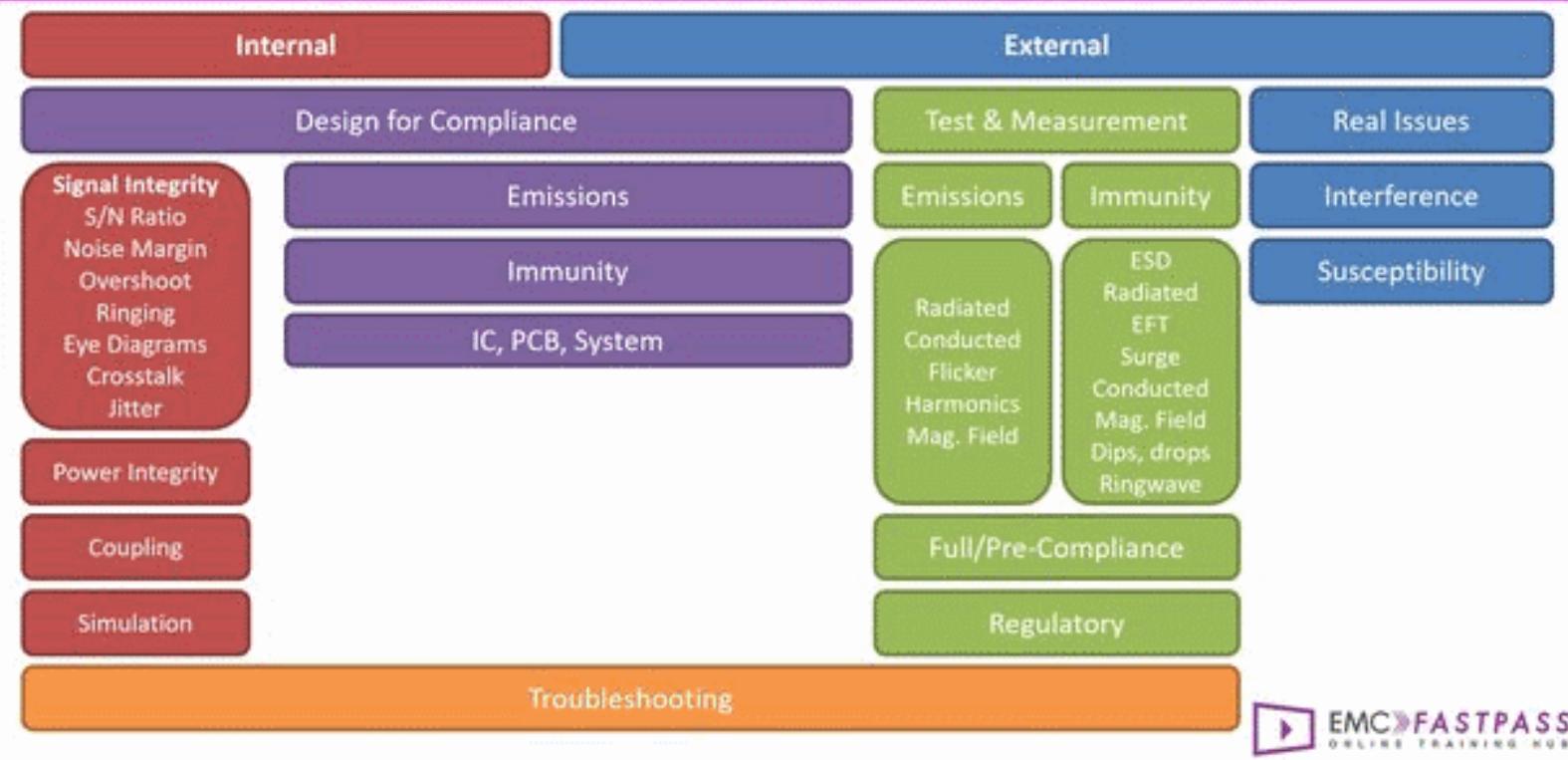
Areas of EMC to Master

EMC is a huge subject, so many engineers can and do make an entire career out of just a subset of it.

Some people focus on the testing aspect, some focus on regulations, some on design and troubleshooting. With so much to learn, it's easy to see how the guys who are really good at this stuff are often coming up to retirement!

Below is my take on some areas of EMC. I've seen other categorizations that come at it from other viewpoints, but as a hardware engineer, this is how I visualize it.

Branches of EMC Knowledge



Branches of EMC

Many of these subjects can be a whole career on their own. It's one of the reasons I like EMC so much - there are always more interesting things to learn!

Test & Measurement

Testing and compliance engineers have a good appreciation for rules & regulations as well as what it takes to make accurate, repeatable measurements. As frequencies increase, this becomes more challenging.

Simulation

2d and 3d EM simulation programs are still fairly niche and expensive, but several companies do specialize in this area (see below). Used extensively in the aerospace and automotive industries where getting things right up front is crucial.

Immunity DFC

Related closely to emissions DFC, but with some extra considerations to take account of, design for immunity compliance is extremely important for many types of products in including medical, automotive, aerospace, military etc.. as well as most electronic products destined for Europe or Australia.

Pre-Compliance Testing

Pre-compliance testing involves early testing of units to give an idea of EMI/EMC performance. Often manufacturers set up their own in-house test setups and engineers must learn how to make reasonably accurate measurements to roughly approximate results from an accredited 3rd party lab.

Signal Integrity

Of course SI is a huge subject. Specialists here can dive into high speed board design and simulations. This area is only going to grow as CPU speeds and memory busses continue in to the GHz regions.

EMC / EMI Troubleshooting

Based on a foundation of hardware design, physics and test & measurement, EMC troubleshooting is a wide and interesting subject. Rarely do you find an identical set of EMC issues and design constraints, so this subject involves problem solving and creativity.

IC DFC

Even at the IC level, almost more-so, EMC must be taken into account. On-chip capacitance allows for a small but very low inductance source of switching current. ICs can also integrate transient immunity protection although additional board level components are often also necessary. Control over these aspects is very much the domain of ASIC design engineers.

Power Integrity

PI is also an interesting and growing field of study and application. It's mainly concerned with how in the world to deliver tens of amps at extremely low impedance to satisfy modern IC current switching demands.

Emissions DFC

Designing circuit boards with EMI/EMC compliance in mind from the outset is in itself a huge area. With many textbooks (see below) and courses to choose from, there's no shortage of ways to improve your knowledge in this area.

Systems & Installations

On a larger scale, EMC can and must be applied to larger objects like cars, trains, planes and even buildings. With unique challenges around cabling, shielding and the safe operation of many electrical modules/devices within a larger system, this area requires another special skillset.

Regulatory Compliance

At larger hardware organizations and 3rd party test labs, often there will be staff or departments dedicated to regulatory compliance. This may involve things like determining applicable standards, ensuring ongoing compliance with updated rules & regulations as well as dealing with compliance impact of product changes.

Where are you in your career continuum?

Given the vastness of the EMC topic, it's unreasonable to expect to learn it all at once. Typically an engineer will learn bits and pieces over time and by the end of their career they eventually have an expert understanding of the subject.

Why 'Learn and Burn' Methodology Doesn't Work For EMC

Hardware engineers like to taunt software engineers for many reasons, but one of them is that they get the luxury of correcting mistakes during the development phase pretty much on the fly. Doesn't compile? Fix error - re-compile - done!

For hardware engineers, of course we try to catch as many functional problems as possible before pulling the trigger on manufacturing a PCB. But the time to identify and remedy a functional hardware issue can be in the order of weeks. We learn lessons, but the feedback loop is much longer than for software engineers.

Because EMC testing typically happens much less often than individual functional PCB spins - maybe twice or 3 times at a well prepared company, or maybe just once at a company who are new to the process, the feedback loop for EMC issues is much longer than for even PCB spins.

And if your product fails EMC, maybe you spend a week or two debugging the problem. So for example, in a period of 6-12 months, you've debugged 1 or 2 EMC problems and learned the theory and lessons that go along with solving those problems.

Given the myriad number of ways to accidentally create an EMC failure mechanism, having an opportunity to practice from failures (learn and burn) only a couple of times a year, is going to make the process of mastering EMC a very long one.

David vs. Goliath

Rules for EMC apply regardless of the size of your company. Do you think the FCC cares if it's a small startup or a multinational's products that cause a radiated emission problem?

They don't, so unfortunately regardless of a company's size and how many products they ship per year, the rules still apply.

But when it comes to preparing a product for testing, the big guys often have a huge leg up on small manufacturers.

Here are some of the ways I've noticed things being done differently when working with various size manufacturers:

| | Company Size | | |
|---|-----------------------|-----------|----------------|
| | Startup/ One-man-band | Mid-size | Multi-national |
| Process | | | |
| EMC requirements known/considered early | Rarely | Usually | Yes |
| PCB/chassis designed with EMC in mind | Rarely | Usually | Yes |
| EMC design review | Rarely | Sometimes | Yes |
| EMI/SI/PI simulations | No | Rarely | Usually |
| Pre-compliance testing | Rarely | Usually | Yes |
| Equipment/Software | | | |
| In-house emissions pre-compliance equipment | No | Usually | Yes |
| In-house immunity pre-compliance equipment | No | Usually | Yes |
| In-house anechoic chamber(s) | No | Rarely | Often |
| In-house full-compliance immunity equipment | No | Sometimes | Usually |
| Accredited/registered lab facility | No | No | Sometimes |
| EMC Expertise | | | |
| Experienced EMC engineer on staff | Rarely | Sometimes | Yes |
| Dedicated compliance officer on staff | No | Rarely | Yes |
| EMC training provided | No | Sometimes | Yes |

So you can see that in terms of chances of passing EMC testing much quicker, the odds are stacked in favour of the larger manufacturers.

Small manufacturers often either don't know about the challenge they're facing, or don't have the resources (financial, manpower, time etc..) to implement processes to deal with the issue.

But, using the resources outlined in this beginner's guide, engineers from all sizes of manufacturers can map out an individualized path to improving knowledge of the subject.

Application Note Resources

These are some useful app notes I've collected over the years.

Hyperlinks often go dead, so rather than continuously update the links, these resources are locally hosted. I do not own the copyright to these, so if you are the owner of any of them and want me to take them down, just [email](#) me. All branding has been preserved.

ESD

[System Level ESD Mitigation](#)

[ESD Selection Guide](#)

[How to Select TVSs](#)

[Design Considerations for System Level ESD Protection](#)

[Uni-Directional vs. Bi-Directional](#)

Surge

[Introduction to Surge Mitigation Techniques](#)

[Surge Testing Overview](#)

[Characterization of Surge Suppressors](#)

Flicker & Harmonics

[Practical Guide](#)

[Applicability Flow Chart](#)

[Class Definitions](#)

[Harmonics In Power Systems](#)

Design Reviews & General Guidelines

EMC and PCB Constraints

EMC for Micros

EMC Design Rule Checking

Ford EMC Design Guide

IBM EMSAT Rules

Intel Guidelines

Design for Guaranteed EMC Compliance

PCB Design Guidelines for Reduced EMI

Expert System Algorithms for Identifying Radiated Emission Problems in PCBs

Filtering

Ferrite Bead Selection

Leakage Currents in Power Line Filters

Automotive

Automotive EMC Intro & Overview

EMI Design Techniques for Micros in Automotive Applications

Design for Guaranteed EMC Compliance with Modelling

Radiated Immunity

Immunity Requirements Related to Design Choices

Conducted Immunity

Conducted Immunity Testing

Pitfalls and Practice of Conducted Immunity Testing

BCI Probe Test Procedure

Conducted Emissions

Power Supply Design Techniques for EMI and Safety

Measuring & Filtering Output Noise

EMI in Power Supplies

Power Supply Line Filter Design

Filtering for Conducted & Radiated EMI

Minimize Ringing (Boost)

Minimize Ringing (Buck)

PCB Stack

Ground Plane Stitching

Stackup Planning

Stack Considerations

Decoupling

Using Decoupling Capacitors

Power Bus Decoupling

Decoupling High Speed Op-Amps

Bypass Cap Selection for High-Speed Designs

PDN

EMC Considerations for DC Power Design

PCB PDN Design Methodology

PDN Applications of Ferrite Beads

Common Mode & Differential Mode Current

How CM Currents Are Created

Understanding CM Currents

EFT

Top 10 Circuit Protection Considerations

Ethernet Protection

Magnetic Field

Practical Guide for EN61000-4-8

Build a Magnetic Field Immunity Tester

LF Magnetic Field Testing

Pre-Compliance

EMC for Test Engineers

Pre-Compliance Options

Workbench EMC Measurements

EMC Demos & Experiments

Understanding Electromagnetic Effects

EMC Education Manual

3 Experiments

Cherry Clough's EMC Demo

Risk Assessment

EMC Design Risk Assessment

EDRA Spreadsheet

IC Level

[Overview of Chip Level EMC Problems](#)

Systems/ Installations

[Fixed Installation Best Practices](#)

[EMC The Easy Way \(Pocket Guide\)](#)

Shielding

[Engineering Aspects of Electromagnetic Shielding](#)

EMC & High Speed Design

[Relationship Between Signal Integrity & EMC](#)

[Predicting & Controlling CM Noise From High Speed Differential Signals](#)

[EMC Countermeasures for HS Differential Interfaces](#)

[PCB Design Techniques For SI and EMC of Gb/s Differential Transmission Lines](#)

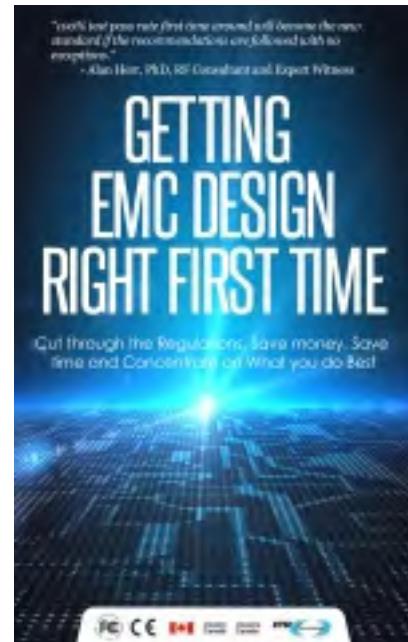
Top 5 Recommended EMC Textbooks

EMC textbooks offer a shortcut to getting a career's worth of knowledge in the subject. For less than the cost of 1 hour in a 3rd party test lab, you can learn what took these engineers years or decades to learn through hard fought battles with EMC. Seems like a good deal!

Getting EMC Design Right First Time (EMC FastPass)

Of course I need to mention our own eBook on the subject. Downloaded thousands of times and praised by many in the industry, I'm proud of the reach and impact of this publication.

Download the first 3 chapters for free [here](#) or buy the full eBook [here](#).

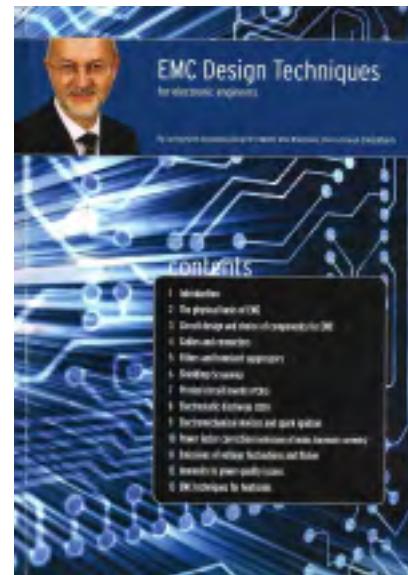


EMC Design Techniques by Keith Armstrong

Keith Armstrong's books are probably my favourite textbooks on the subject due to the balance between theory and practical application.

With lots of pictures and diagrams of real-world solutions, he offers a wealth of information on the subject picked up over decades of experience.

This particular book covers a lot of the system level considerations including shielding, cabling & connectors, immunity protection and much more. A must have for any hardware engineer or consultant. [Get it here](#).



EMC for Printed Circuit Boards by Keith Armstrong

This book is more focused specifically on PCB design for compliance, covering subjects including basic high speed digital design, decoupling, PDN considerations and layer stacks etc.

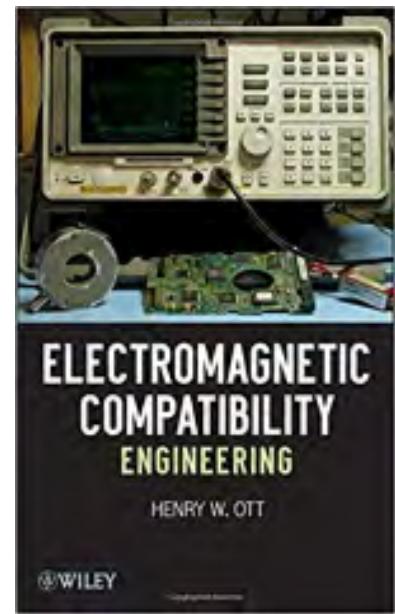
Again, striking a fine balance between theory and practical solutions, this is also one of my favourites.



Electromagnetic Compatibility Engineering by Henry Ott

No list of EMC books would be complete without including Henry Ott's classic reference manual.

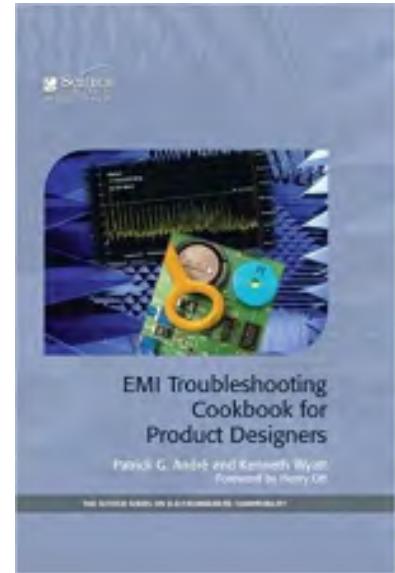
A must have for anyone's EMC book collection, it contains a wealth of material on a huge range of applications. If you have a specific question about design for EMC compliance, chances are this book covers it. [Get it here](#).



EMI Troubleshooting Cookbook by Patrick Andre and Kenneth Wyatt

This really helpful book written by industry veterans Kenneth Wyatt and Patrick Andre offers insight into the tools and techniques used for solving many different types of emissions and immunity issues.

If you have a specific issue you need to troubleshoot, this book gives advice from engineers who have been in the trenches for many years. Ken also has a companion [online course on EMC troubleshooting](#) in the EMC FastPass training hub that offers over 5 hours of video training on the subject. [Get the book here](#).



Other books

Some other EMC textbooks I like that just missed the cut:

- [EMC For Product Designers](#) by Tim Williams
- [EMC For Systems and Installations](#) by Tim Williams & Keith Armstrong
- [PCB Design For Real-World EMI Control](#) by Bruce Archembault
- [Signal and Power Integrity](#) by Eric Bogatin

Recommended Websites

[Clemson University vehicular EMC lab](#)

[Henry Ott Consultants](#)

[INARTE \(EMC Certifications\)](#)

Industry Publications



EMC Related Software

PI/SI

Altera PDN calculation spreadsheet

Mentor Hyperlynx

Ansys EMC simulation

Polar instruments simulation

CST EMC studio

FEKO EMC analysis

Design Rule Checkers

NEC EMI Stream

CST Boardcheck

Zuken EMC Adviser

Calculators

Saturn PCB toolkit (Impedance calculators etc)

Max emissions calculator

Ultracad calculators

Congratulations! You've made it through the entire Beginner's guide to EMC testing! Now you're ready to take the next step in your journey to mastering EMC compliance.

Example Online Course Learning Path For Electronics Engineers

In the section below, check out some online course offerings from EMC FastPass to help you to reach the next level of your career from the comfort of your own office.

Level 1

- First time experience with EMC
- Learn about test requirements and how tests are applied to products
- Learn EMC troubleshooting and pre-compliance techniques

Level 2

- EMC of design medium to high complexity boards
- Up to 8 layers PCB
- Micro-controllers up to 1 GHz
- Serial and parallel data-busses >500 MHz
- Switch mode power supply design for compliance

Available Courses

- [EMC Testing Beginner's Bundle](#)
- [EMC Troubleshooting For Product Designers](#)
- [EMC Design For Compliance \(Emissions\)](#)
- [EMC Design For Compliance \(Immunity\)](#)

