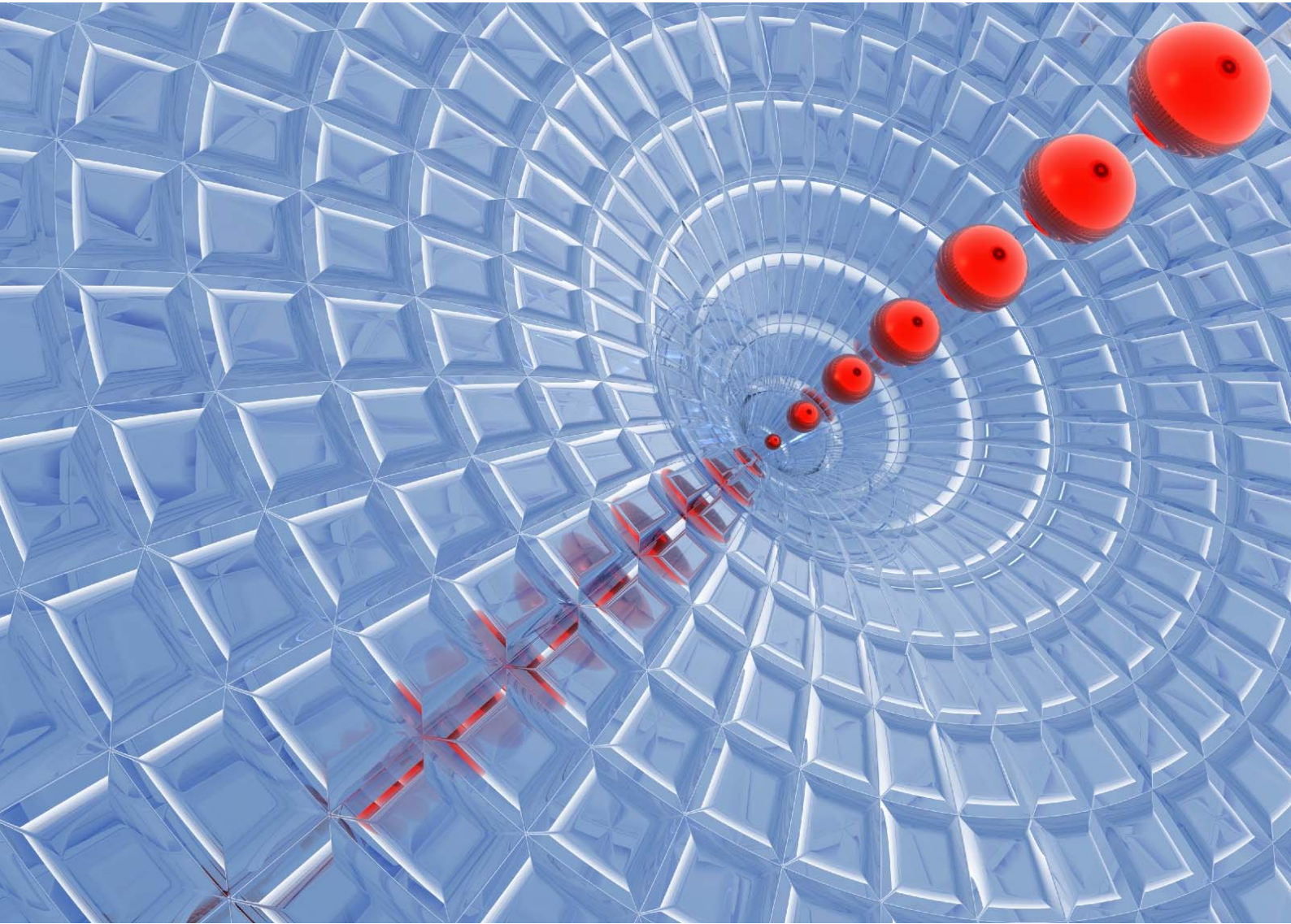




Effects of EMC on Smart Appliance Designs



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Introduction

When we hear the term “appliance” we think of common household devices such as air conditioners, blenders, coffee makers, dishwashers, electric knives, fans, microwave ovens, refrigerators and vacuum cleaners. These examples contain among them motors, switches, thermostats and electrically-actuated valves – all well-known electromechanical technologies, with perhaps some simple solid-state electronics added.



Newer appliance designs are reducing cost, expanding functionality and increasing reliability by adopting programmable electronics such as application specific integrated circuits (ASICs), microprocessors, and intelligent sensors, transmitters and actuators. In addition, such “smart” appliances are adopting powerline and wireless communication techniques to enhance their utility even further – for remote control over a “smart grid,” or for remote recordkeeping, for example.

The migration of appliance technology from electromechanical to programmable electronic and wireless has significant consequences for EMC design and regulatory compliance. Even for simple appliances, the designer may be faced with unfamiliar standards governing user safety and radio interference. For more complex appliances, stringent “functional safety” requirements may affect EMC testing.

This document is intended to help the reader become aware of global EMC issues and design considerations for “smart” appliances. It is not intended as a comprehensive catalogue or toolkit. EMC consultants and test laboratories can provide targeted assistance with up-to-date information on regulations and compliance procedures.

EMC - Electromagnetic compatibility

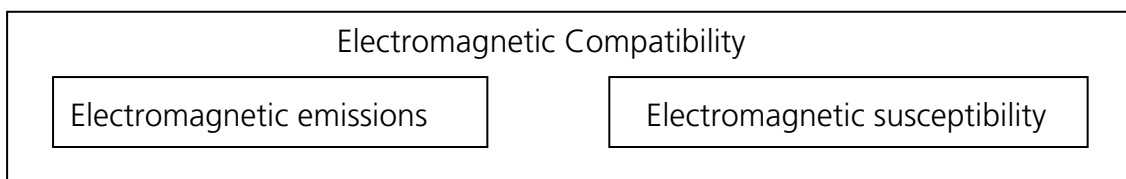
Electromagnetic compatibility is defined as the condition which exists when equipment is performing its designed functions without causing or suffering unacceptable degradation due to electromagnetic interference to or from other equipment. EMC refers to a kind of environmental equilibrium. In this case, the environment is an electromagnetic one - consisting of invisible disturbances which travel through the air or through metal cabinets or wires.

EMC has two components, illustrated in the diagram below:

- 1) Electromagnetic emissions, from the appliance itself; emissions from the appliance can interfere with radio and TV broadcasting or sensitive services such as radio navigation or radio astronomy. The term EMI (Electromagnetic Interference) refers to electromagnetic energy which interrupts, obstructs, or otherwise degrades or limits the effective performance of equipment; and
- 2) Electromagnetic susceptibility of the appliance to disturbances in its environment, resulting in appliance malfunctions caused by static discharges, radio transmitters, cell phones or other nearby electrical or electronic devices. The term Immunity refers to the condition which exists when equipment operates within acceptable limits when exposed to electromagnetic environments imposed by an external source.

When a particular appliance is not generating excessive disturbances, and when it is operating correctly in the presence of such disturbances, the condition of electromagnetic compatibility is satisfied. Whether or not EMC is subject to government regulations in a particular market, EMC is an important design goal to assure reliable appliance operation and to avoid interference to nearby devices and radio services.

Over time, the nature of EMC considerations in the residential environment has changed. The introduction of digital circuitry into appliance designs has added narrowband, high frequency emissions to the possibility of broadband interference from DC motors and electromechanical switches. Electromagnetic susceptibility has been affected both by the use of potentially sensitive semiconductors in appliances, and by a residential environment that now includes many more disturbance sources such as cell phones, portable phones, remote controls and home entertainment electronics.



Regulatory requirements

Background

The regulation of electromagnetic emissions started with commercial radio broadcasting, so that interference with broadcast reception would be minimized. In the United States, the Federal Communications Commission (FCC) was established in 1934 to regulate broadcasting and interference. In the same year, the German “High-frequency device law” was published. Spectrum regulators in other parts of the world were established around this same time to deal with the rapid growth of the broadcast industry. To this day, emissions are regulated worldwide to prevent interference to radio and TV broadcasting, and sensitive services such as radio navigation and radio astronomy.

Immediately after radio receivers found their way into automobiles in the 1930’s, the subject of susceptibility arose – those receivers picked up interference from automotive ignitions and even static from the tires. Both sources of interference were quickly resolved, but the concept of EMC had been established. During the Second World War, the dense packaging and high power of military electronics accelerated the development of standards for both emissions and susceptibility.

Regulation of emissions from consumer devices grew mid-century with the advent of electrical household appliances and semiconductors, the latter enabling low-cost wireless remote controls and portable telephones. The digital electronics contained in personal computers that became popular during the 1970’s was found to generate potent radio interference. As a result, digital device regulations were established around the world – in the USA under FCC Part 15 Subpart J in 1979, internationally by the IEC standard CISPR 22 in 1985, and in the European Union under the EMC Directive in 1989.

EMC regulations now play an essential part in both governmental and private standards – to prevent radio interference and assure equipment functionality in aerospace, automotive, commercial, medical, military and residential applications. We will explore how “smart” appliances pose unique EMC challenges for both design and regulatory compliance.

EMC

The regulation of EMC varies around the world by product use and jurisdiction. In the United States of America (USA), only the emissions of residential and commercial appliances are specified – adequate levels of susceptibility or immunity are left to the marketplace to determine. Emissions-only regulations for residential and commercial products are also found in Australia, Canada, China and Japan.

Some common residential and commercial emissions standards are listed in Table 1 below:

Product type	USA	European Union	International
Household appliances	-	EN 55014-1	CISPR 14-1
Audio/visual, broadcast receiver	47 CFR Part 15	EN 55013	CISPR 13
Information technology (ITE)	47 CFR Part 15	EN 55022	CISPR 22
ISM (Industrial, Scientific, Medical) that generates radio-frequency energy	47 CFR Part 18	EN 55011	CISPR 11

Table 1 – Common residential and commercial emissions standards

In the European Union (EU), regulation of both emissions and immunity for residential, commercial and industrial products of all types is in force, to assure the free movement of goods among member states. South Korea has also adopted the more comprehensive approach of the EU. The most common residential and commercial susceptibility/immunity standards are listed in Table 2 below:

Disturbance type	Common source	European Union	International
ESD (Electrostatic Discharge)	Static buildup	EN 61000-4-2	IEC 61000-4-2
Radio-frequency Radiated Immunity	Broadcast stations, consumer wireless > 80 MHz	EN 61000-4-3	IEC 61000-4-3
EFT/B (Electrical Fast Transient Burst)	ac branch switch arcing	EN 61000-4-4	IEC 61000-4-4
Surge	Lightning-induced	EN 61000-4-5	IEC 61000-4-5
Radio-frequency conducted Immunity	Broadcast stations, consumer wireless < 80 MHz	EN 61000-4-6	IEC 61000-4-6
Power line magnetic immunity	ac power wiring	EN 61000-4-8	IEC 61000-4-8
Power line variations	Ac branch load switching	EN 61000-4-11	IEC 61000-4-11

Table 2 – Common residential and commercial immunity standards

Emissions - USA



In the USA, the FCC exempts from its technical regulations appliances that contain “incidental radiators” such as switches and motors. Only appliances containing radio frequency (RF) or digital circuitry – defined as having clocks or oscillators operating above 9 kHz – fall under Part 15 rules, and even then there are additional exemptions under which the digital circuitry in appliances may fall:

- Power consumption below 6 nanowatts (nW); this would apply to most calculators and some digital clocks.
- Battery-operated only, and having an operating frequency below 1.705 MHz.
- Used exclusively in transportation vehicles; these are subject to other industry standards.
- Digital devices used in large motor-driven appliances such as dishwashers and air conditioners.

This last exemption to Part 15 regulation – digital circuitry used exclusively in appliances – was intended only for large appliances, but has been widely misinterpreted to apply to all appliances. The FCC allowed the exemption on the basis that their large motors effectively mask any emissions produced by the low frequency microprocessors they employ. There is no such basis for exempting a hair dryer, rice cooker or massager.

Notwithstanding any or all of the exemptions listed above, the appliance manufacturer is obliged to assure that his devices do not cause interference to radio or TV. FCC Part 15.103 states:

*The operator of the exempted device shall be required to stop operating the device upon a finding by the Commission or its representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected. **Although not mandatory, it is strongly recommended that the manufacturer of an exempted device endeavour to have the device meet the specific technical standards in this part.***

The simplest way for the appliance manufacturer to comply with the intent of 15.103 is to have the appliance tested for compliance with either the Class A (non-residential limits) or Class B (residential limits), if there is any possibility that the appliance may be causing interference. Appliances intended for use in the home would, of course, be subject to Class B emission limits.

Appliances that use RF energy to do some kind of work (such as heating or ionization) are subject to FCC Part 18 (ISM devices) rather than Part 15. Examples

of such appliances are microwave ovens, wireless battery chargers and compact fluorescent lamps. The emission limits and measurement procedures under Part 18 are different from those of Part 15, and the product labelling is different too. FCC regulations for appliances are summarized in Table 3 below.

FCC EMC regulations, appliances:

	emissions	immunity	example
no digital circuitry	n/a*	n/a	hair dryer
with digital circuitry	15 subpart B**	n/a	setback thermostat
with ISM function	Part 18	n/a	microwave oven wireless charger RF lighting

* but cannot cause interference.

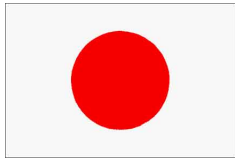
** only large appliances are exempt.

Table 3 - FCC regulations applicable to appliances in the USA

FCC rules, including Parts 15 and 18, are available online at:

http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?&c=ecfr&tpl=/ecfrbrowse/Title47/47tab_02.tpl

Emissions - Japan



As with the FCC in the USA, residential appliances intended for use in Japan are subject to compliance only with emission requirements; susceptibility is not regulated but is left to the marketplace. Self-declaration of conformity to the Electrical Appliance and Material Safety Law ("DENAN") is appropriate for most electrical appliances. Transition deadlines of March 31, 2006 to March 31, 2011 from the prior Material Control Law to the present DENAN are largely past. The emission limits are drawn from IEC CISPR standards and are summarized in Table 4.

Japan EMC regulations, appliances:

	emissions	immunity	example
no digital circuitry	CISPR 14:1993/A1:1996	n/a	hair dryer
audio-visual	CISPR 13:1996/A1:1998	n/a	CD player
with digital circuitry	CISPR 22:1993/A1:1995	n/a	computer
with ISM function	High-frequency appliances (ISM)	n/a	microwave oven

Table 4 - EMC regulations applicable to appliances in Japan

Appliances in Japan are not subject to the low-frequency harmonics (EN/IEC 61000-3-2) and flicker (EN/IEC 61000-3-2) emission limits that apply in the EU. These standards are discussed more fully in the EU section below.

Emissions - Australia



Australia does not impose susceptibility or immunity requirements under its EMC Framework. Rather, the Australian Communications and Media Authority (ACMA) recognizes a wide variety of joint Australian/New Zealand (AS/NZS), IEC, CISPR and CENELEC standards for self-declaration and C-tick marking connoting EMC compliance. Earlier versions of standards are superseded on clearly-defined dates posted on ACMA's EMC Standards List at http://www.acma.gov.au/WEB/STANDARD/pc=PC_310707. AS/NZS CISPR 14.1 (appliances emissions) and AS/NZS 61000.6.3 (generic) are the most appropriate standards for compliance, as well as AS/NZS CISPR 22. As with Japan, appliances in Australia and New Zealand are not subject to the low-frequency harmonics (EN/IEC 61000-3-2) and flicker (EN/IEC 61000-3-2) emission limits that apply in the EU.

Designs for emissions compliance

“Smart” appliances will contain some digital circuitry. The key design features to meet emissions compliance are:

For AC conducted compliance:

- consider bypass capacitors across the ac line, or a modular line filter for more severe noise
- use a common-mode choke to attenuate higher frequency conducted emissions.
- assure that any third-party switching power supplies already meet emission limits

For RF radiated emission compliance:

- use the lowest-power and slowest speed logic circuitry possible
- keep the circuit layout as compact as possible
- physically separate clock/driver circuits from I/O circuits as much as possible
- use capacitive bypassing or ferrite beads on lines leaving the circuit board
- use the appliance enclosure for shielding or signal grounding, if it is metallic
- for non-metallic enclosures, use an internal shield for severe interference

Emissions and Susceptibility - EU



In the European Union, both appliance emissions and susceptibility or immunity are regulated under the EMC Directive 2004/108/EC for the purpose of CE-marking by “harmonized” standards that are listed periodically by the European Commission at:

<http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/reflist/emc.html>

These standards are drawn largely from those published by the European Organization for Electrical Standardization CENELEC. It should be noted that these standards are not mandatory, but if they are used to demonstrate compliance then conformity is presumed.

The EMC Directive and its official interpretations allow many fewer exemptions than FCC rules, but appliances that contain inherently “benign” components do not need to be tested. Such “benign” components include passive resistance loads, ac induction motors, simple quartz watches, incandescent lamps, home and building switches that do not contain any active electronic components and passive antennas used for TV and radio broadcast reception.

The harmonized emission and immunity standards in the EU that are commonly applied to appliances are shown in Table 5 below.

RF interference and immunity, EU appliances

	emissions	immunity	example
general	EN 55014-1 EN 61000-3-2 EN 61000-3-3	EN 55014-2	hair dryer
with ISM function	EN 55011 EN 61000-3-2 EN 61000-3-3	EN 55014-2	microwave oven
with digital function	EN 55014-1 EN 61000-3-2 EN 61000-3-3	EN 55014-2	setback thermostat

Table 5 - CENELEC standards applicable to appliances in the EU

The emissions standard EN 55014-1 requires ac conducted measurements similar to FCC Part 15, EN 55011 and EN 55022. However, it uses as a proxy for radiated emission measurement above 30 MHz an absorbing clamp or ferrite transformer that is moved along each appliance cable, including the ac power cable. Use of the absorbing clamp to measure disturbance power is predicated on the assumption that most of the radiated interference from appliances smaller than 1m on a side propagates along its cables and not out from the enclosure.

Appliance measurements using the absorbing clamp are further detailed in the IEC standard CISPR 16-2-3. The method is quicker than radiated emissions measurements, and the test site requirements are also simpler. A diagram of disturbance power emissions measurement on an appliance using the absorbing clamp is shown in Fig. 1:

EN 55014-1 emissions for appliances - uses absorbing clamp and covers 30 – 300 MHz

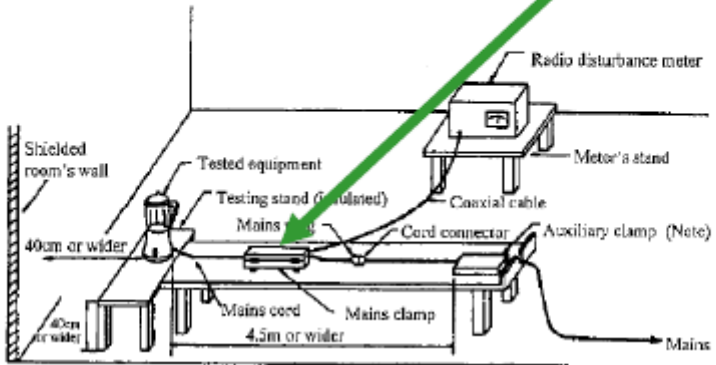


Figure 1 – Absorbing clamp used to measure appliance emissions.

The emissions standard EN 55014-1 allows for the possibility of digital circuitry in the “smart” appliance, but the possibility of digital emissions above 300 MHz is not foreseen in the standard. It does include radiated emissions limits and methods, but only for toys.

If the appliance contains sources of emissions above 300 MHz, not necessarily a “smart” appliance but more likely in that case than otherwise, it is prudent to include EMC testing to a radiated emissions standard in addition to EN 55014-1. Reasonable choices would be either EN 55022 (for information technology equipment) or EN 61000-6-3 (generic emissions for residential, commercial and light industrial environments – the radiated emission limits are identical to EN 55022).

Several years ago a British importer of hair dryers was fined £6000 because two hair dryers, when tested for compliance to the “essential requirements” of the EMC Directive, failed the disturbance power limits of EN 55014-1 by up to 8 dB, but they also failed generic radiated emission limits by 19 dB. The hair dryers also caused visible interference to TV reception. Many in the EMC community at this time were surprised that the UK authorities chose to apply an EMC test (radiated emissions) over and above the appropriate product family standard EN 55014-1 for the hair dryers. The UK authorities considered that EN 55014-1 was not sufficient. Therefore, careful consideration needs to be given to the appropriate EMC testing of “smart” appliances that are likely to generate high-frequency emissions.



Designs for disturbance power compliance

The absorbing clamp used to measure disturbance power is sensing common-mode signals in the cable being tested. In order to reduce these common-mode signals:

- consider bypass capacitors across the ac line, or a modular line filter for more severe noise
- use ferrite beads or common-mode chokes on signal lines
- for any shielded (screened) cables, minimize the impedance between cable shield and appliance enclosure or ground; improve termination of cable shield to connector, and connector to appliance enclosure or ground.

Harmonic and flicker emissions

Table 5 contains references to the low-frequency (< 2 kHz) standards EN 61000-3-2 (harmonic emissions) and EN 61000-3-3 (flicker emissions). These standards only apply to equipment in the EU drawing less than 16 A/phase. Related standards cover equipment with higher current consumption. EN 61000-3-2 and EN 61000-3-3 are so-called “horizontal standards,” in that they apply to all types of equipment within their scopes, including home appliances, in addition to other EMC standards.

Harmonic emissions occur when the appliance power supply imposes a distorted current waveform onto the ac line, typically through diode rectification or electronic switching. The effect of high harmonic emissions is not so much the disturbance of other equipment connected to the same ac line, but rather the potential for overheating of a branch circuit feeding other equipment that also generates harmonic emissions. EN 61000-3-2 specifies that appliances drawing less than 75 W are exempt, from testing, and that “professional” equipment rated above 1 kW is also exempt.

Flicker emissions occur when the appliance presents a slowly- and quickly-varying load to the ac line. Limits are based on the threshold of annoying flicker caused by a 60 W incandescent lamp connected to the same ac branch as the appliance. Note that flicker emissions are not regulated in the EU on the basis of disturbance to other appliances, but rather on the irritability to bystanders. EN 61000-3-3 specifies that tests need not be made on equipment which is unlikely to produce significant voltage fluctuations or flicker.



In the example of a setback thermostat in Table 3, testing to neither EN 61000-3-2 nor EN 61000-3-3 would be applied, because either: (a) the thermostat is battery-powered and not connected to the ac line, or (b) if ac-powered it consumes less than 75 W and by itself is unlikely to produce significant flicker emissions.

Designs for harmonic and flicker emissions compliance

For harmonic emissions compliance:

- do not use a linear ac power supply > 75 W; use a power-factor-corrected (PFC) switching supply.

For flicker emissions compliance:

- use solid-state and soft-start techniques for switching loads
- where real loads must be switched on and off, consider transferring to equivalent dummy loads.

Appliance susceptibility and EN 55014-2

The harmonized product family standard EN 55014-2 draws on most of the common EMC disturbance tests and applies them selectively, depending on the technology in the appliance. Four categories are defined, as shown in Table 6 below:

	Category I	Category II	Category III	Category IV
circuitry	No electronic control circuitry	Electronic control circuitry, clocks < 15 MHz	Battery-powered, clocks < 15 MHz	Everything else
examples	Tools, thermostats	Motor-operated appliances, toys	Electronic toys	

Table 6 – Appliance categories defined in EN 55014-2

Based on these categories, EN 55014-2 then defines which disturbance phenomena are to be applied to the appliance during testing, which performance criteria must be met, and the levels of the disturbances. The tests to be applied by category are shown in Table 7 below:

disturbance	Category I	Category II	Category III	Category IV
ESD	n/a	B	B (C, some toys)	B
RF radiated	n/a	n/a	A	A
EFT/B	n/a	B	n/a	B
Surge	n/a	B	n/a	B
RF conducted	n/a	A (230)	n/a	A (80)
Mains variations	n/a	C	n/a	C

Table 7 – Applicability of susceptibility tests by appliance category

If the appliance contains no electronic control circuitry, no disturbances are applied. The appliance is deemed to comply without testing. The performance criteria are:

- A - performs as intended during and after test
- A (80) - criterion A, with upper limit of testing 80 MHz.
- A (230) - criterion B, with upper limit of testing 230 MHz.
- B - may degrade during test, returns to normal after test.
- C - test may cause loss of function, which may be self-recoverable or by operator action

Examples of permissible degradations in performance, in terms of measurable appliance parameters such as speed, torque, etc. are also given in EN 55014-2.

The reference standards and test levels specified in EN 55014-2 are given in Table 8 below:

EMC disturbance	reference standard	test level
ESD	EN 61000-4-2	4 kV contact, 8 kV air
RF radiated	EN 61000-4-3	3 V/m. 80% modulated
EFT/B transients	EN 61000-4-4	0.5 kV signal lines, 1 kV ac lines
Surge	EN 61000-4-5	1 kV differential, 2 kV common mode
RF conducted	EN 61000-4-6	1 V signal lines, 3 V ac lines
Mains variations	EN 61000-4-11	100% interrupt, 0.01s; 60% dip, 0.2s; 30% dip, 1s.

Table 8 – Overview of EN 55014-2 EMC tests and levels

Just as we saw with the appliance emissions standard EN 55014-1, when “smart” functions are added to the appliance, additional susceptibility tests to those listed above may be needed to assure reliable operation and compliance with the essential requirements of the EMC Directive.

Designs for susceptibility/immunity compliance

ESD

- for metallic enclosures, assure good contact all along seams
- for non-conductive enclosures, assure no gaps
- keep sensitive wiring away from conductive enclosure
- provide capacitive bypassing and clamping components for wiring entering circuit boards

RF radiated

- use metallic enclosure for shielding, or provide internal shielding
- provide ferrite beads and/or capacitive bypassing for sensitive wiring on or entering circuit board
- keep circuit wiring and boards as short as possible

EFT/B

- use capacitive bypassing or modular filter on ac power entry and cables > 3m
- place bypassing or filtering of ac power entry as close as possible to enclosure boundary
- use capacitive bypassing or ferrite beads on internal wiring that is susceptible

Surge

- use capacitive bypassing or modular filter on ac power entry
- use clamping components at power entry, to limit surge energy

RF conducted

- use capacitive bypassing or modular filter on ac power entry and cables > 3m

Mains variations

- assure adequate frequency response and energy storage in power supply

Communications

One way to enhance the functionality of home appliances is to endow them with the capability of communicating with a home computer, phone line or each other. The designer's choice of whether radio or powerline communications is the medium is constrained by the performance characteristics of each and national regulations that vary from place to place. In any case, it is usually possible to embed an approved or compliant communications module into the appliance, minimizing the design time and regulatory compliance effort. There are often additional EMC or radio tests necessary to assure compliance of the "smart" appliance with the installed communications module.

Powerline communications

Power wiring is everywhere in the home, and products have been developed to use it as a communications bus. However, the ac wiring generally carries a great deal of induced noise from network switching equipment, other home appliances and electronics and radio transmitting sources that couple into the wiring. As a result, reliable powerline communications (PLC) with the home typically use robust encoding such as spread spectrum technology to superimpose control or data signals on the ac line. Industry standards govern the signalling protocols, but regulatory compliance falls under spectrum regulators such as the FCC.

In the USA, home powerline communications falls under the Part 15 category of carrier current systems. They are regarded as “unintentional radiators” subject to the rules in 15.109(a), (e), and (g) and the general radiated emission limits in 15.209. The FCC’s Class B radiated emission limits can be used to assess compliance of an installed system, or CISPR 22 Class B as an FCC-accepted alternative. The only ac conducted emission limit is 1000µV (60 dBµV) over the AM broadcast frequency range 535 – 1705 kHz. There are no regulatory compliance requirements for susceptibility or immunity.

In Canada, residential and office powerline communications are regulated under ICES-006. For systems operating above 1.705 MHz the radiated emission limits are identical to FCC limits. However, below 535 kHz ICES-006 imposes limits on carrier current output voltages that do not exist in FCC rules. Both the FCC and Industry Canada require verification of carrier current systems in three separate locations.

The regulatory situation for powerline communications in the EU presently divides at the signalling frequency of 148.5 kHz. Harmonized standards exist for both emissions and susceptibility below that frequency, but for broadband powerline communications above 1 MHz only an immunity standard is available as shown in Table 9 below:

Signalling range	Harmonized emissions standard	Harmonized immunity standard
95 – 148.5 kHz	EN 50065-1	EN 50065-2-1
1.6 – 30 MHz	none	EN 50412-2-1

Table 9 – EU powerline communications standards

EN 50065-1 is a complex emissions standard that divides the operating range 95 – 148.kHz into several sub bands, two of which require a signalling protocol. Thus it is limited to low-frequency control and data applications.

While the European Commission has emphasized that all such systems must meet the essential requirements of the EMC Directive, little guidance is available on how to do that for systems operating above 1 MHz. Amendments to CISPR 22 are underway to accommodate higher levels of conducted emissions for PLC systems than those allowed by the present ac conducted limits.

Radio

For the “smart” appliance designer looking at wireless communications, there are several system architectures of interest:

- Short/medium range low-power radio link(s) appliance-to-appliance or appliance-to-PC
- Long range low-power radio link(s) in appliance(s) to public telephone (PSTN) gateway
 low-power radio link(s) in appliance(s) to PC-to-Internet
 low-power radio link(s) in appliance(s) to cellular modem in PC or freestanding cellular modem(s) in appliance(s)

By exploiting the use of a PSTN or Internet gateway, wireless links (and also powerline buses) allow appliances to be interrogated by the owner at any location over a secure path; or permit the appliance to report impending or actual failure modes to a central repair facility; or to be shut down by the local utility over a “smart grid” to reduce peak demand or take advantage of off-peak pricing.



If powerline communications is hampered by differing national regulations, radio communications is similarly burdened, except that:

- there are a few short-range radio bands available more-or-less globally, such as 2.4 GHz (including such IEEE 802 protocols as Bluetooth, Wi-Fi and Zigbee)
- embedded cellular modems are available to individually satisfy most national spectrum allocations

Some generally available wireless frequency bands and regulations are listed in Table 10 below

Frequency band	FCC	Industry Canada	EU
Low-power, short distance (1 – 10m)			
433.92 MHz	15.231*	RSS-210 A.1*	EN 300 220
2.45 GHz	15.249	RSS-210 A2.9	EN 300 440
Low-power, medium range (10 – 100m) high-speed data			
2.45 GHz	15.247	RSS-210 A.8	EN 300 328 EN 300 440
5 GHz	15.401	A.9	EN 301 893

* Protocol requirements on type of communication and transmission rate.
Table 10 – A sample of wireless regulations for common frequency bands

The corresponding standards for some public telephone (PSTN) interfaces are:

FCC	47 CFR Part 68, TIA-968-B
Canada	CS-03
EU	ES 203 021-1, -2 and -3

Under the EU Radio and Telecom Terminal Equipment (RTTE) Directive 1999/5/EC, the only essential requirements for terminal interfaces are EMC and safety. Therefore the ETSI ES standards listed above are discretionary but recommended. For a telephone terminal interface in the EU the typical mandatory standards would be EN 55022 (emissions) and EN 55024 (immunity) and EN 60950-1 (safety).

The essential requirements for radio equipment under the RTTE Directive include EMC, safety and spectrum protection. Therefore in addition to the spectrum standards listed in Table 10 for the EU, there are these additional EMC standards:

Spectrum standard	EMC standards
EN 300 220, EN 300 440	EN 301 489-1, -3
EN 300 328	EN 301 489-1, -17
EN 301 893	EN 301 489-1, -17

EN 301 489-1 is the core EU EMC standard for radio equipment that defines applicable EMC tests by equipment type, and performance criteria. The EMC tests are largely those listed in Tables 1 and 2 above. The EMC standards EN 301 489-3 and -17 apply specific setup and operating conditions appropriate to the frequency band and equipment.

There are no susceptibility/immunity requirements under FCC rules for the wireless bands above.

Designs for communications compliance

- Assure that transmitter modules are already certified for the jurisdiction; “compliant with” is not the same as “certified.”
- Appliances containing cellular modems will generally require approval by the cellular network operator, in addition to modem certification.
- Use the transmitter module in accordance with any user guidance or certification conditions; antenna choices may be restricted.
- Exercise care in selecting operating frequency bands; there are very few bands that are acceptable worldwide. On the other hand, a region-specific band may be less subject to interference than a more popular global one.

Product safety

Appliance safety standards concern the hazards of shock, fire, heating, and similar physical phenomena. “Smart” appliances present no unusual EMC hazards except in four categories:

1. wireless appliances that can be used during life safety emergencies; related safety standards generally contain additional tests to assure the integrity of the wireless communications.
2. appliances for use in the EU that can generate strong and potentially hazardous low-frequency electromagnetic fields.
3. “smart” appliances with embedded radios, where the combination of radiofrequency output power and proximity to the user is potentially hazardous.
4. “smart” appliances that use electronic circuitry for safety-critical functions such as motion or power shutoff.

Category 4 is addressed in the section below on *Functional safety*, and categories 2 and 3 are addressed in the section below on *Electromagnetic exposure*.

Functional safety

The IEC standard series IEC 62508-1...-7 is directed at the structures for defining and reducing the hazards and risks associated with electrical/electronic/programmable electronic (E/E/PE) safety-related systems. The impact of functional safety on EMC is perhaps best captured in IEC 51508-2 clause 7.2.3.2(e), bold added:

- e) the electromagnetic immunity limits (see IEC 61000-1-1) which are required to achieve electromagnetic compatibility – the electromagnetic immunity limits should be derived taking into account both the electromagnetic environment (see IEC 61000-2-5) and the required safety integrity levels;

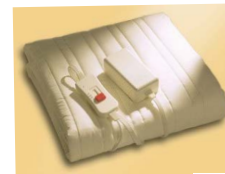
NOTE 1: It is important to recognize that the safety integrity level is a factor in determining electromagnetic immunity limits, especially since the level of electromagnetic disturbance in the environment is subject to a statistical distribution. ...For higher safety integrity levels it may be necessary to have a higher level of confidence, which means that **the margin by which the immunity limit exceeds the compatibility level should be greater for higher safety integrity levels.**

Thus the susceptibility/immunity levels specified in Tables 5, 7, 8 and 9 above may not be sufficient for safety-related functions implemented in “smart” appliances. The IEC 61508 series provides guidance for evaluating and designing to the appropriate requirements.

Electromagnetic exposure

Strictly speaking, EMC refers to the harmonious operations of equipment with each other in the context of an electromagnetic environment. In many cases persons are part of that environment, and consideration must be given for “smart” appliances to any adverse effect of electromagnetic exposure on users and operators of that equipment. The nature of any electromagnetic threat varies by disturbance frequency, from skin surface currents at very low frequencies to cell heating at frequencies in the MHz and GHz ranges.

National regulations for electromagnetic exposure generally divide by considering whether the exposure results as a natural by-product of the operation of the appliance (such as a heating blanket) or whether there is an intentional radiating source of radio frequency (RF) energy present (radio transmitter). Table 11 details this division.



	USA	EU
Electromagnetic fields (EMF) as a by-product of normal operation	<p>Microwave ovens: 21 CFR 1030: Leakage limit 1 mW/cm² new, 5 mW/cm² afterward.</p> <p>Otherwise: only guidelines (IEEE C95.1)</p>	<p>EU Council Recommendation 1999/519/EC; harmonized standard EN 50366 for appliances.</p>
Radiated fields produced intentionally for communications	<p>47CFR 1.1310, 2.1091, 2.1093.</p> <p>SAR evaluation for user distances < 20 cm.</p> <p>MPE evaluation for user distances > 20 cm</p>	<p>EU Council Recommendation 1999/519/EC; harmonized standards for radios such as EN 50360, EN 50371, EN 50385</p>

Table 11 – Overview of USA and EU regulations for electromagnetic exposure

In practice, appliance EMF evaluation under EN 50366 in the EU is limited to frequencies below 400 kHz and therefore considers *low-frequency effects*. Radiated fields from transmitters in the USA, EU and many jurisdictions elsewhere are typically evaluated above 300 MHz, and involve *high-frequency effects*.

EU low-frequency EMF limits: EN 50366

The test procedures in EN 50366 measure magnetic flux density emanating from the appliance over the range 10 Hz to 400 kHz. The magnetic flux density limit at 50 Hz is 100 microTeslas (µT). For comparison, the earth’s magnetic field generates a steady-state or DC magnetic flux density from 30 µT to 60 µT.

The measurement distances for evaluation differ according to the typical separation between the appliance and the user, as in Table 12 below:

Measurement distance, cm	Appliance type
0	Electric blanket, dental hygiene, hair clipper, indoor whirlpool bath
10	Facial sauna, hair dryer, water bed heater
30	Dishwasher, washing machine, hand tool, microwave oven, refrigerator
50	Air conditioning unit, heater, clock, vacuum cleaner

Table 12 – measurement distances in EN 50366 for evaluation of EMF

Compliance with EN 50366 is mandatory for appliances to meet CE-marking requirements for safety. There are no corresponding requirements in the USA.

Designs for EMF compliance

Appliances with motors; working at high frequencies to 400 kHz; working with very high currents; evaluated at 0 cm

- Assure adequate magnetic shielding; twist or shield ac power feed and internal wiring

RF exposure from radios

Owing to the popularity of cell phones, Bluetooth, Wi-Fi and other wireless devices, there are concerns about the health effects of such radios in close proximity to the user. Many jurisdictions have RF exposure rules for transmitters in place, including the USA, Canada, the EU, and Australia. Most of the rules are based on the heating effect of the RF energy on human cells, as the RF energy is non-ionizing and no other potential sources of cell damage have been conclusively observed.

The method of evaluation of RF exposure from a radio transmitter depends on its typical proximity to the user or others nearby. The information in Table 13 below is for US parameters but other jurisdictions are similar.

User distance	Evaluation type	method
< 20 cm	Specific Absorption Rate (SAR)	<ol style="list-style-type: none"> 1. Appliance with transmitter is placed near the body simulator filled with fluid approximating dielectric properties of brain or muscle. 2. Electric field inside body simulator is scanned to determine maximum power density or SAR from transmitter outside. 3. SAR limits do not vary with frequency, but with body part exposed. Hands, wrists and legs can dissipate heat better than head or body and have higher SAR limits.
> 20 cm	Maximum Permissible Exposure (MPE)	<ol style="list-style-type: none"> 1. RF power to antenna is measured. 2. Gain of antenna is considered to calculate maximum power density at 20 cm or larger user distance. 3. MPE limits vary with RF frequency.

Table 13 – RF exposure evaluation of appliances containing radio transmitters

The graphical results of a typical SAR scan on a cellular handset are shown in Figure 2 below. Note that the place of highest SAR is at the base of the handset antenna:

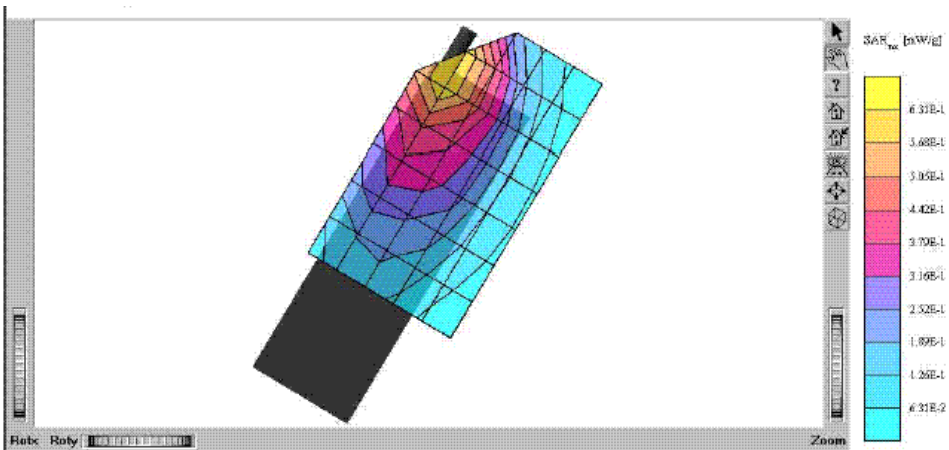


Figure 2 – SAR scan of a cellular handset

In most regulatory regimes, average transmitter powers of 20 mW or less do not require SAR evaluation regardless of the user distance. Transmitter power above 0.6 W approaches the upper limits of SAR for head-held devices such as cellular handsets.

Transmitters operating > 20 cm from users (and most installations in fixed appliances would fall in this category) would meet FCC 1.1310 MPE limits with 1 W power output and no antenna gain (0 dBi) from 30 to 300 MHz. Allowed power to meet MPE limits rises to 5 W from 300 to 1500 MHz and remains flat at 5 W above 1500 MHz. These power levels are reduced if the antenna gain is greater than 0 dBi.

Designs for RF exposure compliance

- Use the lowest transmitter power consistent with reliable operation
- Multiple radio transmitter modules in one appliance may require additional RF exposure evaluation

For more information on specific testing and certification information, please contact Intertek at 1-800-WORLDCON, email icenter@intertek.com, or visit our website at www.intertek.com.

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