An overview of radiated EMI specifications for power supplies

Texas Instruments

Timothy Hegarty
Applications Engineer,
Texas Instruments, Phoenix, AZ

Several governing bodies regulate the permissible levels of radiated emissions generated by an end product to maintain electromagnetic compatibility (EMC).

Radiated electromagnetic interference (EMI) from a switching power supply is a dynamic and situational problem that relates to parasitic effects, circuit layout and component placement within the power supply itself, as well as the overall system in which it operates. Thus, the issue of radiated EMI is quite challenging from the design engineer's perspective, so you must address it as early as possible in the design phase. An understanding of the relevant EMI standards pertaining to the application becomes essential.

Introduction

Radiated emissions affect a power converter's EMI signature at high frequencies [1]. The upper test frequency for radiated tests extends to 1GHz or higher depending on the specification, and much above that for conducted emissions [2]. Performing radiated EMI measurements, while not as straightforward as conducted emissions tests, is necessary for compliance testing and can easily become a bottleneck in a product's development cycle. In this paper, I'll offer some perspective on standards for radiated emissions, particularly those pertaining to automotive, multimedia and industrial applications.

Radiated EMI standards for automotive systems

Today's automobiles have increased their electronic content, with numerous microprocessors, various radio-frequency (RF) transmitters and receivers, motor drive systems, and associated power management. Tracking all possible interactions that might lead to a radiated EMI problem is a formidable task – particularly given the relatively small volume in a vehicle characterized by densely packed arrangements of power and signal runs in the cable harness. Nevertheless, it is possible to test components and systems in order to meet automotive EMC requirements. As such, assessing EMI performance is an issue of heightened concern for engineers involved in automotive design and testing [3].

UNECE Regulation 10

Titled "Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility," United Nations Economic Commission for Europe (UNECE) Regulation 10 revision 5 (R10.05) requires that automotive manufacturers gain type approval for all vehicles, electronic subassemblies (ESAs), components and separate technical units [4]. A type-approved certified system is then labeled with uppercase E mark.

From a regulatory standpoint, R10.05 contains two groups of tests for radiated EMI: broadband (BB) emissions caused by (for instance) ignition systems, brushed DC motors and on-board battery-charging units, and narrowband (NB) emissions from switching power supplies, clock harmonics and so forth. The limits are defined for both whole vehicle and ESA-/component-level testing, and assume a measurement resolution bandwidth (RBW) of 120kHz.

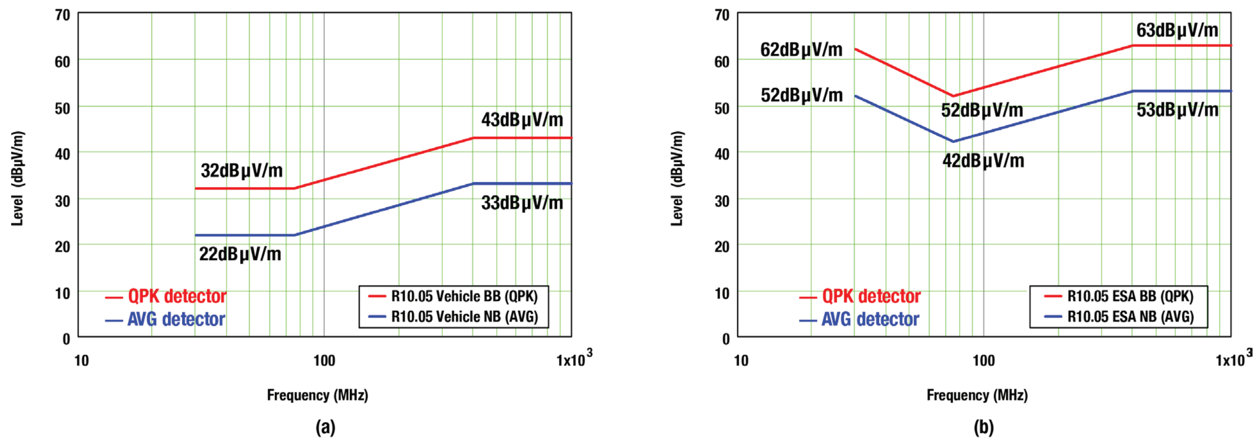

Figure 1. *UNECE Regulation 10 radiated EMI limits for vehicles at 10m (a); and ESAs/components at 1m (b).*

Figure 1 provides limits for BB and NB radiated emissions over the applicable frequency range of 30MHz to 1GHz when measured using quasi-peak (QPK) and average (AVG) detectors, respectively, as defined by Comité International Spécial des Perturbations Radioélectriques (CISPR) 16. The correlation factor between QPK and AVG measurements is 10dB at 120kHz RBW. The measuring antenna distance is 10m for vehicles and 1m for ESAs. An additional 10dB is allowed if the antenna is positioned at 3m for vehicle testing.

CISPR 12 and CISPR 25

R10.05 refers extensively to CISPR 12 [5] and CISPR 25 [6], which are international standards containing limits and procedures for the measurement of radio disturbances to protect off-board and on-board receivers, respectively. CISPR 25, which has more recent origins than CISPR 12, is generally an engineering standard often referenced as a basis for internal product specifications defined by an automotive manufacturer and its suppliers, but it is not the source for conformity assessments and regulatory compliance. That distinction falls more on CISPR 12 and particularly R10.05 since the discontinuation of the EU's automotive EMC Directive [7].

CISPR 12 protects radio reception away from the vehicle and is a whole vehicle test rather than applying to subassemblies. CISPR 25, meanwhile, protects radio reception in the vehicle and therefore has limit classes defined in bands for various radio services. CISPR 25 includes both component or module emissions measurements as well as whole vehicle emissions tests using the antenna provided with the vehicle.

Figure 2 shows the Class 5 radiated emission limits using peak (PK) and AVG detectors for components/modules. Measurements are taken apropos receivers in the broadcast and mobile service bands operating within the vehicle. The lowest measurement frequency relates to the European longwave (LW) broadcast band of 150kHz to 300kHz, and the highest frequency is 2.5GHz in consideration of *Bluetooth*® and Wi-Fi® transmissions. Because the components used in an automobile typically have both BB and NB emissions, the limits in CISPR 12/25 no longer reference "broadband" and "narrowband," but instead reference detector type for both.

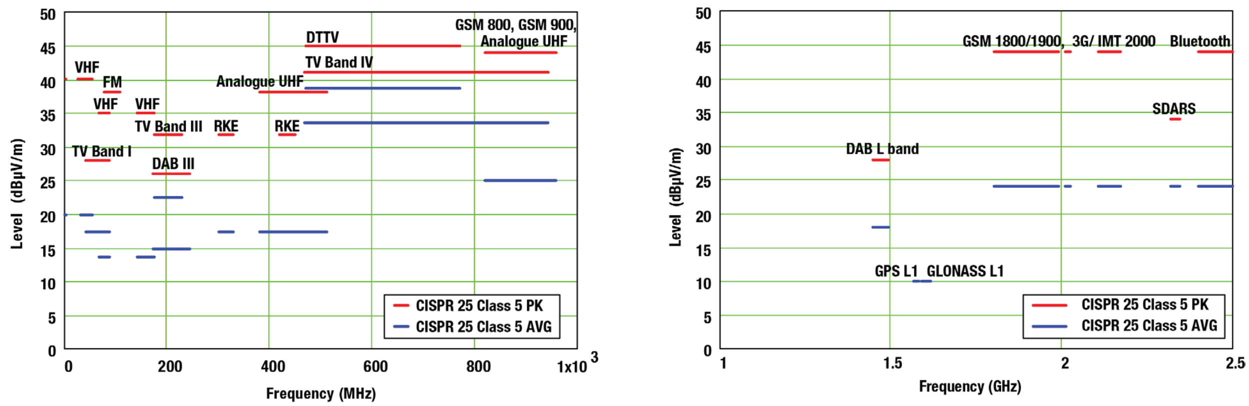

Figure 2. *CISPR 25 Class 5 radiated limits for components/modules using the Absorber-Lined Shielded Enclosure (ALSE) test method with an antenna distance of 1m.*

Antenna systems for CISPR 25

Measurements are made using linearly polarized electric field antennas that have a nominal 50Ω output impedance. **Table 1** and **Figure 3** show the antennas recommended by CISPR 25 to increase consistency of results between laboratories.

A vertically mounted active monopole rod antenna with counterpoise is used for low-frequency measurements. Biconical and log-periodic dipole array (LPDA) antennas generally cover the frequency ranges of 30MHz to 200MHz and 200MHz to 1GHz, respectively. A dual-ridge-horn antenna (DRHA) is commonly used from 1GHz to 2.5GHz. The broadband (hybrid bicon/log or "bilog") antenna is a larger format than the biconical or log-periodic antennas and is sometimes used to conveniently cover a larger frequency range spanning 30MHz to 1GHz.

Frequency range	Recommended antenna	Measurement polarization
150kHz to 30MHz	1m vertical monopole with counterpoise	Vertical only
30MHz to 300MHz	Biconical	Horizontal and vertical
200MHz to 1GHz	Log-periodic	
30MHz to 1GHz	Broadband (bicon + log ⇒ "bilog")	
1GHz to 2.5GHz	Horn or log-periodic	

Table 1. *Recommended antennas per CISPR 25; the biconical and log-periodic antenna overlap in frequency, whereas a bilog antenna covers the cumulative of their frequency ranges.*

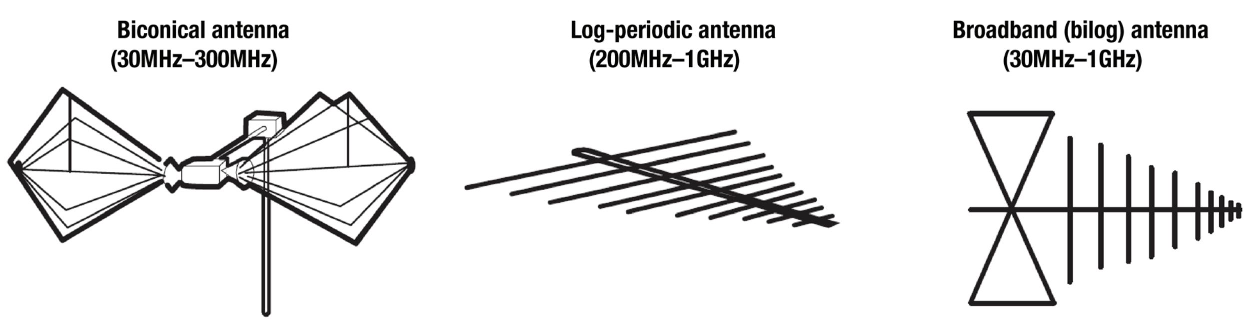

Figure 3. *Measurement antennas referenced in the CISPR 25 specification.*

Radiated EMI tests using an ALSE

Figures 4, 5 and **6** depict the ALSE test setups defined in CISPR 25 for radiated emission measurements of components and modules over the frequency ranges specified in Table 1.

The equipment under test (EUT) and cable harness are placed on a nonconductive, low relative permittivity material ($\varepsilon_r \leq 1.4$) 50mm above the ground plane. The length of the harness parallel to the front of the ground plane is 1.5m, with the total length of the test harness between the EUT and the load simulator not to exceed 2m. The long segment of the test harness is located parallel to the edge of the ground plane facing the antenna at a distance 100mm from the edge. The requirements for the ground plane are a minimum width and length of 1m and 2m, respectively, or underneath the entire equipment plus 200mm, whichever is larger.

The horn antenna is aligned with the EUT, whereas the other antennas are placed at the midpoint of the wiring harness. All measurements are performed with a 1m antenna distance. Measurements in the frequency range from 150kHz to 30MHz are performed with vertical antenna polarization only. Scans above 30MHz are performed with both horizontal and vertical polarizations.

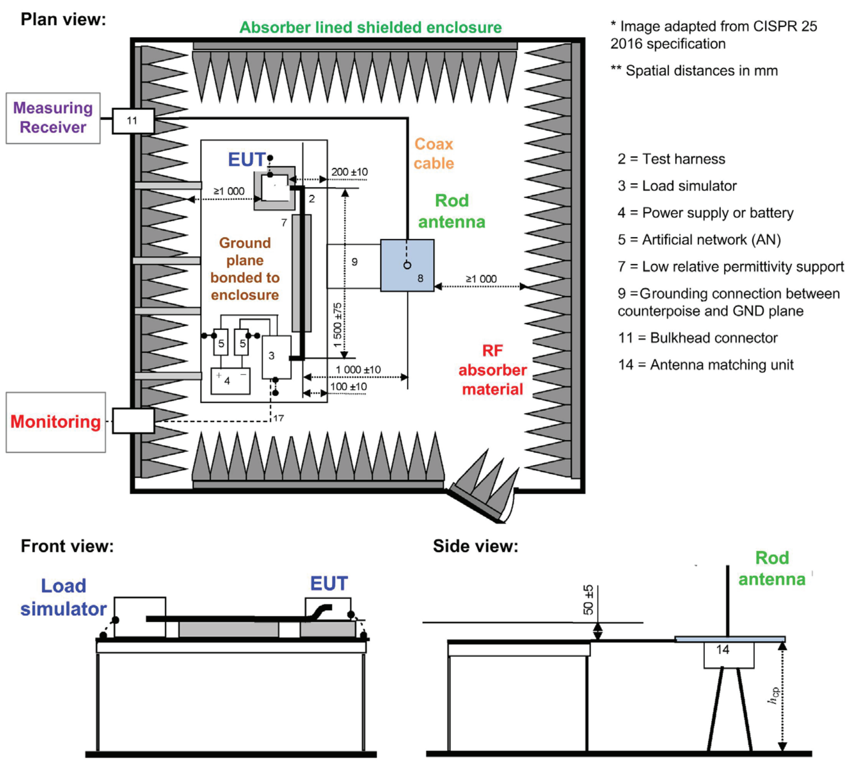

Figure 4. *CISPR 25 radiated emissions measurement setup with active rod antenna (150kHz to 30MHz).*

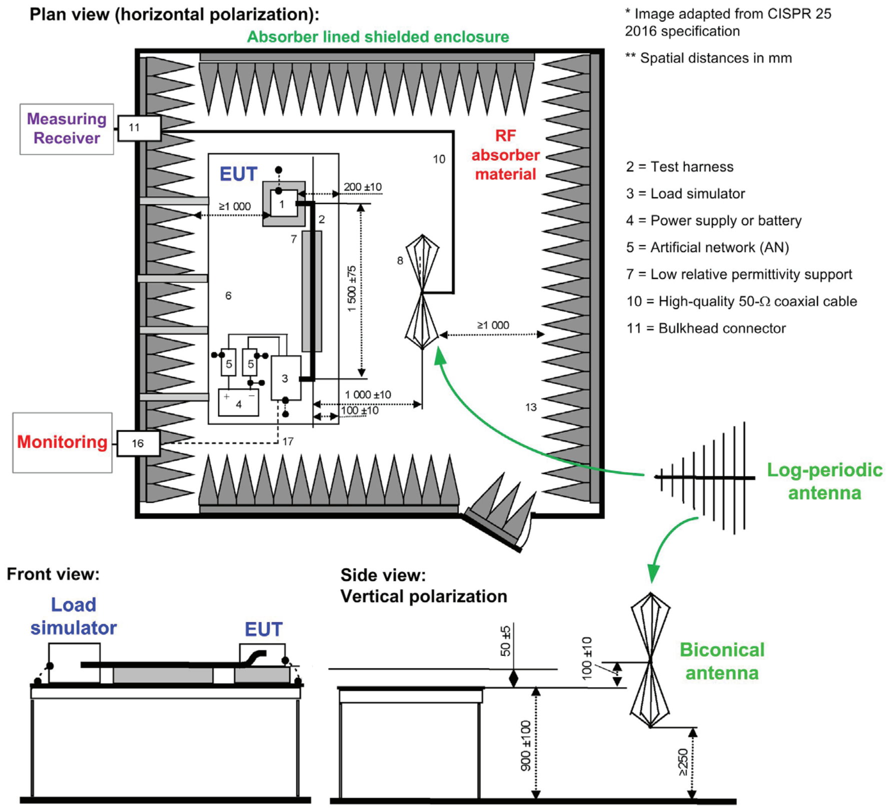

Figure 5. *CISPR 25 radiated emissions measurement setup with biconical antenna (30MHz to 300MHz) or log-periodic antenna (200MHz to 1GHz).*

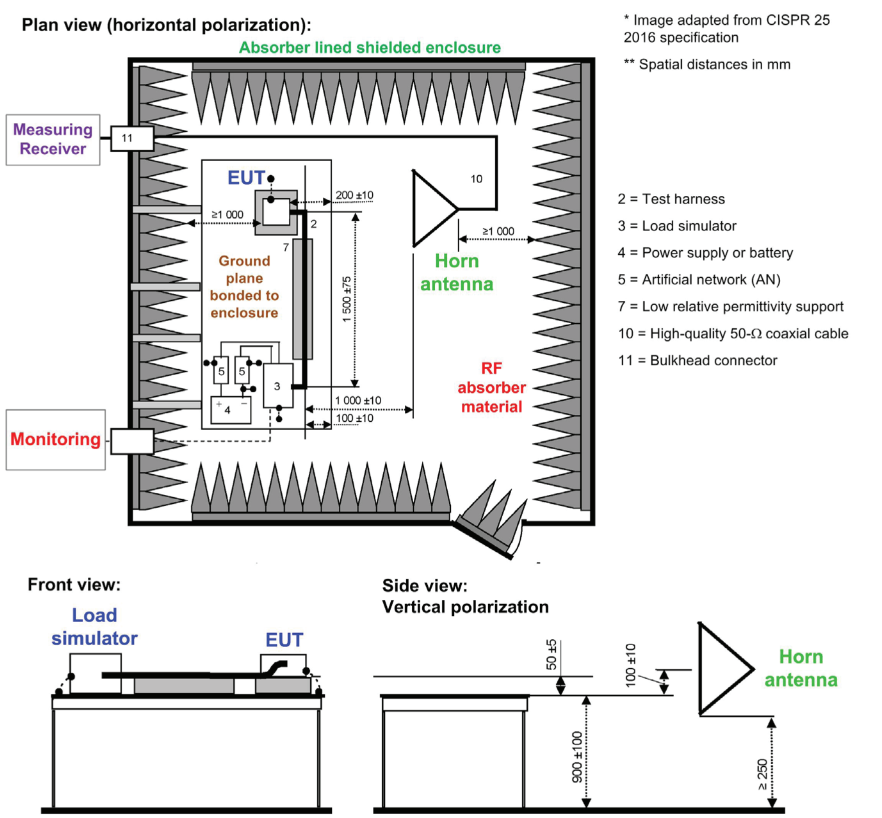

Figure 6. *CISPR 25 radiated emissions measurement setup with horn antenna (above 1GHz).*

Radiated EMI standards for multimedia equipment

For many years, information technology (IT) equipment with a supply voltage not exceeding 600V has used the well-known European Standard EN 55022, derived principally from the CISPR 22 [8] product standard, with the CE Declaration of Conformity (DoC) for external power supplies referencing EN 55022 to demonstrate compliance with the essential requirements of the EU's EMC Directive 2014/30/EU [9].

However, CISPR 22/EN 55022 was recently subsumed into CISPR 32/EN 55032 [10], a new product family standard for multimedia equipment (MME) that is effective as a harmonized standard in compliance with the EMC Directive. Equipment intended primarily for use in a residential environment must meet Class B limits, with all other equipment complying with Class A. Meanwhile, products designed for North American markets have complied with limits set by Section 15.109 of the Federal Communications Commission (FCC) Part 15 Subpart B for unintentional radiators [11].

CISPR 22/32 and FCC Part 15

Table 2 presents the specified Class A and Class B radiated emission limits from FCC Part 15 for unintentional radiators. In addition, clause 15.109(g) of the specification allows the use of CISPR 22 limits for radiated emissions as given in **Table 3**. The limits in both tables assume a QPK detector function and an RBW of 120kHz for frequencies below 1GHz. **Tables 4** and **5** present limits for frequencies above 1GHz using PK and AVG detectors and a receiver RBW of 1MHz.

For a given measurement distance, Class B limits for residential or domestic applications are generally more restrictive by a 6dB to 10dB margin than Class A limits for commercial use. Tables 2 and 3 also include an inverse linear distance (1/d) proportionality factor of 20dB/decade, used per 15.31(f)(1), to normalize limits for 3m and 10m antenna measurement distances to determine compliance. For example, if the antenna is placed at 3m instead of 10m due to test facility limitations, then the limit amplitudes are adjusted by approximately 10.5dB. **Figure 7** plots the relevant limit lines for Class A and Class B at a 3m antenna distance.

Frequency range (MHz)	3m distance		10m distance	
	Class A (dBµV/m)	Class B[1] (dBµV/m)	Class A[2] (dBµV/m)	Class B (dBµV/m)
30-88	49.6	**40**	**39.1**	29.5
88-216	54	**43.5**	**43.5**	33
216-960	56.9	**46**	**46.4**	35.5

Notes:

[1]Class B limits are specified by the FCC at a distance of **3m** and extrapolated here for 10m by subtracting 10.5dB.

[2]Class A limits are specified by FCC at a distance of **10m** and extrapolated here for 3m by adding 10.5dB.

Table 2. *Radiated emissions field strength QPK limits per 47 CFR 15.109(a) and (b), 30MHz to 960kHz.*

Frequency range (MHz)	3m distance		10m distance	
	Class A (dBµV/m)	Class B (dBµV/m)	Class A (dBµV/m)	Class B (dBµV/m)
30-230	50.5	40.5	**40**	**30**
230-1,000	57.5	47.5	**47**	**37**
Note: *The limits are specified in CISPR 22 at* **10m** *and extrapolated here for 3m by adding 10.5dB.*				

Table 3. *Radiated emissions field strength QPK limits per 47 CFR 15.109(g)/CISPR 22/32, 30MHz to 1GHz.*

Frequency range (GHz)	Class A (dBµV/m)		Class B (dBµV/m)	
	AVG	PK	AVG	PK
0.96-40	60	80	54	74
Note: *The limits are specified in CISPR 22 at 10m and extrapolated here for 3m by adding 10.5dB.*				

Table 4. *Radiated emissions field strength limits at 3m per 47 CFR 15.109(a) and (b), 960kHz to 40GHz.*

Frequency range (GHz)	Class A (dBµV/m)		Class B (dBµV/m)	
	AVG	PK	AVG	PK
1-3	56	76	50	70
3-6	60	80	54	74
Note: *The limits are specified in CISPR 22 at 10m and extrapolated here for 3m by adding 10.5dB.*				

Table 5. *Radiated emissions field strength limits at 3m per 47 CFR 15.109(g)/CISPR 22/32, 1GHz to 6GHz.*

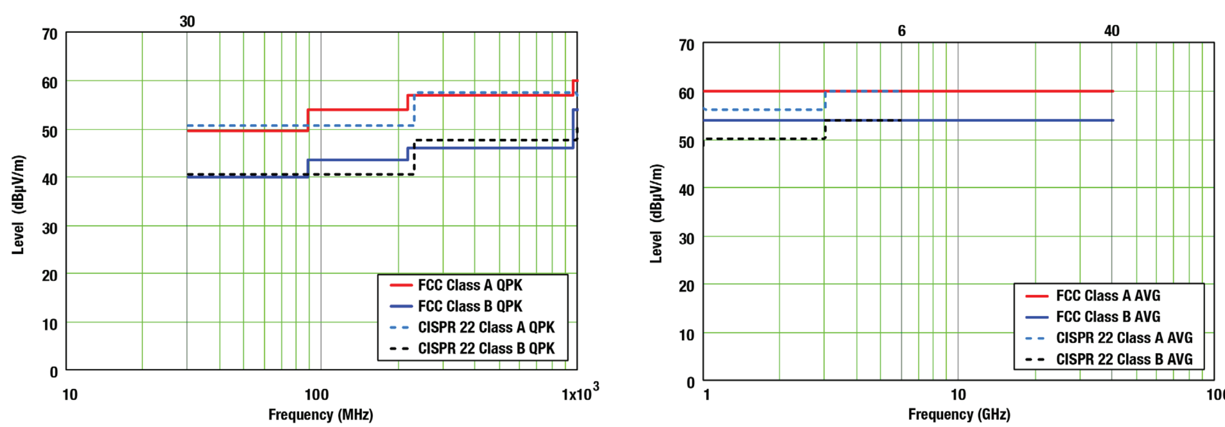

Figure 7. *FCC Part 15 and CISPR 22/32 radiated limits for Class A and Class B using QPK and AVG detectors below and above 1GHz, respectively.*

As depicted in **Figure 8**, a radiated EMI test procedure involves placement of the EUT and support equipment on a nonconductive turntable 0.8m above the reference ground plane in a semi-anechoic chamber (SAC) or open area test site (OATS), as defined in CISPR 16-1. The EUT is placed 3m away from the receiving antenna, which is mounted on an antenna tower.

A PK detector pre-scan using a calibrated bilog broadband antenna detects emissions from 30MHz to 1GHz with both horizontal and vertical antenna polarizations. Such an exploratory test determines the frequencies of all significant emissions. This is followed by a QPK detector check of relevant trouble spots to record the final, formal compliance measurements. The RBW of the EMI receiver is set at 120kHz during the test.

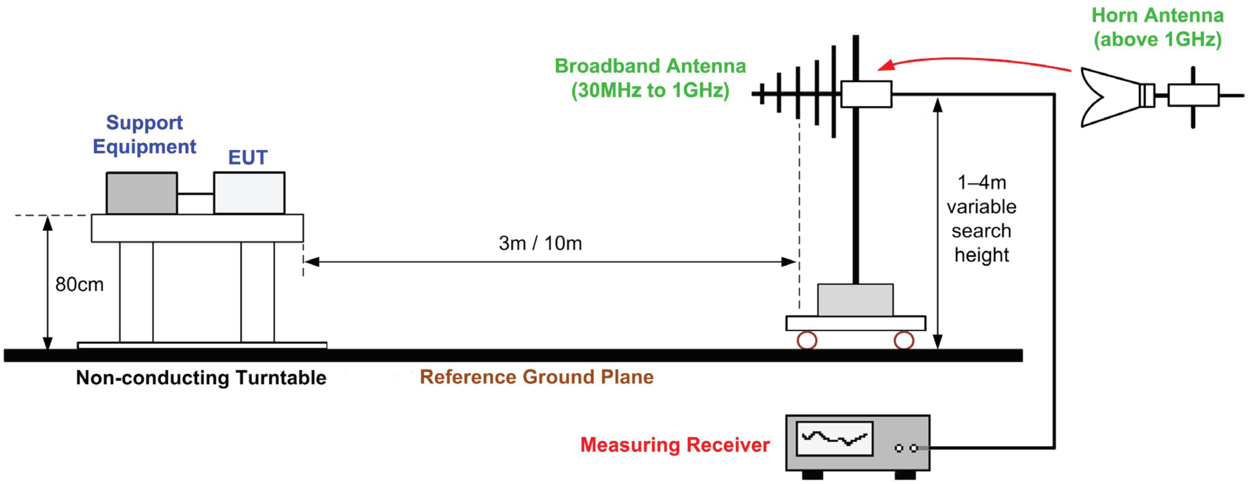

Figure 8. *Radiated emissions measurement setup for FCC Part 15 and CISPR 22/32.*

The antenna is configured for horizontal and vertical polarizations (by rotating it by 90 degrees relative to the ground plane) and adjusted in height between 1m and 4m above the ground plane to maximize the field strength reading at each test frequency in consideration of ground plane reflections. It's required to vary the antenna-to-EUT azimuth during the measurements by rotating the EUT on a turntable 0 to 360 degrees to find the maximum field-strength readings from an EUT directional standpoint.

A PK detector pre-scan using a horn antenna may be used for scans above 1GHz, followed by an AVG detector at frequencies close to the limit. The EMI receiver RBW is set at 1MHz. A height scan is not required, as the antenna is more directional and reflections from the ground plane and chamber walls are less troublesome. However the EUT's emissions at these frequencies are also more directional, so the turntable is again rotated through 360 degrees and antenna polarization is oriented for maximum response. The upper range of concern is conditional on the EUT's highest internal frequency according to **Table 6**.

EUT's highest internal frequency	Upper frequency of measurement range
Below 1.705MHz	Testing not required
1.705MHz to 108MHz	1GHz
108MHz to 500MHz	2GHz
500MHz to 1GHz	5GHz
Above 1GHz	Fifth harmonic of highest frequency or 6GHz (CISPR 22/32) and 40GHz (FCC Part 15), whichever is lower

Table 6. *Radiated emissions maximum measurement frequency based on the highest frequency of the EUT internal clock source(s).*

Radiated EMI standards for ISM equipment

CISPR 11 is the international product standard for EMI disturbances from industrial, scientific and medical (ISM) RF equipment [12]. CISPR 11 applies to a wide variety of applications, including wireless power transfer (WPT) charging equipment, Wi-Fi systems, microwave cooking appliances and arc welders.

Equipment in Group 1 contains all ISM equipment in which there is intentionally generated and/or conductively coupled RF energy that is necessary for the internal functioning of the equipment itself.

Group 2 contains all ISM equipment in which RF energy is intentionally generated and/or used for material inspection, analysis or treatment.

Each group is further subdivided in two classes: Class A equipment is for use in all establishments other than domestic and can be measured on a test site or in situ; Class B covers domestic and is measured only on a test site. **Figure 9** provides CISPR 11 radiated limits for Group 1 equipment. For a detailed description of the various test setups, review the CISPR 11 specification document.

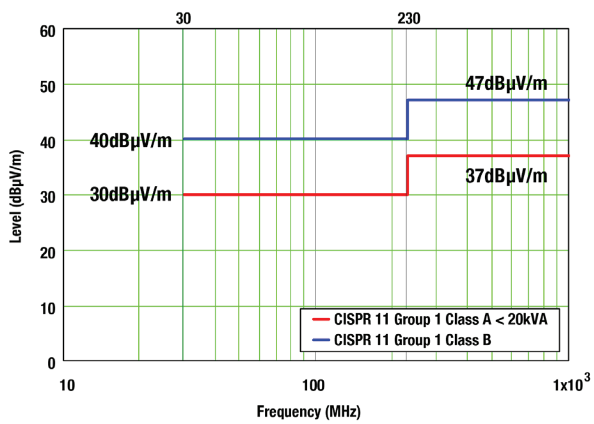

Figure 9. *CISPR 11/EN 55011 Group 1 radiated emission limits, QPK detector, measured on a test site with 10m antenna distance.*

Certain industrial end equipment may have dedicated system-level standards that direct EMC tests by referencing CISPR 11. For instance, IEC 62040-2 provides EMC requirements for uninterruptible power systems (UPS) that deliver output voltages not exceeding 1500VDC or 1000VAC. Another system-level standard is IEC 61800-3 that dictates emission requirements and specific test methods for adjustable-speed motor drive systems.

Note that a "generic" emissions standard applies if no relevant dedicated product or product-family emissions standard exists. For instance, International Electrotechnical Commission (IEC) 61000-6-3 applies to products targeted for residential/commercial/light-industrial applications [13], while IEC 61000-6-4 covers heavy-industrial environments [14].

Summary

The permissible levels of radiated emissions generated by an end product are regulated by numerous governing bodies. **Table 7** presents a cursory glance of applicable standards for the relevant product sector.

Given the imperative of achieving regulatory compliance to specifications, commercial products have to be meticulously designed to minimize the amount of EMI produced during normal operation. The design engineer should possess a detailed understanding of the applicable standards to perform initial pre-compliance testing and also to oversee full compliance measurements at a certified test house.

Product sector		IEC/CISPR standard	EN standard	FCC standard
Vehicles, boats & devices with internal combustion engines	Off-board receivers	CISPR 12	EN 55012	–
	On-board receivers	CISPR 25	EN 55025	–
Multimedia Equipment		CISPR 32	EN 55032	Part 15
ISM		CISPR 11	EN 55011	Part 18
Household appliances, electric tools & similar apparatus		CISPR 14-1	EN55014-1	–
Luminaires, lighting equipment		CISPR 15	EN 55015	Part 15/18
Equipment with no product-specific standard	Commercial/light-industrial	IEC 61000-6-3	EN 61000-6-3	–
	Heavy-industrial	IEC 61000-6-4	EN 61000-6-4	–

Table 7. *The main product standards for radiated emissions.*

References

1. Timothy Hegarty, "The engineer's guide to EMI in DC/DC converters (part 4): radiated emissions," How2Power Today, April 2018 issue.
2. Timothy Hegarty, "An overview of conducted EMI specifications for power supplies," Texas Instruments white paper SLYY136, February 2018.
3. Robert Loke and Robert Blattner, "Automotive EMI reduction techniques, applications and solutions," TI training webinar, April 16, 2018.
4. UNECE Regulation No. 10, revision 5, "Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility," October 16, 2014.
5. CISPR, CISPR 12:2007, sixth edition, "Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers."
6. CISPR, CISPR 25:2016, fourth edition, "Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers," October 27, 2016.
7. ETS Lindgren, "Automotive component EMC testing: CISPR 25, ISO 11452–2 and equivalent standards," February 2016.
8. "Achieving low noise and low EMI performance with DC/DC switching regulators," Texas Instruments EMI landing page.
9. European Commission, EMC Directive 2014/30/EU.
10. CISPR, CISPR 32:2015, second edition, "Electromagnetic compatibility of multimedia equipment – Emission requirements."
11. Code of Federal Regulations (CFR), CFR Title 47, FCC Part 15, Subpart B – Unintentional Radiators, Section 15.109, Radiated emission limits.
12. CISPR, CISPR 11:2015, edition 6.1, "Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement."
13. IEC, IEC 61000-6-3:2006, second edition, "Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments."
14. IEC, IEC 61000-6-4:2018, third edition, "Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments."