A Hierarchical Model for Prescribing EMC Design Targets to the Components of a System

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Abstract

Components of a System (i.e., Units, Shelves, or Modules) cannot meaningfully be tested for system-level emissions compliance by themselves. The lack of EMC Design objectives for emissions at the sub-system level makes it ambiguous for component designers to decide whether a given component design is EMC-sufficient. This paper introduces and discusses a qualitative methodology for defining practical EMC design targets for the components of a System for production purposes. This is a preliminary step in attempting to address this need, using a combination of common-sense, stand-alone component-level emissions testing strategy and periodic design reviews of components during their design cycle.

Keywords

EMC Design Targets, Unit Level EMC Testing, Shelf Level EMC Testing, System Level EMC Testing, Allocated Emissions Levels, Pre-Compliance Testing.

INTRODUCTION

The component designer is often faced with the dilemma of having to specify and/or produce a Unit, Shelf or a Module which must not make the System fail Radiated and Conducted Emissions compliance tests, without information about the EMC emissions characteristics of other components. Since only System-Level Emissions are controlled by EMC regulatory bodies, the designer has no direct way of assessing the EMC sufficiency of a component (except if a whole system - assuming all components are available at the same time - was idly waiting for the purpose of repeat pre-compliance tests). In some simple configurations, 3D EM Field simulations can be used to predict the system-level emissions behavior of interconnected units and modules (see for example [1]), but this is not always feasible or practical for any system. To complicate things even more, competitive pressures demand that many of these components be designed for deployment in several different products with significantly different electrical and mechanical characteristics. Typically, these Units and Modules deploy several active non-linear devices (such as DC/DC Converters for generating several different secondary DC voltages needed on-board), which have been known to “behave” differently when deployed in different platforms with singular electrical load characteristics and boundary conditions. Hence it is not always easy or even meaningful to characterize component-level emissions, without qualifying the same to a specific product. The purpose of the current paper is to formulate a quasi-deterministic framework for producing budgeted EMC design targets in terms of stand-alone Shelf, Unit and Module Level emissions levels. In the case of Conducted Emissions, one may take advantage of the fact that the observed conducted EMI signal voltage levels will be a superposition of all the voltages contributed by the individual Units supplied by the same power bus (see circuit diagram in Figure 1). This may make things relatively easier to quantify by the simplifying assumption of uniform contribution by similar or comparable Units.

![Figure 1. Contribution of Conducted Emissions on the Primary DC Power Bus](image-url)
Definitions of Terms
The terms used in this paper tend to be used in connection with Wireless Base Station systems. The author is not aware of any one particular standard reference that covers all of these terms in the context of the focus area of this paper. Therefore, although the purpose of this paper is not to introduce new definitions of terminology for system components, for the sake of clarity, consistency and to reduce the possibility of causing inadvertent misperceptions, the following set of definitions will be adhered to in the remainder of this paper:

Unit:
A Circuit Pack (CP), Printed Circuit Board (PCB), or Printed Wiring Board Assembly (PWBA). A circuit pack may also be considered a populated PWB or card. Units populate a Shelf (see below) and must have connectors that allow them to be plugged into the common back-plane of the Shelf.

Module:
A module is a special kind of “Unit” whose connections are made via cables/connectors and not via a back-plane type connector. A hardware module (which may also be composed of several PWBs) usually fits into a card-cage or directly into a frame or cabinet. Multiple modules can populate a shelf (fully or partially) or a frame. Examples of modules are RF Filters or RF Power Amplifiers used in wireless Base Stations populating outdoor frames, which do not plug into a backplane.

Shelf:
A shelf is defined as an assembly that is mounted in a common frame with connections made via cables/connectors (same as "sub rack" or "card-cage"). Generally, several types of shelf may be encountered as follows:

   a. Self-contained shelves that only require power and/or signals to be connected.
   b. Shelves that are populated only by Modules.
   c. Shelves that are populated only by Units.
   d. Shelves that are populated by Module(s) and Units

Frame:
Same as rack, cabinet or enclosure. A frame can accommodate one or more shelves and/or modules simultaneously. A frame provides the physical mounting points for one or more shelves as defined above e.g. a cabinet. Frames can be indoor or outdoor.

Unit-Level Performance:
Unit Level Performance is the evaluation of performance of the individual circuit pack on a stand-alone basis. This may consist of Near-Field, Radiated Emissions and Conducted Emissions assessments.

Module-Level Performance:
A complete module may be tested for Emissions for the purpose of pre-compliance testing, as if it were a complete system. This would be done in order to identify potential EMC issues at the module-level. Module-level testing would be done either by itself or in an otherwise empty shelf, in a manner that its set-up, operating environment and configuration would best approximate the real environment in a complete system to ensure the testing results reflect the most conservative scenario. Results obtained in this manner would be used to identify and mitigate potential sources of EMI at the module-level. In specific cases, a module could be housing a complete system and could perform system functionalities. For such cases system-level emissions compliance criteria would be allocated to the module.

Shelf-Level Performance:
A fully populated shelf may be tested for Emissions for the purpose of pre-compliance testing, as if it were a complete system. Shelf-level testing would be done in such a manner that its set-up, operating environment and configuration would simulate the real situation in a complete system as much as possible to ensure the testing results reflect the most conservative scenario. Results obtained in this manner would be used to identify and mitigate potential sources of EMI at the shelf-level.

System Level Performance:
The emissions performance of a system as a whole, in its many unique and different implementations may be characterized in terms of a set of “parameters” imposed by the specific architecture of a system. Some of the most obvious examples of these parameters are:

   i. software versions for different customers
   ii. variants of the same functional hardware Units (i.e., for RF Amplifiers, Filter Panels, Radio Units, etc)
   iii. cost-reduced versions of Units
   iv. variants of the same functional Modules
   v. variants of the same functional Shelves
   vi. variants of the same functional frames (indoor vs. outdoor, etc)
   vii. AC vs. DC powering of same system

For most systems there are also other less obvious parameters which make the total number of possible ways of configuring the system (i.e., combinations of these parameters) surprisingly large. Thus, the task of compliance testing for a single system can easily grow out of proportions. In such cases, allocation of EMC design targets to different variants and versions of the components used in the system can greatly simplify the test process. When this is done, the
number of combinations to be tested is drastically reduced. It is logical to assess performance at three distinct but familiar levels of design, namely Unit/Module Level, Shelf Level and Frame Level:

1. **Unit or Module Level**: at this level, the use of indirect attributes, such as dedicated software versions, choice of alternate chips for the same function(s), etc. can help characterize these parts. The information gained from this is used to improve, correct and/or suppress potential problems at the earliest stage in the development cycle where there is the lowest cost/time impact.

2. **Shelf Level**: When performing shelf level evaluation, several important parameters, such as alternate Primary DC Voltage (24VDC vs. -48VDC), normal or cost-reduced card cage, indoor or outdoor versions should be accounted for.

3. **Frame Level**: Frame Level Performance hence testing is impacted by parameters such as indoor/outdoor versions, Primary DC Voltage, number of expansion frames, differences in local regulatory codes in different marketing regions, etc.

**Original EMI Sources:**
These are the sources of emissions (conducted or radiated) that can be traced exclusively to one type of Unit and in many cases down to a specific device or chip on the Unit. These sources can be identified via pre-compliance testing at the component level. The direct mitigation of known such sources is the most effective means of ensuring System-Level emissions compliance.

**Secondary EMI Sources:**
These are the sources of emissions (conducted or radiated) that appear to facilitate efficient means of coupling for the emissions from the Original EMI Sources to spread to the other parts of the system. The mitigation of such sources is always very time-consuming and expensive, however in many cases it may be the only feasible way to make the System emissions compliant.

**CHOOSING COMPONENT-LEVEL EMC DESIGN TARGETS**
The term “EMC-Sufficiency” will be used here to stereotype hardware modules or sub-system modules that are capable of satisfying their corresponding EMC design targets as verified via component-level pre-compliance tests (see below). This term is defined as follows:

**EMC-Sufficiency:**
A component is considered EMC sufficient if it meets prescribed EMC design targets. EMC sufficiency can also be defined broadly in terms of the following properties of a hardware module:

- **a)** The extent to which the hardware module will allow conformance to the radiated and conducted EMI threshold(s) at system level, as determined by how well the component meets its prescribed EMC Design target

- **b)** The extent to which it satisfies to the EMI immunity criteria specified by regulatory agencies,

- **c)** The extent to which it interferes with other hardware modules, in the same system.

For component-level pre-compliance testing purposes, a system of hierarchical criteria, heretofore to be referred to as “component-level EMC design targets” have been used by the author. The numerical values of relative levels quoted here are based on the majority of testing and EMC Design experience accumulated over a number of years for different versions of Wireless Base Station equipment and their components (No claim or implication is made by this paper about the applicability of these design targets to any other products).

**Workable EMC Design Targets for Radiated and Conducted Emissions**
Although these figures do not always work for all systems and all components, they define a valuable “grid” of references for choosing workable and flexible EMC design targets for the component designers.

**System Level** 6dB below regulatory limits (this figure would cushion measurement uncertainties)

**Shelf Level** 16dB below regulatory limits. A stand-alone shelf is tested as if it was a system.

**Unit Level** No single numerical threshold can be expected to be appropriate to all types of units, because the population of units per shelf for a specific unit can vary greatly, to say the least. Hence different design targets should be allocated to different units for an assortment of units populating a shelf. Generally, two testing schemes may be used for units and modules: either on a stand-alone basis using a test jig or while inserted in a minimally-populated card-cage or shelf. In either case, power, timing reference and a simulated traffic load to be applied to the unit under test are important parameters to be selected, on a case-by-case basis, in order to ensure an appropriate test configuration. For each unit or module, the tester will adopt one or possibly both of these test schemes (i.e., stand-alone unit or unit in the card-cage), based on knowledge, prior experience and engineering judgment, as appropriate.
The adjustable design targets described above can be referenced to any applicable standard on emissions compliance in order to derive prescribed EMC targets in absolute units (i.e., dBµV for voltage or dBµV/m for E-field magnitude). These shelf and unit level EMC Design targets may then be adopted by the component designer(s) either to be used for in-house design or for generating EMC Design specifications for component vendors.

**Unit/Module Level Pre-Compliance Testing**

The purpose of Unit/Module level pre-compliance testing is essentially, to:

i. check if a component meets prescribed EMC design target(s)
ii. identify and locate Original Sources of EMI (see definition above)
iii. use the preceding test data to derive or modify Unit/Module level EMC Design Targets

However, the block diagram in Figure 2 conveys the essential steps involved. Readiness for System-level emissions compliance testing in a routine and predictable manner is facilitated by the systematic identification and mitigation of the Original EMI sources in every Unit and Module of the system.

**Shelf and Frame Level Pre-Compliance Testing**

The system is not ready for formal compliance testing unless Shelf and Frame level pre-compliance test outcomes are favorable. The sequence of steps involved in this process, starting from Unit/Module pre-compliance test are:

a) Identify/Compile relevant data on Original EMI sources (i.e. near-fields originating on PWBs or, Units) for every hard ware unit early in design cycle, via unit-level near-field investigations. The main reason for this step is the identification of Original EMI sources and compilation of their attributes. This step was described in Figure 2 in the previous section.

b) Identify/Compile Conducted Emissions (CE) source data for worst-case shelf-level configurations, via shelf-level measurements.

c) Identify/Compile Radiated Emissions (RE) source data for worst-case shelf-level configurations, via shelf-level radiated EMI measurements

d) Identify and Mitigate confirmed coupling mechanisms of original EMI sources, with indirect EMI sources (see definition below) for every shelf-level configuration. Evidence for such coupling is typically reflected by the frequency of observed far-field sources.

e) Review/Modify PWB designs to assure unit and shelf-level EMC-sufficiency early in the design cycle.

f) Optimize the system against intra- and inter-cabinet interactions, based on the information gathered in steps (a) through (d) above.

The sequence of steps (b) through (f) listed above and in Figure 3 is implemented repeatedly unit shelf and frame-level EMC sufficiency is achieved. When this is accomplished, the system is deemed ready for undergoing formal compliance testing. The process is depicted by the block diagrams in Figure 3. The procedural steps are discussed in greater depth in the following sections. The concept of "EMC-Sufficiency" which was introduced above for Units and Modules may be extended to Shelves and Frames with little change, as the performance of the latter at-par with the prescribed target(s) for emissions.
The most important outcomes of the process depicted in Figure 3 are:

a. the confirmation of the readiness of the system for formal regulatory compliance test
b. the Unit/Module/Shelf and Frame Level EMC design targets have been shown to be adequate
c. with a reasonable degree of confidence, the “grid” of EMC Design Targets and references established for the current system may be applied to future systems of similar or approximate architecture, planned to be populated by the same set of components at multiple levels.

The database accumulated for the “current” system could guide the EMC Design process toward succeeding generations of the same system and its components (i.e., cost-reduced versions of Units, Modules, Shelves and Frames). The individual steps outlined in Figures 2 and 3 are discussed in greater detail in the next section.

**IMPLEMENTATION of PROCEDURAL STEPS**

The basic sequence of steps is to be implemented as many times as necessary (typically two or three in most cases), in the order(s) depicted in Figures 2 and 3, till EMC Sufficiency is achieved. When this is accomplished, the system is considered ready for formal regulatory compliance testing at the system level. Each of the basic steps is described in greater detail as follows:

**Identify/Compile Relevant Data on Original EMI Sources**

This step is mainly a survey of near-field sources on individual PWBs. Table 1 summarizes most of the data gathered for each EMI source in this step:

**Table 1. Near-Field /Original EMI Source Attributes**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>spectral plot(s) at specific locations</td>
<td>receiver bandwidth</td>
</tr>
<tr>
<td>frequency of observed peak(s)</td>
<td>associated clock bit rate</td>
</tr>
<tr>
<td>E-field strength (dBuV/m)</td>
<td>Location(s) of relevant ICs on PWB</td>
</tr>
<tr>
<td>E-field polarization</td>
<td>Observed and/or suspected interaction mechanisms</td>
</tr>
<tr>
<td>Approximate polar and azimuth angles of EUT orientation</td>
<td>associated device(s) description(s)</td>
</tr>
<tr>
<td>Associated clock bit rate</td>
<td>Description of test setup/configuration</td>
</tr>
</tbody>
</table>

**Identify/Compile Far-Field EMI Source Data for Worst-Case Shelf-Level Configurations**

The purpose of this step is the identification of original EMI sources that couple efficiently to the Shelf-Level radiated fields. Original EMI sources couple to the far-fields when net power is radiated into surrounding free space by currents and fields induced on the bounding surfaces of the shelf structure, by these sources. The present step enables one to focus resources on a small subset of the observed original EMI sources, that have the potential to be problematic at the system level. Some of the attributes to be compiled in this step are listed in Table 2.

**Table 2. Far-Field EMI Source Attributes**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>spectral plot</td>
<td>frequency of observed peak(s)</td>
</tr>
<tr>
<td>E-field strength (dBuV/m)</td>
<td>E-field polarization</td>
</tr>
<tr>
<td>E-field polarization</td>
<td>Approximate polar and azimuth angles of EUT orientation</td>
</tr>
<tr>
<td>Associated clock bit rate</td>
<td>Associated clock bit rate</td>
</tr>
<tr>
<td>Multiple of fundamental (or, harmonic number)</td>
<td>Nature of coupling mechanism (e.g. resonance of shelf cavity)</td>
</tr>
<tr>
<td>Description of test setup/configuration</td>
<td></td>
</tr>
</tbody>
</table>
Identify / Compile Conducted EMI Source Data for Worst-Case Shelf-Level Configurations

The purpose of this step is to make conducted EMI measurements at the shelf-level. Conducted EMI on individual feeders and their returns are investigated (9KHz-30MHz). When AC power is used for remote locations, the appropriate EMI frequency range will be applicable.

Review/Modify Unit and Shelf Designs to Assure Unit and Shelf-Level EMC-Sufficiency

Identify and Mitigate confirmed coupling mechanisms of original EMI sources, with indirect EMI sources. Having identified the original EMI sources that are potentially non-compliant, in this step the coupling mechanism is mitigated by a combination of modifying layout and circuitry at circuit pack level and modifying design at shelf level.

Optimize the System for Formal Compliance Testing

This step consists of a re-assessment of the design primarily at the shelf, frame and system levels, to identify, mitigate or minimize potential inter-shelf and inter-cabinet level interactions.

TESTING METHODS

The essential goal of the scheme presented in this paper is to guide, prepare and “groom” a product or system for formal emissions compliance testing starting from concept to production phases. Therefore it makes only good sense to adhere to relevant well-established test procedures and methods with appropriate provisions and modifications as described below. Four basic types of tests are used in the steps defined above:

i. Near-Field Testing, using near-field probes and a spectrum analyzer. This test is used essentially to identify original source frequencies, their locations and relative strengths.

ii. Frequency Response Measurements, to identify effective frequency pass-bands of the system primary power bus and its extensions (see [2] and [3] for several implementations of this method).

iii. Radiated Emissions Testing (see CISPR22 [2], Telcordia GR-1089-CORE [3] and others), using appropriate receive-antennas starting from 30MHz and up. Units, Modules and Shelves are tested on a stand-alone basis. This test is used to identify the frequencies of original EMI sources that effectively couple their power to far-fields. Therefore, this test helps one to selectively focus resources only on significant propagating modes.

iv. Conducted Emissions Testing (see CISPR22 [2], Telcordia GR-1089-CORE [3] and others), using a standard LISN, at the following sampling points:
   a) Unit Level (not plugged to backplane): DC power pins (-ve and +ve on unit connector, only those units accepting primary power [-48/+24 volts]). (If necessary, primary power will be supplied to the unit during testing).
   b) Shelf Level: DC power feeder and its return, for all feeders servicing a given shelf.
   c) Frame Level: AC power feeders to co-located AC/DC Converters.

SUMMARY

Although no quantitative claims may be made at this time, in the author’s experience the implementation of the hierarchical EMC Design Targets and grids of references described in this paper has had a very perceptible impact in reducing the cumulative number of hours spent for system-level emissions mitigation during formal compliance testing on the overall, for over several years.

REFERENCES


