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SERIES K: PROTECTION AGAINST INTERFERENCE

System level radiated emissions compliance using mathematical modelling

ITU-T Recommendation K.62

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System level radiated emissions compliance using mathematical modelling

Summary

This Recommendation supports telecommunication operators in demonstrating the compliance of the radiated emissions generated by telecommunication systems.

Telecommunication operators typically construct their systems from many items of equipment that are each engineered to individually meet EMC requirements, including radiated emissions. This means that a system will typically contain a number of emissions sources (i.e., separate equipment items) at a number of common frequencies. This is true if the system contains many items of the same equipment or many items of different equipment.

For such a system, the superposition of these multiple emissions has the potential to produce a system emission level that is greater than the system emission limit. This is of fundamental concern for telecommunication operators seeking to demonstrate the compliance of the radiated emissions of their systems.

This Recommendation introduces a statistical approach to systems radiated emission compliance. By applying a statistical approach to the treatment of basic variables that are not known by the operator, a method is presented that allows the system emission level to be described statistically in terms of a probability and cumulative probability distributions.

These distributions allow the compliance of the system emission level, with respect to a limit, to be expressed as a statistical confidence level (rather than as a simple "Pass" or "Fail" statement). It is proposed that the 80% confidence level be used for compliance to align with the approach taken for series production equipment within CISPR 22.

The method presented may also be used by other organizations that either build or operate other systems that are formed from the integration of many items of digital electronic equipment that each individually comply with their own radiated emissions limit.

Source

ITU-T Recommendation K.62 was approved on 29 February 2004 by ITU-T Study Group 5 (2001-2004) under the ITU-T Recommendation A.8 procedure.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

CONTENTS

Introduction

Telecommunication operators typically construct their systems from many items of equipment that are each engineered to individually meet EMC requirements, including radiated emissions. This means that a system will typically contain a number of emissions sources (i.e., separate equipment items) at a number of common frequencies. This is true if the system contains many items of the same equipment or many items of different equipment.

The system as a whole will generally be expected to comply with a radiated emissions limit. This may be the same or different to the limit applicable to the individual constituent equipment. For each common emission frequency, the presence of many individual sources within the system means that the system emission level may be higher than that of the individual equipment.

A method is presented that allows the radiated emissions to be assessed without performing practical measurement. The method presented is particularly suited to the analysis of systems that are physically very large, for which practical testing is both prohibitively expensive and practically difficult to perform.

ITU-T Recommendation K.62

System level radiated emissions compliance using mathematical modelling

1 Scope

This Recommendation provides a procedure for demonstrating the compliance of the radiated RF emissions from telecommunication systems.

Telecommunication operators typically construct their systems from many items of equipment that are each engineered to individually meet EMC requirements, including radiated emissions. This means that a system will typically contain a number of emissions sources (i.e., separate equipment items) at a number of common frequencies. This is true if the system contains many items of the same equipment or many items of different equipment.

For such a system, the superposition of these multiple emissions has the potential to produce a system emission level that is greater than the system emission limit. This is of fundamental concern for telecommunication operators seeking to demonstrate the compliance of the radiated emissions of their systems.

This Recommendation introduces a statistical approach to systems radiated emission compliance. By applying a statistical approach to the treatment of basic variables that are not known by the operator, a method is presented that allows the system emission level to be described statistically in terms of a probability and cumulative probability distributions.

These distributions allow the compliance of the system emission level with respect to a limit to be expressed as a statistical confidence level (rather than as a simple "Pass" or "Fail" statement). It is proposed that the 80% confidence level be used for compliance to align with the approach taken for series production equipment within CISPR 22.

The method presented may also be used by other organizations that either build or operate other systems that are formed from the integration of many items of digital electronic equipment that each individually comply with their own radiated emissions limit.

This Recommendation does not define radiated emissions limits or methods of measurement for telecommunication systems.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[1] CISPR 22 (1997), *Information technology equipment – Radio disturbance characteristics – Limits and method of measurement*.

[2] ITU-R Recommendation P.525-2 (1994), *Calculation of free-space attenuation*.

[3] ITU-R Recommendation P.526-8 (2003), *Propagation by diffraction*.

3 Terms and definitions

This Recommendation defines the following terms:

3.1 equipment: Within this Recommendation, the term "equipment" applies to an item that forms a basic building block of a system. An equipment is generally supplied to the telecommunication operator by a third-party manufacturer and is placed on the market as a separate item. As a result, an equipment will have been engineered to meet local EMC requirements, including radiated emissions.

3.2 system: Within this Recommendation, the term "system" applies to that item formed from the integration of many items of equipment, all at the same physical location, to deliver a defined function. All cables used to interconnect the constituent equipment that together form the system, are also part of the system. All interconnect cables that connect a system with other systems are not considered part of the system.

3.3 system emission level: The emission level of the system, generated through the superposition of the emissions radiated at the common frequency by the system's constituent equipment.

Within this Recommendation, this term is represented mathematically as E_S.

3.4 probability distribution: The probability distribution of an unknown, continuous variable, x, that exists within the range $x_{min} \le x \le x_{max}$ is written as $p(x)$. The probability distribution quantifies the probability (i.e., the relative frequency of occurrence) with which the variable will exist within the range x and $x + dx$.

By definition,

$$\int_{x_{min}}^{x_{max}} p(x)dx = 1$$

3.5 cumulative probability distribution: The cumulative probability distribution of an unknown, continuous variable, x, that exists within the range $x_{min} \le x \le x_{max}$ is written as $CP(x)$. The cumulative probability distribution quantifies the probability (i.e., the relative frequency of occurrence) with which the variable x exists within the range:

$$x_{min} \le x \le x'$$

where the value x' falls within the range $x_{min} \le x \le x_{max}$

By definition,

$$CP(x) = \int_{x_{min}}^{x'} p(x)dx$$

3.6 compliance probability: The probability (i.e., the relative frequency of occurrence) with which the system emission level, E_S, will exist within the range:

$$E_{Smin} \le E_S \le E_L$$

where:

E_{Smin} is the lower limit (i.e., minimum value) of the system emission level

E_L is the system emission limit

The compliance probability is, therefore, the probability with which the system emission level will meet the system emission limit.

The compliance probability is the cumulative probability value for $E_S = E_L$, i.e.,

$$compliance\ probability = \int_{E_{Smin}}^{E_L} p(E_S)dE_S$$

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations:

CPD Cumulative Probability Distribution

EMC Electromagnetic Compatibility

ITE Information Technology Equipment

PD Probability Distribution

RF Radio Frequency

5 General principles

When a system contains a number of equipment items that individually emit at a common frequency, the superposition of these multiple emissions has the potential to produce a system emission level that is greater than the typical equipment emission level. This is a concern for telecommunication operators seeking to act responsibly and manage the EMC of their systems.

If the individual equipment emission levels are known (at some known measurement distance) for each common emission frequency, mathematical tools do exist to predict the radiated emissions level of the system at this common frequency.

Imagine that a number, N, of radiated RF emissions at some common frequency, f, are incident at some point of measurement. It is possible to represent each radiated emission at the point of measurement in the time-domain as a simple cosine function. The ith radiated emission may be written as:

$$E_i(t) = E_{0i} \cos(\alpha \pm \varpi t) \quad (1)$$

where:

$E_i(t)$ is the instantaneous radiated emission level due to the ith radiated emission at time, t, at the point of measurement

E_{0i} is the amplitude of the ith radiated emission at the point of measurement

α_i is the phase difference between the ith radiated emission and some agreed reference at the point of measurement

$\varpi = 2\pi f$

The combination of these radiated emissions at the point of measurement can also be expressed as a simple cosine function at the same frequency, viz:

$$E_0(t) = E_0 \cos(\alpha \pm \varpi t) \quad (2)$$

where:

$E_0(t)$ is the instantaneous combined radiated emission level at time, t, at the point of measurement

E_0 is the amplitude of the combined radiated emission level

α is the phase difference between the combined radiated emission level and some agreed reference at the point of measurement

and

$$E_0^2 = \sum_{i=1}^{N} E_{0i}^2 + 2\sum_{j>i}^{N} \sum_{i=1}^{N} E_{0i} E_{0j} \cos(\alpha_i - \alpha_j) \tag{3}$$

Careful examination of this equation indicates that, to know the amplitude of the combined radiated emission level, E_0, two pieces of information are required for each radiated emission:

- the amplitude, E_{0i};
- the phase, α_i, with respect to some reference.

While the telecommunication operator can generally have knowledge of the amplitude, E_{0i}, at the point of measurement, the operator cannot have knowledge of the phase value at the point of measurement. This means that the operator has only half the information required to use this equation. Hence, the conventional mathematical tools are not ideally suited to this problem.

It is possible for the telecommunication operator to use the conventional mathematical tools to determine the upper limit to the system emission level. This is the system emission level produced when each individual equipment emission arrives at the point of measurement in phase. However, it is not recommended that the upper limit to the system emission level be considered in the compliance of the system's radiated RF emissions.

In the absence of specific information, it is possible to assume that the phase value for each radiated emission is:

- able to adopt any value within its physical range; and
- equally likely to do so.

These are the two properties of a mathematically random variable. Hence, it is reasonable to assume that the phase value for each radiated emission is random.

Examination of Equation (3) indicates that it is periodic in 2π, i.e., all unique values occur while the phase value is within the range $0 \le \theta \le 2\pi$. This means that the phase term can no longer be described by a known, finite value. It is instead described by a PD, $p(\theta)$. The mathematical properties of θ noted previously gives rise to the PD presented within Figure 1, this being known as either the random PD or the rectangular PD (due to its shape).

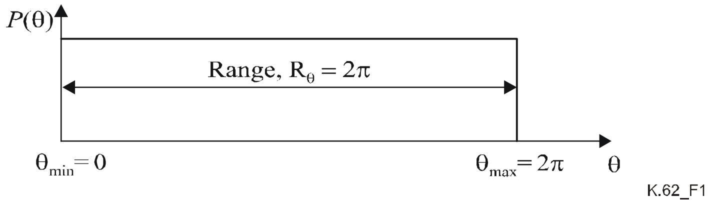


Figure 1/K.62 – The rectangular/random PD

The value of $p(\theta)$ is found, from the definition of the random PD, to be:

$$p(\theta) = \frac{1}{2\pi} \tag{4}$$

The use of a PD to represent the value of each phase term within Equation (3) allows the generation of the associated PD for the system emission level.

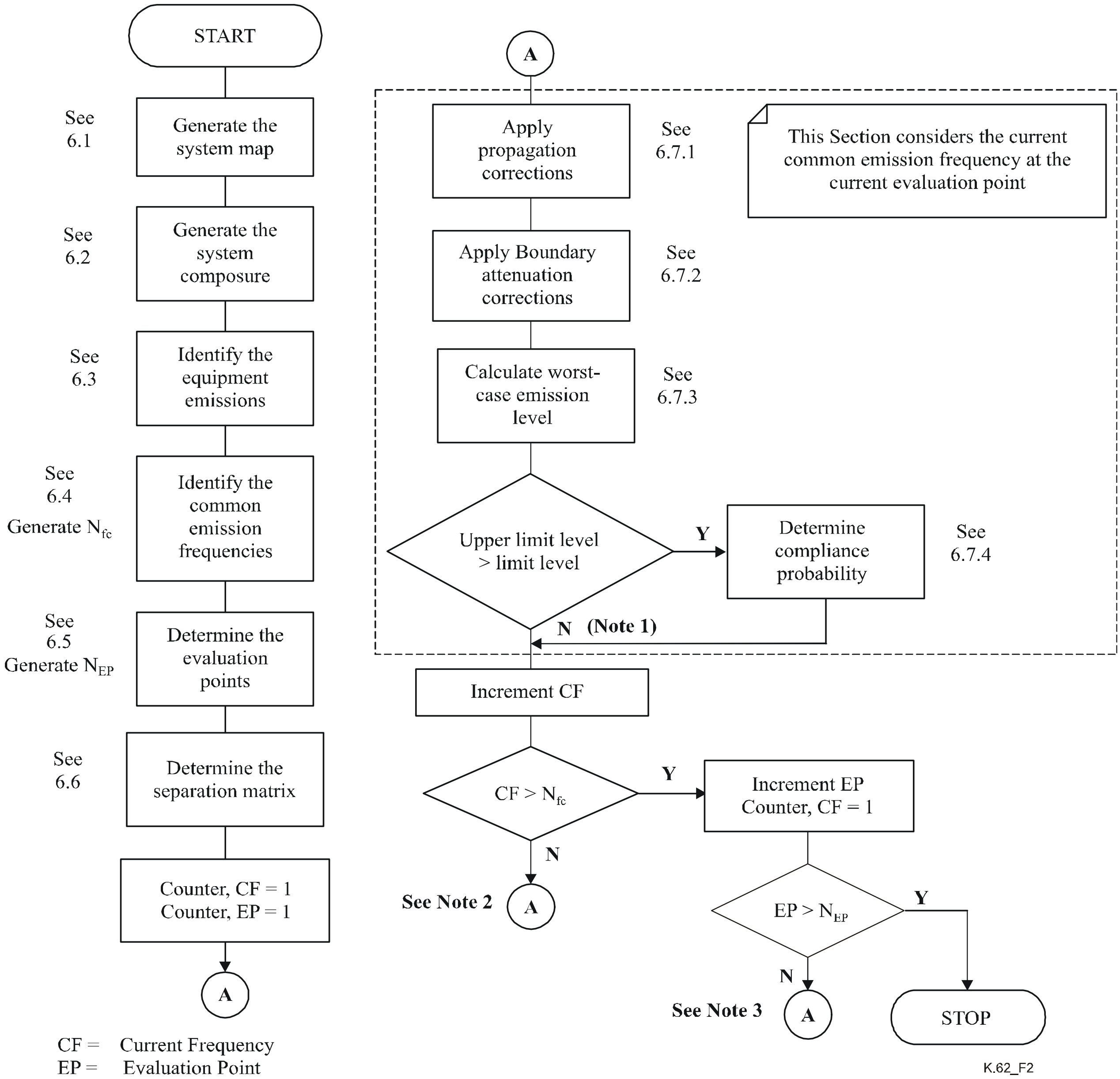
Knowledge of the PD allows generation of the associated CPD of the system emission level. Where the upper limit to the system emission level exceeds the defined emission limit, the CPD may be used to quantify the compliance probability of the system with this limit.

Appendix I presents examples of the PDs and CPDs that are generated through the use of this approach. The examples serve to illustrate the fact that the system emission level is, generally, highly unlikely to adopt its upper limit value. This is the reason for rejecting use of the upper limit to the system emission level in the compliance of the system's radiated RF emissions. The examples also serve to illustrate the fact that, generally, the system emission level is most likely to adopt some value that is lower than its upper limit value.

The system is deemed to satisfy the defined emissions limit if the compliance probability with this limit is no less than 80%. This approach aligns with that taken within section 7.2 of [1].

6 Method

This clause presents an overview of the method to be applied to assess the radiated emissions of a system. The method involves the execution of the process summarized within the flowchart presented as Figure 2. It is recommended that this flowchart be considered throughout consideration of this clause.



NOTE 1 – If upper limit < limit level, compliance probability is 100%.

NOTE 2 – Repeat process at the next evaluation point, considering the next common emission frequency.

NOTE 3 – Repeat process at next evaluation point, starting at the first common emission frequency.

Figure 2/K.62 – Systems emission method

6.1 System map

A system map shall be generated. This is a simple scale diagram that presents the positions of the systems' constituent equipment and the system boundary.

The system boundary is generally defined as the physical limit beyond which radiated emissions have the potential to degrade the reception of radio services. The system boundary is generally the boundary between a closed area that is controlled by an operator, and public space within which radio operators (not associated with the operator) are free to locate. The system boundary, therefore, arises from the nature of the system and its location.

The system boundary may be:

- A site fence: for systems installed within a site that is controlled by the operator;

- A building wall: for systems installed within a building that is controlled by an operator but which has no additional surrounding land (typical of metropolitan buildings);
- Internal wall(s): for systems installed within multi-function buildings, within which the operator has control of a defined area, the rest of the building being shared with other users (typical of metropolitan areas).

6.2 System composure

A list of the equipment contained within the system shall be compiled. This list shall generally record:

- the equipment's function;
- the equipment's name (as branded by the manufacturer);
- the equipment's manufacturer;
- the number of items of the equipment that exist within the system.

6.3 Equipment emissions

Information concerning the radiated emissions performance of the individual equipment is then compiled. Essentially, four items of information are required for each emission:

- the frequency;
- the polarity (either horizontal or vertical);
- the level;
- the measurement distance.

If EMC test reports are available for the equipment, these may allow identification of this information for the highest radiated emissions measured (these being below the emissions limit to which the equipment is engineered).

If test reports are not available, it is possible to perform radiated emissions measurements of an equipment item to allow identification of the frequencies and the levels at which the highest radiated emissions were measured (these being below the emissions limit to which the equipment is engineered).

In both cases, care must be taken during the compilation of this information to ensure that the equipment configuration during testing is as representative as possible to its installation within the system. Of particular concern are:

- Housing: when under test, the equipment should have been located in the same racking/shelving practice as is to be used within the system;
- Cabling: when under test, the equipment configuration should have included the same interconnections as when installed within the system, with the same cable types and same signalling (simulated or exercised).
- Exercising: when under test, the equipment was exercised in a manner representative of its operation when deployed within the system (this being related to cabling, discussed previously).

If test reports are not available and radiated emissions measurements are not to be performed on an equipment item, it is possible to make the default assumption: that the emissions of the equipment item are at the level of the emissions limit to which it has been engineered across the full frequency range. This default situation is very much an aggressive scenario, since telecommunication equipment does not generally emit at levels near to their emissions limit across the full frequency range covered by their limit: instead, equipment emissions are near to the limit for only a small percentage of the total frequency range covered by a limit.

Each equipment item shall be assumed to radiate entirely isotropically at the frequencies and levels identified in this method.

6.4 Common emissions frequencies

The information compiled during the 6.3 stage shall allow identification of the common emissions frequencies within the system: i.e., those frequencies at which two or more equipment items emit in the same polarity.

This will allow the determination of the value of N_{fc} – the number of common emissions frequencies within the system.

For each common emissions frequency, the following information is to be compiled:

- the frequency;
- the equipment emitting at this frequency;
- the polarity.

6.5 Evaluation points

The system map, system composure and equipment emissions shall be examined to generate a set of evaluation points. Evaluation points are those positions on the system map and outside the system boundary at which the systems radiated emissions are to be evaluated.

It is recommended that a number of evaluation points (N_{EP}) be considered, i.e., system level emissions should not be considered at a single point. It is also recommended that the number of evaluation points increases as the physical size of the system under consideration increases.

Factors to consider in the selection of evaluation points include:

- known positions of existing radio users – these will require special attention;
- instances in which equipment items are located short distances from the system boundary (short meaning a distance less than or equal to the distance at which their emissions were measured); this is particularly true if these items have already been identified as having common emissions frequencies and individually emit at a relatively high level;
- locations adjacent to the system boundary with a high probability of radio deployment (such as high-density housing for systems located within urban areas, residential areas for systems located within suburban areas);
- publicly-accessible areas immediately adjacent to the system boundary (of particular interest in addressing the interference potential of the system to public mobile radio services, such as mobile telephony).

6.6 Separation matrix

A separation matrix shall be compiled. This records the straight-line separation distance between each equipment item within the system and each evaluation point.

6.7 Evaluation method

For each selected evaluation point and identified common emission frequency, the systems radiated emissions shall be determined using the following procedure.

6.7.1 Correction I: Propagation

The system map shall be consulted to determine the propagation path between each item of equipment and each evaluation point.

The propagation paths vary in complexity. Examples include (in order of increasing complexity):

i) Blocked path: there exists no simple, straight-line propagation path between the equipment and the evaluation path – some conducting structure standing between the equipment and the evaluation point essentially screens the equipment emissions.

ii) Direct path: there exists a simple, straight-line propagation path between the equipment item and the evaluation point that is free of conducting structures that may reflect, diffract or block the propagation of the equipment emissions to the evaluation point. This straight line may cross a number of boundaries requiring consideration (see 6.7.2).

iii) Indirect reflected path: there exists an indirect path between the equipment item and the evaluation point that involves at least one reflection of the equipment's emissions by an adjacent conducting structure.

iv) Indirect diffracted path: there exists an indirect path between the equipment item and the evaluation point that involves the diffraction of the equipment's emissions by an adjacent conducting structure.

v) Complex path: there exists a propagation path between the equipment item and the evaluation point that involves one or more instances of one or more of the previously discussed elementary paths.

As the complexity of the propagation path increases, the reduction in the level (i.e., the propagation attenuation) of the equipment emissions that arrive at the evaluation point also increases. Hence, it is possible to perform several iterations of study in which progressively more complex propagation paths are included. The first such iteration would consider the blocked and direct paths only. The second may consider the blocked, the direct and the first order reflected paths (i.e., a reflected path that contains a single reflection). The third iteration may consider the blocked, the direct and the first and second order reflected paths.

It is necessary to adjust the equipment emissions levels identified within 6.3 to account for the propagation path between the equipment item and the evaluation point.

The adjustment can consider any radio propagation model that is felt to apply given the emission frequency and propagation path under consideration. Two examples are provided in [2] and [3].

As a minimum, in the absence of a known and validated radio propagation model, simple far-field free-space propagation may be assumed. This involves use of the following propagation equation:

$$E_0(d_2) = E_0(d_1) - 20\log_{10}\left\{\frac{d_2}{d_1}\right\} \tag{5}$$

where:

d_1 is the separation distance in metres between the equipment and the measurement antenna during the radiated emissions measurement

d_2 is the separation distance in metres between the equipment and the evaluation point

$E_0(d_1)$ is the amplitude of the equipment emission (expressed in logarithmic units) when measured at distance d_1

$E_0(d_2)$ is the amplitude of the equipment emission (expressed in logarithmic units) predicted at distance d_2 due to propagation between distance d_1 and d_2

The value of d_2 is found for each equipment item emitting at the common frequency from the separation matrix.

6.7.2 Correction II: Boundary attenuation

When the propagation path between the equipment item and the evaluation point passes through one or more physical boundaries (a wall, a chain-link fence etc.), the equipment emissions levels identified within 6.3 may be corrected by the associated boundary attenuation values, if these are known.

If these values are unknown, the operator may use "typical" values derived from previous experience.

It is also possible to assume no boundary attenuation. This will have the effect of increasing the system emissions level.

6.7.3 Assessment I: Highest system level emission

Having completed the steps described within clauses 6.1 through 6.7.2, the corrected equipment emissions levels are available at the current evaluation point.

For each emission frequency of interest, the upper limit to the system emission level is calculated. This is performed using the following equation:

$$E_{MAX} = \sum_{i=1}^{N} E_{0i} \tag{6}$$

where:

- N is the number of different equipment items within the system emitting at the common frequency and polarity of interest
- E_{0i} is the adjusted amplitude (i.e., the amplitude at the evaluation point expressed in linear units) of the emissions of the ith equipment type at the common frequency of interest
- E_{MAX} is the upper limit to the system emissions level (expressed in linear units) at the common emissions frequency of interest

The upper limit to the system emission level is compared with the system emission limit.

If the upper limit to the system emission level is equal to or below the system emission limit, the system emissions clearly comply with this limit for the frequency and polarity of interest. If this is true, no further action needs to be taken for the current common emissions frequency at the current evaluation point.

If, however, the upper limit to the system emission level exceeds the system emission limit, it is necessary to continue to the next step, documented in 6.7.4.

6.7.4 Assessment II: Monte Carlo analysis

If the upper limit to the system emission level returned by Equation (6) exceeds the system emission limit, Monte Carlo simulation techniques may be applied to Equation (3) to numerically generate the PD and CPD that describe the system emission level.

The CPD is used to obtain the compliance probability of the system emission level with the system emission limit.

If the compliance probability is greater than or equal to 80%, the system emissions are deemed to comply with the system emission limit for the frequency and polarity of interest.

If the compliance probability is less than 80%, the telecommunication operator is recommended to first review the level of detail considered within the assessment performed.

If the assessment considered that all equipment items emit at their limit level across the full frequency range of the limit (as discussed in 6.3), it is recommended that the analysis be repeated to identify the common frequencies and the emissions details of the equipment that emit at these frequencies.

If the assessment considered only the minimum propagation correction (as discussed in 6.7.1), it is recommended that the analysis be repeated with more accurate propagation corrections considered.

If the assessment considered no boundary attenuation values (as discussed in 6.7.2), despite there being physical boundaries for the system under consideration, it is recommended that the analysis be repeated with these boundary attenuation values included.

If the compliance probability remains below 80% after these factors have been accounted for within the analysis, only then it is recommended that the telecommunication operator seeks to reduce the system emission level in such a way that the compliance probability of at least 80% is achieved. The use of Monte Carlo simulation techniques allows the impact of many possible changes to be investigated. It is recommended that the most convenient change to the system be implemented.

Appendix I

Example distributions

This appendix presents and discusses some examples of the PDs and CPDs generated upon the application of the method presented within this Recommendation.

I.1 N = 2

When the system contains two items that emit at a common frequency, the PD and CPD display a characteristic form. Examples are displayed in Figures I.1 and I.2 for the case of common emissions amplitudes (in this case $E_1 = E_2 = 40$ dBμV/m).

Examination of Figures I.1 and I.2 indicates that the amplitude of the system emission level in this case occurs between the upper limit of (40 dBμV/m + 20 $\log_{10}\{2\}$) 46 dBμV/m and a lower limit of zero.

Figure I.1 indicates that the PD displays a clear maximum at the worst-case field level: the worst-case system-level amplitude is, therefore, the most likely to occur.

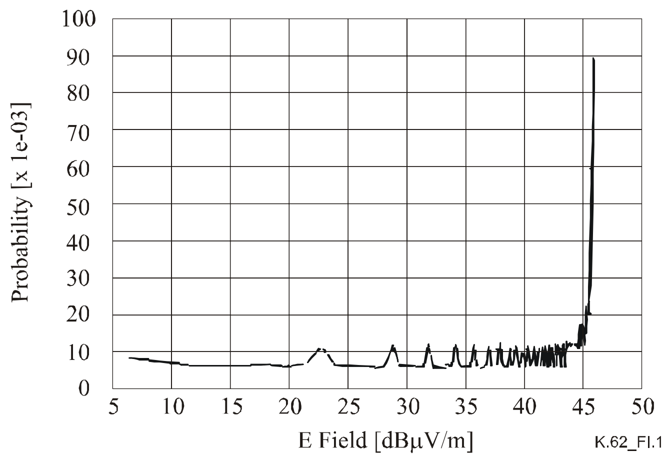


Figure I.1/K.62 – Example PD for N = 2

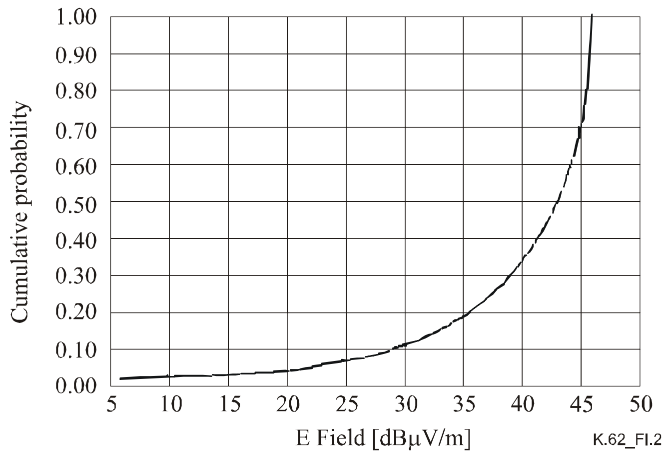


Figure I.2/K.62 – Example CPD for N = 2

I.2 N = 3

When the system contains three items that emit at a common frequency, the PD and CPD also display a distinct form. Examples are displayed in Figures I.3 and I.4 for the case of common emissions amplitudes (in this case $E_1 = E_2 = E_3 = 40$ dBμV/m).

Examination of Figures I.3 and I.4 indicates that the amplitude of the system emission level in this case occurs between the upper limit of (40 dBμV/m + 20 $\log_{10}\{3\}$) 49 dBμV/m and the lower limit of zero.

Figure I.3 indicates that the PD displays a clear maximum at the common emissions amplitude, i.e., when $E_S = E_1$. This means that the amplitude of the composite system that is most likely to occur is the common amplitude of the constituent equipment: i.e., that the telecommunication operator is most likely to measure no change in the emissions amplitude when moving from one equipment item to three equipment items.

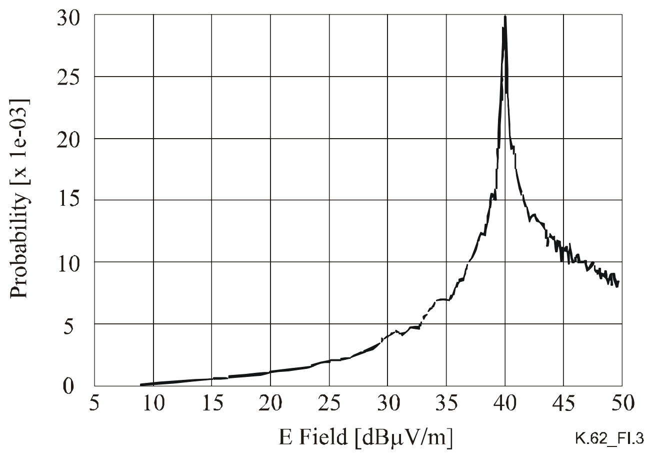


Figure I.3/K.62 – Example PD for N = 3

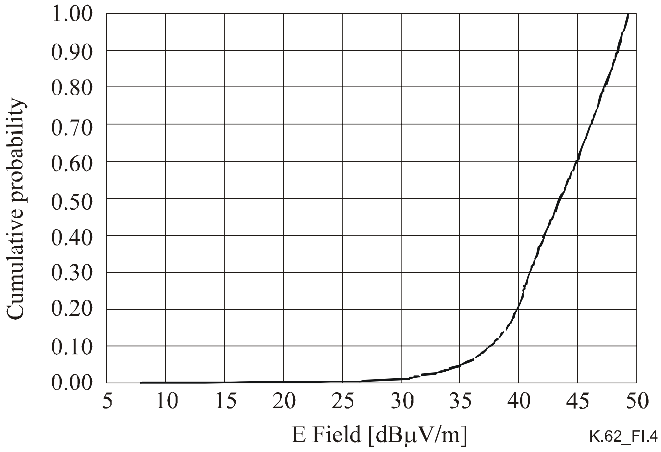


Figure I.4/K.62 – Example CPD for N = 3

I.3 N = 4

When the system contains four items that emit at a common frequency, the PD and CPD display a characteristic form. Examples are displayed in Figures I.5 and I.6 for the case of common emissions amplitudes (in this case $E_1 = E_2 = E_3 = E_4 = 40$ dBµV/m).

Examination of Figures I.5 and I.6 indicates that the amplitude of the system emission level in this case occurs between the upper limit of (40 dBµV/m + 20 $\log_{10}\{4\}$) 52 dBµV/m and a lower limit of zero.

Figure I.5 indicates that the PD displays a maxima at the system emissions amplitude of ~46 dBµV/m. This is noted to be some 6 dB below the upper limit level.

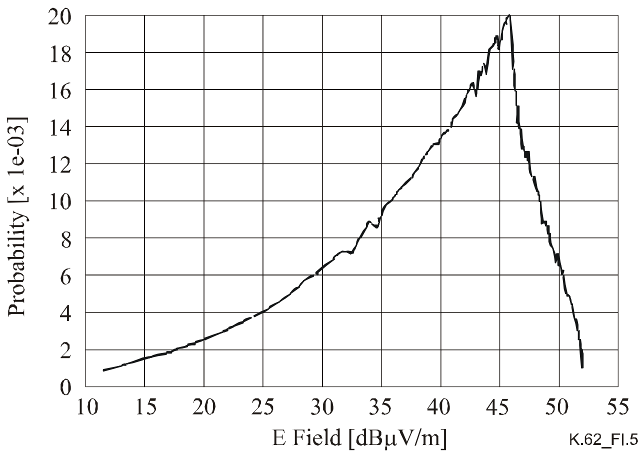


Figure I.5/K.62 – Example PD for N = 4

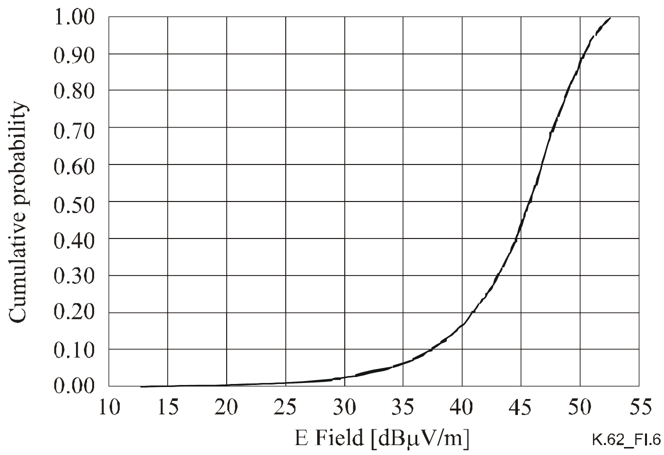


Figure I.6/K.62 – Example CPD for N = 4

I.4 N = 5

When the system contains five items that emit at a common frequency, the PD and CPD display a characteristic form. Examples are displayed in Figures I.7 and I.8 for the case of common emissions amplitudes (in this case $E_1 = E_2 = E_3 = E_4 = E_5 = 40$ dBμV/m).

Examination of Figures I.7 and I.8 indicates that the amplitude of the system emission level in this case occurs between the upper limit of (40 dBμV/m + 20 $\log_{10}\{5\}$) 53.97 dBμV/m and a lower limit of zero.

Figure I.7 indicates that the PD displays a maxima at a system emission level of ~45 dBμV/m. This is noted to be some ~9 dB below the worst-case value.

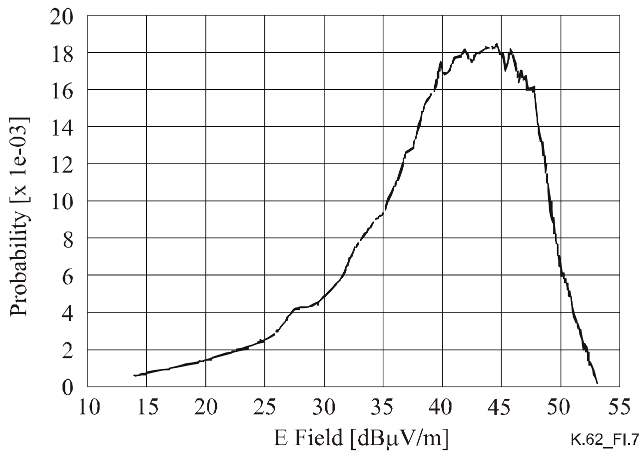


Figure I.7/K.62 – Example PD for N = 5

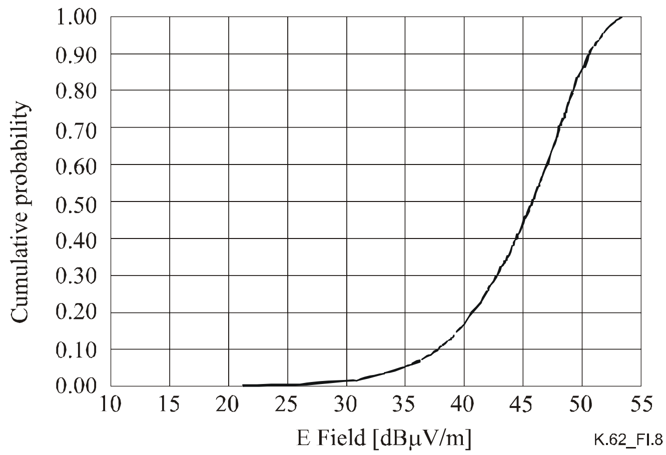


Figure I.8/K.62 – Example CPD for N = 5

I.5 N = 10

When the system contains ten items that emit at a common frequency, the PD and CPD display a characteristic form. Examples are displayed in Figures I.9 and I.10 for the case of common emissions amplitudes (in this case 40 dBµV/m).

Examination of Figures I.9 and I.10 indicates that the amplitude of the system emission level in this case occurs between the upper limit of (40 dBµV/m + 20 $\log_{10}\{10\}$) 60 dBµV/m and a lower limit of zero.

Figure I.9 indicates that the PD displays a maxima at a system emission level of ~48 dBµV/m. This is noted to be some 12 dB below the worst-case value.

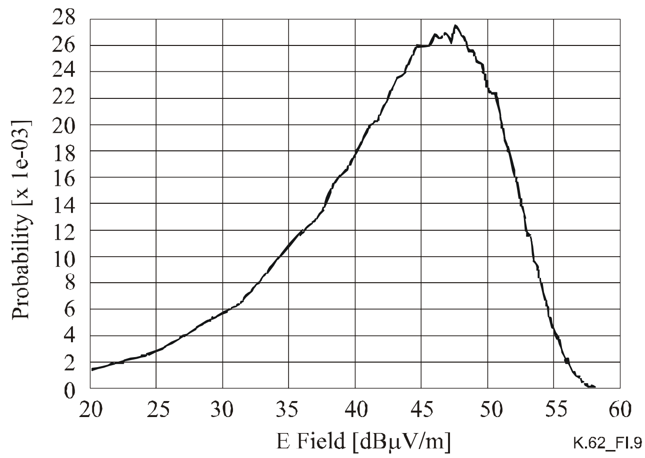


Figure I.9/K.62 – Example PD for N = 10

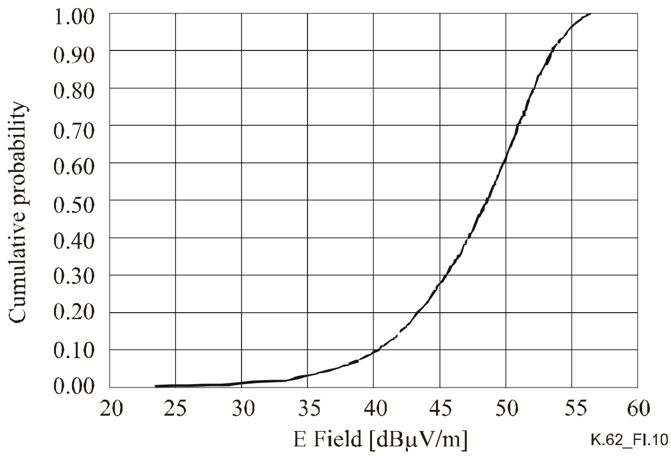


Figure I.10/K.62 – Example CPD for N = 10

I.6 N = 100

When the system contains one hundred items that emit at a common frequency, the PD and CPD display a characteristic form. Examples are displayed in Figures I.11 and I.12 for the case of common emissions amplitudes (in this case 40 dBµV/m).

Examination of Figures I.11 and I.12 indicates that the amplitude of the system emission level in this case occurs between the upper limit of (40 dBµV/m + 20 $\log_{10}\{100\}$) 80 dBµV/m and a lower limit of zero.

Figure I.11 indicates that the PD displays a maxima at a system emissions amplitude of ~58 dBµV/m. This is noted to be some 22 dB below the worst-case value.

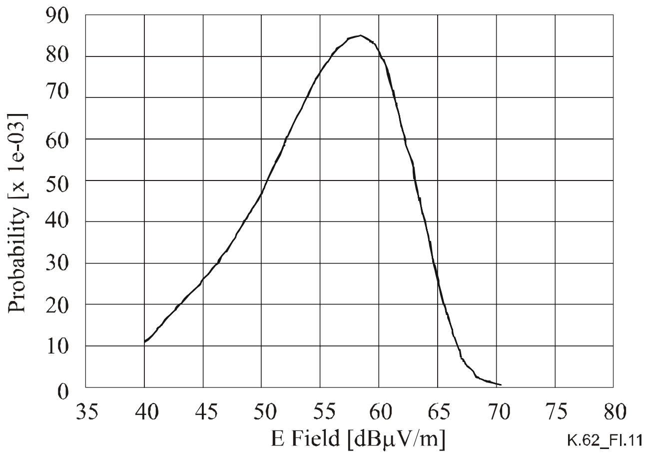


Figure I.11/K.62 – Example PD for N = 100

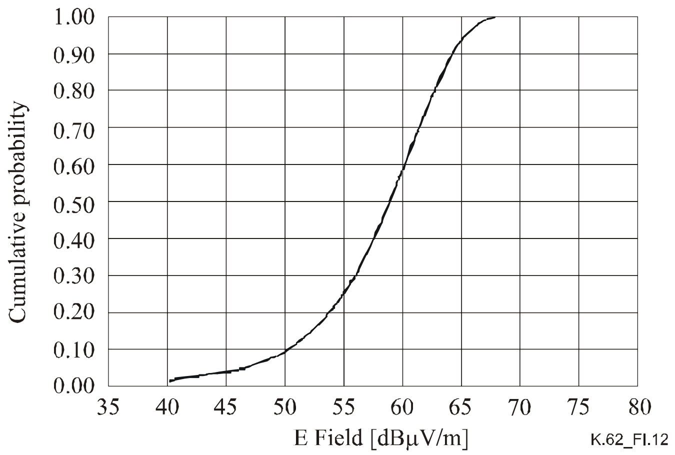


Figure I.12/K.62 – Example CPD for N = 100

I.7 Review of probability distributions

Review of the PD plots presented in the previous examples indicates a pattern: as the number of independent emissions at a common frequency increases, the likelihood of the upper limit level occurring decreases.

For example:

- When only two radiated field terms are being added, the PD reaches its maxima when the system emission level approaches the worst case.
- When ten radiated field terms are being added, the PD reaches a minima when the systems emissions amplitude approaches the worst case. For the example displayed, the worst-case amplitude is 60 dBμV/m, but the PD approaches zero values above 58 dBμV/m.
- When one hundred radiated field terms are being added, the PD reaches a minima when the systems emissions amplitude approaches the worst case. For the example displayed, the worst-case amplitude is 80 dBμV/m, but the PD approaches zero values above ~70 dBμV/m.

Hence, the worst-case amplitude is extremely unlikely to occur and, hence, should not be used as the basis of system compliance.

Also, as the number of independent emissions at a common frequency increases, the margin between the system emission level that is most likely to occur, and the upper limit to the system emission level, increases.

For example:

- When only two radiated field terms are being added, the PD reaches its maxima when the system emissions amplitude approaches the worst case. Hence, the margin between the most likely and worst-case levels is 0 dB.
- When ten radiated field terms are being added, the PD reaches a maxima at ~48 dBμV/m while the upper limit is 60 dBμV/m. Hence, the margin between the most likely and upper limit is ~12 dBμV.
- When one hundred radiated field terms are being added, the PD reaches a maxima at ~58 dBμV/m while the upper limit is 80 dBμV/m. Hence, the margin between the most likely and upper limit is ~22 dBμV.

An intuitive explanation for this behaviour exists. The upper limit to the system emission level is associated with a single, specific combination of events: when *all* of the radiated field terms arrive at the evaluation point in-phase with one another. As more radiated field terms are added, the probability of this singular event occurring becomes progressively smaller. For other lower emissions amplitudes, there are generally many different combinations of phase values (i.e., many different events) among the radiated field terms that generate the amplitudes. Hence, the probability of these amplitudes occurring is higher.

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