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TECHNICAL REPORT

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Specification for radio disturbance and immunity measuring apparatus and methods –
Part 4-3: Uncertainties, statistics and limit modelling – Statistical considerations in the determination of EMC compliance of mass-produced products

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FOREWORD

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CISPR 16-4-3, which is a technical report, has been prepared by CISPR subcommittee A: Radio interference measurements and statistical methods.

This second edition of CISPR 16-4-3 cancels and replaces the first edition published in 2003 and constitutes a technical revision. It includes a new mathematical approach for the application of the 80%/80% rule, based on a method involving an additional acceptance limit. The mathematical basis for this new method is also provided. Furthermore, an additional test approach, based on the non-central *t*-distribution and using frequency sub-ranges has been added as well, along with a description of the properties of all methods which are available at this point in time.

This consolidated version of CISPR 16-4-3 consists of the second edition (2004) [documents CISPR/A/491/DTR + CISPR/A/492/DTR and CISPR/A/507/RVC + CISPR/A/508/RVC] and its amendment 1 (2006) [documents CISPR/A/666/DTR and CISPR/A/691/RVC].

The technical content is therefore identical to the base edition and its amendment and has been prepared for user convenience.

It bears the edition number 2.1.

A vertical line in the margin shows where the base publication has been modified by amendment 1.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-3: Uncertainties, statistics and limit modelling – Statistical considerations in the determination of EMC compliance of mass-produced products

1 Scope

This part of CISPR 16 deals with statistical considerations in the determination of EMC compliance of mass-produced products.

The reasons for such statistical considerations are:

a) that the abatement of interference aims that the majority of the appliances to be approved shall not cause interference;

b) that the CISPR limits should be suitable for the purpose of type approval of mass-produced appliances as well as approval of single-produced appliances;

c) that to ensure compliance of mass-produced appliances with the CISPR limits, statistical techniques have to be applied;

d) that it is important for international trade that the limits shall be interpreted in the same way in every country;

e) that the National Committees of the IEC which collaborate in the work of the CISPR should seek to secure the agreement of the competent authorities in their countries.

Therefore, this part of CISPR 16 specifies requirements and provides guidance based on statistical techniques. EMC compliance of mass-produced appliances should be based on the application of statistical techniques that must reassure the consumer, with an 80 % degree of confidence, that 80 % of the appliances of a type being investigated comply with the emission or immunity requirements. Clause 4 gives some general requirements for this so-called 80 %/80 % rule. Clause 5 gives more specific requirements for the application of the 80 %/80 % rule to emission tests. Clause 6 gives guidance on the application of the CISPR 80 %/80 % rule to immunity tests. The 80 %/80 % rule protects the consumer from non-compliant appliances, but it says hardly anything about the probability that a batch of appliances from which the sample has been taken will be accepted. This acceptance probability is very important to the manufacturer. In Annex A, more information is given on acceptance probability (manufacturer's risk).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-161:1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*
Amendment 1 (1997)
Amendment 2 (1998)

CISPR 16-4-2, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Uncertainty in EMC measurements*

3 Terms, definitions and symbols

For the purpose of this document, the terms, definitions and symbols given in IEC 60050-161 apply.

4 General requirements

The following interpretation of CISPR limits and of methods of statistical sampling for compliance of mass-produced appliances with these limits should be applied.

4.1 Limits

4.1.1 A CISPR limit is a limit that is recommended to national authorities for incorporation in national standards, relevant legal regulations and official specifications. It is also recommended that international organizations use these limits.

4.1.2 The significance of the limits for type-approved appliances shall be that, on a statistical basis, at least 80 % of the mass-produced appliances comply with the limits with at least 80 % confidence.

4.2 Type testing approaches

Type tests can be made using the following two approaches.

4.2.1 Use of a sample of appliances of the same type

When using this approach, the sample of appliances of the same type shall be evaluated statistically in accordance with the methods described in Clause 5 (emission tests) and Clause 6 (immunity tests).

Statistical assessment of compliance with limits shall be made according to the methods described in Clauses 5 and 6 or in accordance with some other method that ensures compliance with the requirements of clause 4.1.2.

4.2.2 Use of a single device with subsequent quality assurance testing

For simplicity, a type test can be performed initially on one item only. However, subsequent tests from time to time on items taken at random from the production are necessary.

4.2.3 Withdrawal of the type approval

In the case of controversy involving the possible withdrawal of a type approval, withdrawal shall be considered only after tests on an adequate sample in accordance with 4.2.1 above.

5 Emission measurements

Statistical assessment of compliance with emission limits shall be made according to one of the three tests described below or to some other test that ensures compliance with the requirements of 4.1.2.

5.1 Test based on the non-central *t*-distribution.

This test should be performed on a sample of not less than five items of the type, but if, in exceptional circumstances, five items are not available, then a sample of three shall be used. Compliance is judged from the following relationship:

$$\bar{x}_n + kS_n \leq L \qquad (1)$$

where

$\bar{x}_n$ = arithmetic mean value of the levels of *n* items in the sample;

$$S_n^2 = \sum\left(x-\bar{x}_n\right)^2/(n-1); \qquad (2)$$

x = level of individual item;

k = the factor derived from tables of the non-central *t*-distribution with 80 % confidence that 80 % of the type is below the limit; the value of *k* depends on the sample size *n* and is stated below:

N	3	4	5	6	7	8	9	10	11	12
k	2,04	1,69	1,52	1,42	1,35	1,30	1,27	1,24	1,21	1,20

L = the permissible limit;

the quantities x, $\bar{x}_n$, S_n and L are expressed logarithmically dB(µV), dB(µV/m) or dB(pW);

If one or some appliance of the sample can not be measured due to the insufficient sensitivity of the test equipment, Annex B describes an approach to solve this situation.

5.1.1 Tests using sub-ranges

5.1.1.1 Introduction

The 80 %/80 % rule shall be used for the specific emission at a specific frequency or frequency range at each EUT of the sample. Modern computer-controlled measurement equipment usually scans the frequency range and measures a limited number of the highest disturbances at certain frequencies of the whole emission spectrum. Because the level of the disturbance at the same frequency or the frequency at the highest emission varies from EUT to EUT, the measured frequencies of the highest disturbance levels usually vary from one EUT to another in a sample. These measurement results cannot be used for the 80 %/80 % rule because one does not obtain measurement levels at approximately the same frequency for each EUT to calculate the average and standard deviation of the EUT's level. For this reason, it is useful to divide the whole frequency range into defined sub-ranges, which allow a statistical analysis of the emission spectrum in the whole frequency range by taking the highest measured level in each sub-range.

For the application of the non-central *t*-distribution in the 80 %/80 % rule, it is necessary to normalise the measured values. These normalised values allow the use of the 80 %/80 % rule in the sub-ranges independently of variations of the limit in a sub-range.

The whole frequency range shall be divided on a logarithmic frequency axis into sub-ranges. The border of the sub-ranges may correspond to changes in limits, if a product committee so requires.

NOTE The division of the frequency range into sub-ranges is applicable only to the test based on the non-central *t*-distribution.

5.1.1.2 Number of sub-ranges

It is suggested that the frequency range of the disturbance measurement method in question is divided into a number of frequency sub-ranges. The span of each frequency sub-range should decrease in a logarithmic way as a function of the frequency. For the different disturbance measurement methods, the following number of sub-ranges is suggested:

– at least 8 sub-ranges in the frequency range of up to 30 MHz for the measurement of the disturbance voltage;

– at least 4 sub-ranges in the frequency range from 30 MHz to 300 MHz for the measurement of the disturbance power, and

– about 8 sub-ranges in the frequency range from 30 MHz to 1000 MHz for the measurement of disturbance field strength.

NOTE 1 The number of sub-ranges shall be determined such that the frequency dependence of the disturbance's characteristic can be estimated. This condition is fulfilled if the ratio of limit to average plus standard deviation of the emission in the sub-ranges does not decrease when the number of sub-ranges is reduced.

NOTE 2 The product committees should determine the number of sub-ranges depending on the disturbance characteristics of the different products.

NOTE 3 The recommended number of sub-ranges is based on the investigations of samples of CISPR 14 and CISPR 22 devices.

NOTE 4 The sub-range transition frequency can be calculated as follows:

$$f = f_{low} \times 10^{\frac{i}{N} log\left(\frac{f_{upp}}{f_{low}}\right)}$$

where

i = 1 … N is the index of the i-th sub-range transition frequency;

f_{low}, f_{upp} are the lower and upper frequency of the frequency range;

N= is the number of frequency sub-ranges.

NOTE 5 For predominantly narrow band emission it is possible to select single narrow band emission by preexamination for the use of the non-central *t*-distribution without using sub-ranges.

5.1.1.3 Normalization of the measured disturbance levels

The average value and the standard deviation of the measured values in a frequency sub-range shall be compared to the limit. Because the limit may not be constant over the frequency sub-range, it is necessary to normalize the measured values.

For normalization, the difference, d_f, between the measured level, x_f, and the limit level, L_f, shall be determined at the specific frequency f that has the largest difference, using Equation (3). The difference is negative as long as the measured value is below the limit.

$$d_f = x_f - L_f \tag{3}$$

where

d_f = the gap to the limit at the specific frequency in dB;

x_f = the measured level in dB(μV or pW or μV/m);

L_f = the limit at the specific frequency in dB(μV or pW or μV/m).

5.1.1.4 Tests based on the non-central *t*-distribution with frequency sub-ranges

As a result of the measurement of all pieces of the sample for each sub-frequency range, the average and the standard deviation of the gap d_f shall be calculated. The average of the gap is

$$\bar{d}_f = \frac{1}{n}\sum_{n} d_f \tag{4}$$

where

n = the number of items in the sample

$\bar{d}_f$ = the average gap in the sub-range and the standard deviation is

$$S_{df} = \frac{1}{\sqrt{n-1}} \sqrt{\sum_{n} (d_f - \bar{d}_f)^2} \tag{5}$$

where S_{df} = the standard deviation in the sub-range.

Compliance is judged from the following relationship:

$$\bar{d}_f + k \cdot S_{df} \leq 0 \tag{6}$$

k: see 5.1 above.

5.2 Test based on the binomial distribution

This test should be performed on a sample of not less than seven items. Compliance is judged from the condition that the number of appliances with an interference level above the permissible limit may not exceed *c* in a sample of size n.

n	7	14	20	26	32
c	0	1	2	3	4

5.3 Test based on an additional acceptance limit

This test should be performed on a sample of not less than five items of a particular type, but if, in exceptional circumstances, five items are not available, then a sample of at least three shall be used. Details on this method are described in 5.5. Compliance is judged if every measured disturbance level x_i satisfies the following relation:

$$x_i \leq AL = L - \sigma_{max} \cdot k_E \tag{7}$$

where

AL is the acceptance limit

L is the permissible limit

σ_{max} is the expected maximum standard deviation of the product, which is 2 times the expected standard deviation, and which is determined by the product committee using the procedure of 5.3.1 or alternatively the following conservative values for the different types of disturbance measurements can be used:

disturbance voltage: σ_{max} = 6 dB*)

disturbance power: σ_{max} = 6 dB**)

disturbance field strength: σ_{max} = xx dB[1]

NOTE 1 The values of 6 dB were determined by measurements of 130*) and 40**) different EUT types (3 or 5 samples each). The value of 6 dB was estimated by comparing the tests using the non-central *t*-distribution with the tests using the additional margin. Both tests give about the same percentage of approvals.

NOTE 2 The disturbance field strength value is under consideration.

———————

1 Under consideration

k_E is the factor derived from tables of the normal distribution with 80 % confidence that 80 % of the type is below the limit; the value of k_E depends on the sample size n and is stated below (see Annex C.1):

n	3	4	5	6
k_E	0,63	0,41	0,24	0,12

The quantities x, L, k_E and σ_{max} are expressed logarithmically as dB(μV), dB(μV/m) or dB(pW).

NOTE With σ_{max} = 6 dB the following additional acceptance limit will be calculated:

Sample size	3	4	5	6
additional acceptance limit [dB]	3,8	2,5	1,5	0,7

5.3.1 Estimation of the maximum expected standard deviation

The expected standard deviation of disturbance emission shall be determined by an efficient number of samples of the product concerned. The following procedure is recommended:

On each investigated frequency or in each frequency sub-range in the sample being investigated, the difference x_{min} between the measured maximum emission x_i and the limit L shall be determined

$$x_{min} = (x_i - L)_{max} \qquad (8)$$

The standard deviation S_{sub} of the differences in a sub-range or investigated frequency of a sample shall be calculated

$$S_{sub} = \frac{1}{\sqrt{n-1}} \sqrt{\sum_n (x_{min} - \bar{x}_{min})^2} \qquad (9)$$

where n is the number of appliances in the sample.

The average standard deviation $\bar{S}_{sample}$ over the sub-ranges shall be determined for each sample. The expected standard deviation S_{expect} is the average over $\bar{S}_{sample}$ of all samples.

The maximum expected standard deviation is two times the expected standard deviation.

NOTE The factor of two is chosen by comparison of the test methods using the additional margin and the non-central t-distribution. Both test methods have, with the factor two, approximately the same rejection rate of samples.

Product committees may verify the expected standard deviation of their products.

5.4 Additional sampling in case of non-compliance

Should the test on the sample result in non-compliance with the requirements in 5.1, 5.2 or 5.3, then a second sample may be tested and the results combined with those from the first sample and compliance checked for the larger sample. For 5.3 this method is only applicable to samples of 7 or less appliances.

5.5 Properties of the different methods that can be used

The possible four test methods for compliance evaluation of mass products are:

- using a single device,
- non-central *t*-distribution (see 5.1),
- binomial distribution (see 5.2) and
- the additional margin (see 5.3)

Each of these methods are based on different statistical methodologies, and therefore each of the methods have different properties (advantages or disadvantages) when applied in practice by manufacturers or authorities.

a) Using a single device

A test on a single device is used by manufacturers. The method requires that repetitive testing of the product over time has to occur.

b) Non-central *t*-distribution:

The test is based on the non-central *t*-distribution and contains the condition of normal distribution for the totality. As long as this condition is fulfilled, the test gives correct results for the approval of a sample. But disapproval may be indicated without reason if one or two measurements are far below the limit and the other measurement results are near (but below) the limit.

If the failure is caused by measurement results far below the limit due to the large standard deviation, alternatively the test with the additional margin may be used for the failed sample. If the sample passes, the product is o.k.

In case of disapproval, it is possible to select further devices from the same product batch and to combine all the failed and newly selected devices in a larger sample.

An advantage of this test method is that the sample can be relatively small.

c) Binomial distribution:

The test is based on the binomial distribution and contains no further condition of distribution for the totality. The test gives correct results for the approval and disapproval of a sample.

In case of disapproval, it is possible to select further devices from the same product batch and to combine all the failed and newly selected devices in a larger sample.

The disadvantage of this test method is that the sample must have at least 7 devices.

d) Additional acceptance limit:

The test is based on the condition of normal distribution for the totality and the estimation of the expected standard deviation. The test gives correct results for the approval of a sample.

If the failure is caused by measurement results which are close to the limit, an additional test on the sample based on the non-central *t*-distribution may be used for the failed sample. If the sample passes the test, the product is o.k.

In case of disapproval, it is possible to select further devices from the same product batch and to combine all the failed and newly selected devices in a larger sample. This method is only applicable to samples with less than 7 devices.

5.6 Compliance criteria and measurement instrumentation uncertainty

The requirement for product compliance contains two parts: one is the requirement of the 80 %/80 % rule and the other is the measurement instrumentation uncertainty as specified in CISPR 16-4-2.

Therefore the outcome of the 80 %/80 % test indicates compliance with the limit as long as the requirement of CISPR 16-4-2 is fulfilled. This means U_{Lab} is lower than or equal to U_{CISPR}.

In cases where U_{Lab} is higher than U_{CISPR}, the measurement results which are used for the 80 %/80 % rule have to be increased by the value Δ.

$$\Delta = \left[U_{\mathrm{Lab}} - U_{\mathrm{CISPR}}\right]_{U_{\mathrm{CISPR}} < U_{\mathrm{Lab}}} \tag{10}$$

6 Immunity tests

6.1 Application of the CISPR 80 %/80 % rule to immunity tests

In the assessment of the immunity of appliances and equipment in large-scale production, consideration should be given to the specification of the statistical method to be used in the CISPR sampling scheme. Two methods have been standardized: one using the binomial distribution and the other using the non-central *t*-distribution.

The binomial distribution method is essentially sampling by attributes. Hence, this method should be used in an immunity test in which the immunity level cannot be determined, with the result that it is only possible to verify whether an appliance or equipment complies with the immunity limit or not, i.e. only a pass or fail test at a specified immunity level is possible.

The non-central *t*-distribution method is essentially sampling by variables. Hence, this method is suitable for an immunity test in which the immunity level or the level of a signal that is a measure of the degradation of operation, can be determined. The latter level shall be expressed in logarithmic units before applying the non-central *t*-distribution method.

6.2 Application guidelines

Subclause 6.1 only gives conditions related to the choice of statistical test method to be used in the assessment of the immunity of appliances and equipment in large-scale production after it has been decided by the relevant Product Committee that a statistical evaluation is needed. A Product Committee may also decide that a type-test alone is adequate.

6.2.1 Sampling by attributes

When testing the immunity of an equipment under test (EUT), the combination of type of disturbance signal and type of susceptible part in the EUT might result in damage to the EUT if the immunity level is exceeded. In such a case, only an immunity test on a Pass/Fail or Go/No Go basis will be possible, i.e. a test which verifies only whether the EUT complies or does not comply with the immunity limit. Consequently, only two test results are possible: the EUT passes or the EUT fails. The properties "pass" and "fail" are attributes of the EUT, so the method based on the binomial distribution has to be used.

An immunity test on a Pass/Fail basis is not necessarily associated with damage to the EUT. If the test is to be carried out with a fixed-level electromagnetic disturbance, it may also be possible to use only the Pass/Fail criterion. Also in this case the sampling method based on the binomial distribution has to be used.

An example of an immunity test on a Pass/Fail basis in view of the possibility of damaging the EUT is the testing of telecommunication equipment for immunity to transients caused by lightning. An example of such a test in view of the fixed-level disturbance is the electrostatic discharge test on (digital) information technology equipment.

6.2.2 Sampling by variables

If the EUT and the chosen immunity test allow the determination of the immunity level or the level of a signal that is a measure of the degradation of operation, these levels will be variables and, hence, a Product Committee may decide to opt for sampling by variables. In that case, the sampling method based on the non-central *t*-distribution has to be used.

Note the above formulation "may decide", as a Product Committee can always decide to opt for a test on a Pass/Fail basis. In addition, note that if the EUT is sufficiently immune, it might not be possible to determine the levels mentioned. This does not exclude, however, the possibility of sampling by variables. Such a situation is completely comparable with the situation in an emission test when the emission level is lower than the noise level of the CISPR receiver.

The determination of the immunity level in an immunity test is, generally speaking, not very practical. It always causes over-exposure of the EUT to the applied disturbance signal, and may easily lead to unforeseen effects during immunity testing. Nevertheless, there is no need to exclude this determination beforehand.

A signal which is a measure of the degradation of operation of the EUT may be available for sampling by variables: for example, the demodulated signal when testing several samples of EUT, say an audio equipment, for their immunity to amplitude-modulated RF signals of constant level and frequency. The level of the demodulated signal is then a measure of the degradation of the EUT. Another example is the bit-error rate when performing immunity tests on digital communication equipment.

Annex A
(informative)

Statistical considerations in the determination of limits of radio interference

NOTE This annex was previously published as CISPR Report 48. Its content is identical to the text taken from the earlier publication CISPR 8B.

A.1 Introduction

Compliance of mass-produced appliances with radio interference limits should be based on the application of statistical techniques that have to ensure the consumer, with an 80 % degree of confidence, that 80 % of the appliances of a type being investigated are below the specified radio interference limit. This so-called 80 % /80 % rule protects the consumer from appliances with too high a radio interference level, but it says hardly anything about the probability that a batch of appliances from which the sample has been taken will be accepted. This acceptance probability is very important to the manufacturer. The manufacturer knows only that if 20 % of the items of the batch are above the relevant limit, the acceptance probability is 20 % and knowledge is necessary about the dependence of the acceptance probability on the sample size and the fraction of items in the batch that are above the relevant limit. The curves representing the acceptance probability versus fraction items above the limit and the sample size as a parameter are called the operating characteristic curves. These curves can be calculated using either the non-central *t*-distribution (sampling by variables) or the binomial distribution (sampling by attributes).

The Poisson distribution cannot be used since the fraction appliances above the limit should be very small (<1 %) and the sample size large (more than 20 items). Besides sampling of batches, it is also possible to ensure conformity of the production by means of control chart techniques. These methods provide a continuous recording of the wanted information – for example, the radio interference level of the appliances being produced.

A.2 Tests based on the non-central *t*-distribution (sampling by variables)

The following condition must be fulfilled:

$$\overline{X} + \mathrm{k}\,S_\mathrm{n} \le L \tag{A.1}$$

and has to ensure, with an 80 % degree of confidence, that 80 % of the appliances produced on a large scale are below a specified radio interference limit L.

Meaning of the symbols used in this expression:

$\overline{X}$ = mean value of the interference level of the sample with size n of the appliances to be tested; $\overline{X}$ is known;

S_n = standard deviation of the interference level of the sample with size n of the appliances to be tested; S_n is known;

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_\mathrm{i} \tag{A.2}$$

$$S_\mathrm{n} = \sqrt{\frac{\sum\left(X_\mathrm{i} - \overline{X}\right)^2}{n-1}} \tag{A.3}$$

k = constant to be determined in such a way that the above-stated rule is satisfied;

L = the permissible radio interference limit; L is an upper limit.

A.2.1 Determination of the constant k

It is assumed that the production being investigated has a normal distribution with the following parameters:

μ = mean value of the radio interference level of all appliances; μ is unknown;

σ = standard deviation of the radio interference level of all appliances; σ is unknown.

Assume: p fraction that is above the limit L (fraction defective) and $(1 - p)$ fraction of the lot below the specified limit L.

Define a constant K_p:

$$p = \int_{K_p}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} dy \qquad \text{(A.4)}$$

in which $f(y) = \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}}$ is the standardized normal density function.

K_p can be determined from appropriate tables of the normal distribution function.

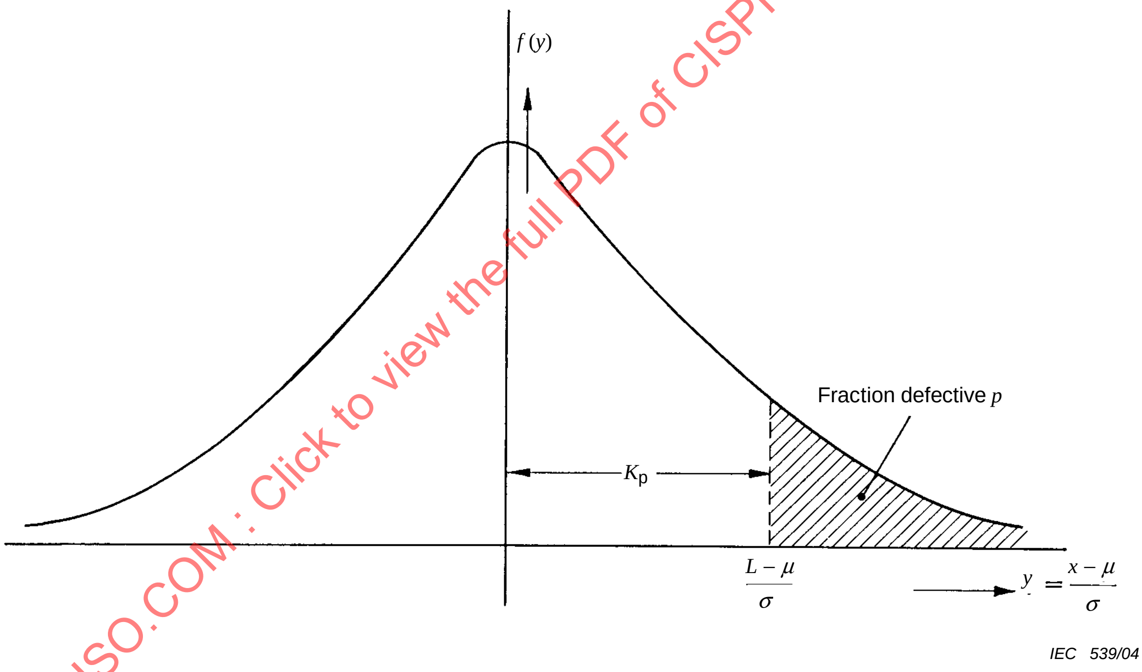


Figure A.1 – Determination of the faction *p*

From the definition of K_p as well as the figure drawn above it follows that:

$$L = \mu + K_p \sigma \qquad \text{(A.5)}$$

with $K_p > 0$

since L is an upper limit.

According to the CISPR, if p = 0,2, then K_p = 0,84. The test instruction can now be read as follows:

$$p\left(\overline{X} + \mathrm{k}S_n \geq L / L = \mu + K_p\sigma\right) = 1 - \alpha \quad \text{(A.6)}$$

The probability α of a batch with a fraction defective p being accepted gives the *consumer's risk.*

For CISPR, α = 0,2 (1 – α = 0,8 → 80 %) and K_p = 0, 84.

To determine the constant k, the expression should be rewritten as follows:

$$p\left(\overline{X} + \mathrm{k}S_n \geq L / L = \mu + K_p\sigma\right) = 1 - \alpha \quad \text{(A.7)}$$

$$= p\left(\frac{\overline{X} - \mu}{\sigma/\sqrt{n}} - \frac{L - \mu}{\sigma/\sqrt{n}} \geq -\frac{\mathrm{k}S_n}{\sigma/\sqrt{n}} \middle/ L = \mu + K_p\sigma\right) \quad \text{(A.8)}$$

$$= p\left(\frac{-\frac{\overline{X} - \mu}{\sigma/\sqrt{n}} + \frac{L - \mu}{\sigma/\sqrt{n}}}{S_n/\sigma} \leq \mathrm{k}\sqrt{n} \middle/ L = \mu + K_p\sigma\right) \quad \text{(A.9)}$$

By definition:

$$t_{\text{n.c.}} = \frac{-\frac{\overline{X} - \mu}{\sigma/\sqrt{n}} + \frac{L - \mu}{\sigma/\sqrt{n}}}{S_n/\sigma}$$

$t_{\text{n.c.}}$ is a non-central *t*-distribution with non-centrality parameter

$$(L - \mu)/\sigma/\sqrt{n} = K_p\sqrt{n} \quad \text{(A.10)}$$

and (n – 1) degrees of freedom.

The non-centrality parameter follows from the condition that not more than a fraction p of the lot being investigated is above the permissible limit.

$$p\left(t_{\text{n.c.}} \leq \mathrm{k}\sqrt{n}\right) = 1 - \alpha \quad \text{(A.11)}$$

$$p\left(\frac{t_{\text{n.c.}}}{\sqrt{n-1}} \leq \mathrm{k}\sqrt{\frac{n}{n-1}}\right) = 1 - \alpha \quad \text{(A.12)}$$

This probability function has been tabulated in [1] and [2]. Some figures are given below.

With α = 0,2, p = 0,1 (1 – α = 80 %, 1 – p = 80 %), the following values for k will be obtained for different sample sizes:

n	4	5	6	7	8	9	10	11	12
k	1,68	1,51	1,42	1,35	1,30	1,27	1,24	1,21	1,20

A.2.2 Determination of the sample size *n*

The producer wants to know the probability of the appliances being accepted and has to know:

$$p\left(\overline{X} + \mathrm{k}S_{\mathrm{n}} \leq L / L = \mu + K_{\mathrm{p}}\sigma\right) \quad \text{(A.13)}$$

By definition, this expression is equal to $\beta(p)$, the acceptance probability. The probability $1 - \beta(p)$ of a batch with a fraction defective p being rejected gives the *producer's risk*.

This can be rewritten as follows:

$$p\left(\frac{t_{\mathrm{n.c.}}}{\sqrt{n-1}} \geq \mathrm{k}\sqrt{\frac{n}{n-1}}\right) = \beta(p) \quad \text{(A.14)}$$

For a lot with the same fraction defective p as in A.2.1, $\beta(p)$ equals α. With p = 0,2, α = 0,2 (CISPR values), β(0,2) is 0,2. From the producer's point of view, $\beta(p)$ should be maximized by improving the production (a smaller percentage of defectives) since $\beta(p)$ depends on the defective fraction.

Generally, the manufacturer needs an acceptance probability as high as 95 %. The function representing the dependence of the acceptable probability $\beta(p)$ on the fraction defective p is called the operating characteristic of the test and $1 - \beta(p)$ the power curve of the test. The mathematical representation for the O.C. curve is

$$\beta(p) = p\left(\frac{t_{\mathrm{n.c.}}}{\sqrt{n-1}} \geq \mathrm{k}\sqrt{\frac{n}{n-1}}\right) \quad \text{(A.15)}$$

for fixed *n*.

In Figure A.1, a few curves are given for α = 0,2. From these curves, it can be seen that in order to ensure the same acceptance probability $\beta(p)$, the percentage of defectives will increase with the sample size. The so-called discriminatory power of the operating characteristic curve increases as the sample size increases and is ideal if n equals the total number of appliances to be approved.

A.2.3 Example (see Figure A.1)

A batch of appliances has to be checked. According to the 80 %/80 % rule with a sample size n = 6, we have k = 1,42. The consumer has an 80 % degree of confidence that 80 % of the batch lies below the limit.

The acceptance probability $\beta(p)$ is 20 % at p = 0,2 (80 % below the limit). To obtain a greater acceptance probability, the percentage defective p should be decreased. At p = 0,035 (96,5 % below the limit), the acceptance probability is 80 %. From every 10 samples consisting of six units taken from lots with p = 0,035, eight samples will on average yield a positive result. At p = 0,009 (99,1 % below the limit), the acceptance probability is 95 %. In the latter case, the manufacturer has to apply a μ and σ which fulfil the expression $\mu + 2{,}4\ \sigma \leq L$.

A.3 Tests based on the binomial distribution (sampling by attributes)

The number of defective units c that occur in a sample of size n has to ensure with an 80 % degree of confidence that 80 % of the appliances produced on a large scale are below a specified radio interference limit L. An item has to be considered defective as soon as its radio interference level is above the specified value L.

A.3.1 Determination of constant c

The occurrence of defective units by sampling a batch of appliances should satisfy the requirement that the occurrences are statistically independent and not more than one occurrence takes place at the same moment.

The binomial distribution is characterized by the fraction defective p of the batch of appliances being tested and the sample size n.

The probability that a sample of size n has exactly c defective items is given by:

$$p(x=\mathrm{c}) = \binom{n}{\mathrm{c}} p^{\mathrm{c}} (1-p)^{n-\mathrm{c}} \quad n, \mathrm{c} \text{ integers} \tag{A.16}$$

and that this sample contains c defective items or less by:

$$p(x \le \mathrm{c}) = \sum_{x=0}^{\mathrm{c}} \binom{n}{x} p^{x} (1-p)^{n-x} \quad n, x, \mathrm{c} \text{ integers} \tag{A.17}$$

$p\ (x \le \mathrm{c})$ represents the distribution function.

The probability that a sample with size n contains more than c defective items should be $(1 - \alpha)$ if the batch of appliances being tested has the maximum allowed fraction defective, hence:

$$p(x \le \mathrm{c}\,/\,p) = 1-\alpha \tag{A.18}$$

$$p(x \le \mathrm{c}\,/\,p) = \sum_{x=0}^{\mathrm{c}} \binom{n}{x} p^{x} (1-p)^{n-x} = \alpha \tag{A.19}$$

According to the CISPR requirements: α = 0,2 and p = 0,2. The corresponding c and n values are given in the left-hand table. The right-hand table represents the values for c and n if α = 0,05 and p = 0,2. c represents the allowed number of defective items and n the sample size.

c	*n*
0	7
1	14
2	20
3	26
4	32
5	38
for a consumer's risk of 20 %	

c	*n*
0	13
1	22
2	29
3	36
4	43
5	50
for a consumer's risk of 5 %	

To have an 80 % degree of confidence that 80 % of the appliances are below the limit, c and n should correspond with the values listed in the left-hand table.

A.3.2 Determination of sample size *n*

Analogously to 2.2, the acceptance probability follows from:

$$p(x \leq c / p) = \beta(p) \quad \text{(A.20)}$$

If p = 0,2 then β(0,2) = α = 0,2. The probability 1 – β(0,2) of the batch of appliances being rejected is 0,8.

The operating characteristic curve is given by

$$\beta(p) = \sum_{x=0}^{c} \left(\frac{n}{x} \right) p^{x} (1-p)^{n-x} \quad \text{(A.21)}$$

Curves have been drawn in Figure A.2.

A.3.3 Control charts

The use of control charts [3] provides information about the influence of the production process on the values to be statistically controlled and indicates the deviations from the original values. In this way, an insight can be gained into the performance of the production process.

Generally, the sample average $\overline{X}$ and the sample standard deviation S_n give a good estimation of the quality characteristics to be studied. For mass-produced appliances, a sufficient number of samples can be taken to ensure conformity of $\overline{X}$ and S_n with the required mean value μ and standard deviation σ. The confidence intervals for various fractions of the production may be predicted from these values.

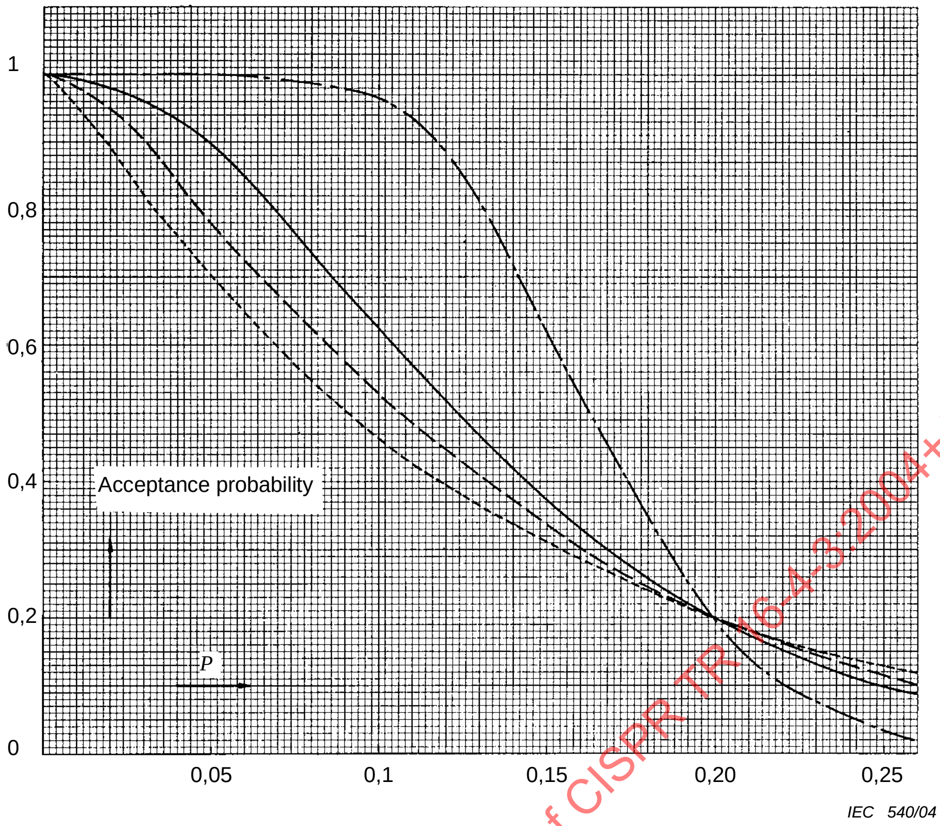
Control chart techniques can easily be applied in such a way that the consumer has the required 80 % confidence that 80 % of the production is below the permissible limit, whereas at the same time the use of small samples is avoided.

A.3.4 Reference documents

[1] RESNIKOFF, GJ. and LIEBERMAN, GJ. *Tables of the non-central t-distribution*. Stanford University, California, 1957.

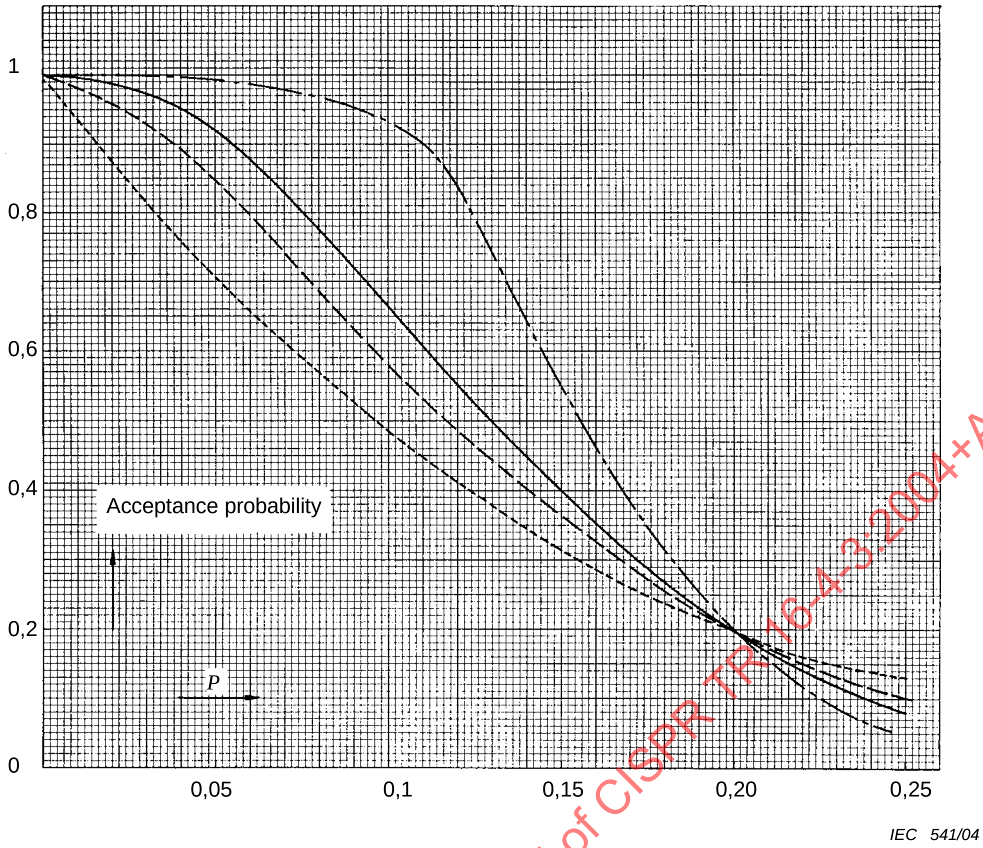
[2] CISPR/WG 8 (Groenveld/Neth.)1, March 1972.

[3] JOHNSON, NL. and LEONE, FC. *Statistics and Experimental Design I.* Wiley and Sons, New York, 1964, pp 298-348.



n = 6 ; k = 1.42
n = 8 ; k = 1.30
n = 12 ; k = 1.20
n = 51 ; k = 0.99

Figure A.2 – Operating characteristic curves for non-central *t*-distribution



n = 7 ; k = 0
n = 14 ; k = 1
n = 20 ; k = 2
n = 49 ; k = 7

Figure A.3 – Operating characteristic curves for binomial distribution

Annex B
(informative)

An analytical assessment of statistical parameters of radio disturbance in the case of an incompletely defined sample

NOTE This annex was previously published as CISPR Report 59.

B.1 Theory

Clause 5 specifies the requirements for the statistical assessment of series-produced equipment. The assessment is based on the non-central *t*-distribution and it requires that the actual levels of the radio disturbance generated by each equipment in a sample is measured. The assessment of acceptability is then made during the mean and the standard deviation of the radio disturbance levels measured.

In a number of cases, it may not be possible to measure the levels of radio disturbance generated by all the units *of* the equipment in the sample because of insufficient sensitivity of the testing apparatus used. In such cases, the available distribution of the values of radio disturbance levels (expressed in decibels) is truncated from below, giving a one-sided and incomplete determination of the distribution.

Figure B.1 shows the probability density function $\varphi(\gamma,\gamma_0)$ of a normal distribution of radio disturbance values truncated from below.

Figure B.2 shows the function $\Phi(\gamma,\gamma_0)$, which is an alternative illustration of the same truncated distribution.

This report presents the analytical method of assessment of mathematical expectation and standard deviation of radio disturbance values distributed according to a normal law, on the basis of the known parameters of truncated distribution and the degree of truncation.

Assume that for the determination of the statistical parameters of the distribution of radio disturbance values one takes a sample of n units from the parent population, which is a normal distribution $N(\mu x;\sigma)$. In this sample, $n_0 < n$ units have a radio disturbance level $X < X_L$, where X_L is the limit of sensitivity of the measuring apparatus, this limit being the point of truncation. Hence, in a sample of the size n there are only $n - n_0$ units with radio disturbance values which are greater than X_L, and for these units only can the radio disturbance levels be measured. It is possible to consider $n - n_0$ of radio disturbance values as the measurements from truncated distribution with the truncation degree $\Phi(\gamma_0)$. The ratio n_0/n is the assessment of the degree or truncation $\Phi(\gamma_0)$.

The average $\overline{X}$ and the standard deviation S of the measured radio disturbance values are an estimation of the parameters μ_x and σ in the parent population of the equipment. $\overline{X}$ and S are determined from the expressions:

$$\overline{X} = \overline{X}_y - \frac{S_y}{\left(\frac{1-\Phi(\gamma_0)}{\varphi(\gamma_0)}\left(\frac{1-\Phi(\gamma_0)}{\varphi(\gamma_0)}+\gamma_0\right)-1\right)^{1/2}} \tag{B.1}$$

$$S = \frac{S_y}{\left(\frac{\varphi(\gamma_0)}{1-\Phi(\gamma_0)}\left(\gamma_0 - \frac{\varphi(\gamma_0)}{1-\Phi(\gamma_0)}\right)+1\right)^{1/2}} \quad \text{(B.2)}$$

where

$\gamma_0 = (X_L - \mu)/\sigma$ is a specified truncation point;

$\Phi(\gamma_0)$ is a value of the normal distribution function

$$\Phi(\gamma) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\gamma} e^{-\frac{x^2}{2}} dx$$

$\varphi(\gamma_0)$ is a value of a probability density function of a normal distribution

$$\varphi(\gamma) = \frac{1}{\sqrt{2\pi}} e^{-\frac{\gamma^2}{2}}$$

The values of the sampling parameters $\overline{X}_y$ and S_y of the truncated distribution included in the formulae (B.1) and (B.2) are determined from the following expressions:

$$\overline{X}_y = \frac{1}{n-n_0} \sum_{i=1}^{n-n_0} X_i \quad \text{(B.3)}$$

$$S_y = \left(\frac{1}{n-n_0-1} \sum_{i=1}^{n-n_0} \left(X - \overline{X}_y\right)^2\right)^{1/2} \quad \text{(B.4)}$$

The mathematical expectation and standard deviation of a radio disturbance value in the parent population of equipment, which has normal distribution, are determined from the parameters of an incompletely determined sample in the following succession:

a) the radio disturbance values produced by all the units of the sample of the size n are measured;

b) the degree of truncation $\Phi(\gamma_0) = \frac{n_0}{n}$ is determined;

c) the values of the specified point of truncation γ_0 are determined from the tables of a function of the normal distribution on the basis of the known values of $\Phi(\gamma_0)$;

d) from the tables of a probability density function of normal distribution the values of $\varphi(\gamma_0)$ are found;

e) the values of the statistical parameters of the truncated distribution of measured disturbance produced by the articles of a sample of the size $n - n_0$ are determined from formulae (B.3) and (B.4);

f) the values of the statistical parameters of the complete distribution of disturbance levels from the sample of equipment of size n are determined from formulae (B.1) and (B.2).

NOTE An example calculation is given in B.2.

The confidence interval of the parameter $\overline{X}$ with the confidence 1 – α is determined by the expression:

$$\overline{X} - U_p S \sqrt{\frac{\mu_x \gamma_0}{n}} < \mu_x < \overline{X} + U_p S \sqrt{\frac{\mu_x \gamma_0}{n}} \qquad \text{(B.5)}$$

where

$U_p = U_{1-\frac{\alpha}{2}}$ is a quartile of distribution N(0.1);

$\mu_x(\gamma_0)$ is a function of truncation degree determined from table B.1.

Table B.1 $\mu_x(\gamma_0)$ as a function γ_0

γ_0	–3,0	–2,5	–2,1	–2,0	–1,9	–1,8	–1,7	–1,6	–1,5	–1,4
$\mu_x(\gamma_0)$	1,000	1,001	1,002	1,003	1,004	1,005	1,006	1,009	1,011	1,015
γ_0	–1,3	–1,2	–1,1	–1,0	–0,9	–0,8	–0,7	–0,6	–0,5	–0,4
$\mu_x(\gamma_0)$	1,019	1,025	1,032	1,042	1,054	1,069	1,089	1,114	1,147	1,189
γ_0	–0,3	–0,2	–0,1	0	0,1	0,2	0,3	0,4	0,5	0,6
$\mu_x(\gamma_0)$	1,243	1,312	1,401	1,517	1,667	1,863	2,118	2,453	2,893	3,473
γ_0	0,7	0,8	0,9	1,0	1,1	1,2	1,3	1,4	1,5	1,6
$\mu_x(\gamma_0)$	4,241	5,261	6,623	8,448	10,90	14,22	18,73	24,89	33,34	44,99
γ_0	1,7	1,8	1,9	2,0						
$\mu_x(\gamma_0)$	61,13	83,64	115,2	159,7						

B.2 Numerical example

A numerical example is given of the calculation of the average value $\overline{X}$ and the standard deviation *S* of the radio disturbance values in the case of an incompletely determined sample. In this example calculation, the sample size is six units of equipment (n = 6). The value of radio disturbance from two units (n_0 = 2) is below the limit of sensitivity of the measuring apparatus ($X < X_L$).

As outlined in the main text, the calculation is performed as follows:

a) The radio disturbance values produced by the six units of equipment of the sample are measured. These are presented in the table below.

Unit of equipment number		1	2	3	4	5	6
The value of radio disturbance	dB	19	23	20	21	$X < X_L$	$X < X_L$

b) The degree of truncation is:

$$\Phi(\gamma_0) = \frac{n_0}{n} = \frac{2}{6} = 0{,}333$$

c) Using the known value of $\Phi(\gamma_0) = 0{,}333$, the value of the normalised point of truncation is determined from the tables of the normal-distribution functions The value is: γ_0 = –0,43

d) From the tables of the probability density function of a normal distribution

$$\varphi(\gamma) = \frac{1}{\sqrt{2\pi}} e^{-\frac{\gamma^2}{2}}$$

$\varphi(\gamma_0) = 0{,}364$ is found.

e) From the formulae (B.3) and (B.4), assessments of the values of the statistical parameters of the truncated distribution of disturbance are made.

$$\bar{X}_y = \frac{1}{n - n_0} \sum_{i=1}^{n-n_0} X_i = 20{,}8 \text{ dB}$$

$$S_y = \left(\frac{1}{n - n_0 - 1} \sum_{i=1}^{n-n_0} \left(X_i - \bar{X}_y \right)^2 \right)^{1/2} = 1{,}7 \text{ dB}$$

f) From the formulae (B.1) and (B.2), assessments of the values of the statistical parameters of the complete distribution of the interference values are made.

$$\bar{X} = \bar{X}_y - \frac{S_y}{\left(\frac{1-\Phi(\gamma_0)}{\varphi(\gamma_0)} \left(\frac{1-\Phi(\gamma_0)}{\varphi(\gamma_0)} + \gamma_0 \right) - 1 \right)^{1/2}}$$

$$\bar{X} = 20{,}8 - \frac{1.7}{\left(\frac{1-0{,}333}{0{,}364} \left(\frac{1-0{,}333}{0{,}364} - 0{,}43 \right) - 1 \right)^{1/2}}$$

$\bar{X}$ = 19,4 dB

$$S = \frac{S_y}{\left(1 + \frac{\varphi(\gamma_0)}{1-\Phi(\gamma_0)} \left(\gamma_0 - \frac{\varphi(\gamma_0)}{1-\Phi(\gamma_0)} \right) + 1 \right)^{1/2}}$$

$$S = \frac{1{,}7}{\left(1 + \frac{0{,}364}{1-0{,}333} \left(-0.43 - \frac{0{,}364}{1-0{,}333} \right) + 1 \right)^{1/2}}$$

S = 2,5 dB

The sample of equipment is then assessed for compliance with the limits as required in the application of non-central *t*-distribution using the formula

$$\bar{X} + kS < L$$

In this particular example, the requirement is 19,4 + 1,42 · 2,5 < L.

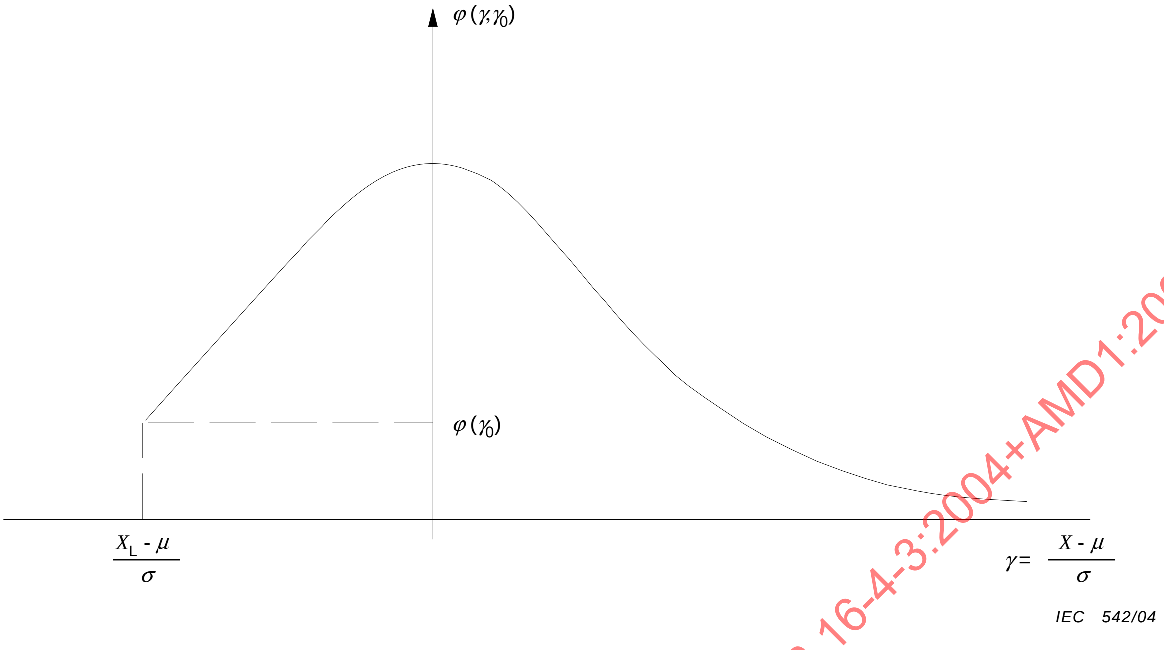


Figure B.1 – The probability density function $\varphi(\gamma;\gamma_0)$

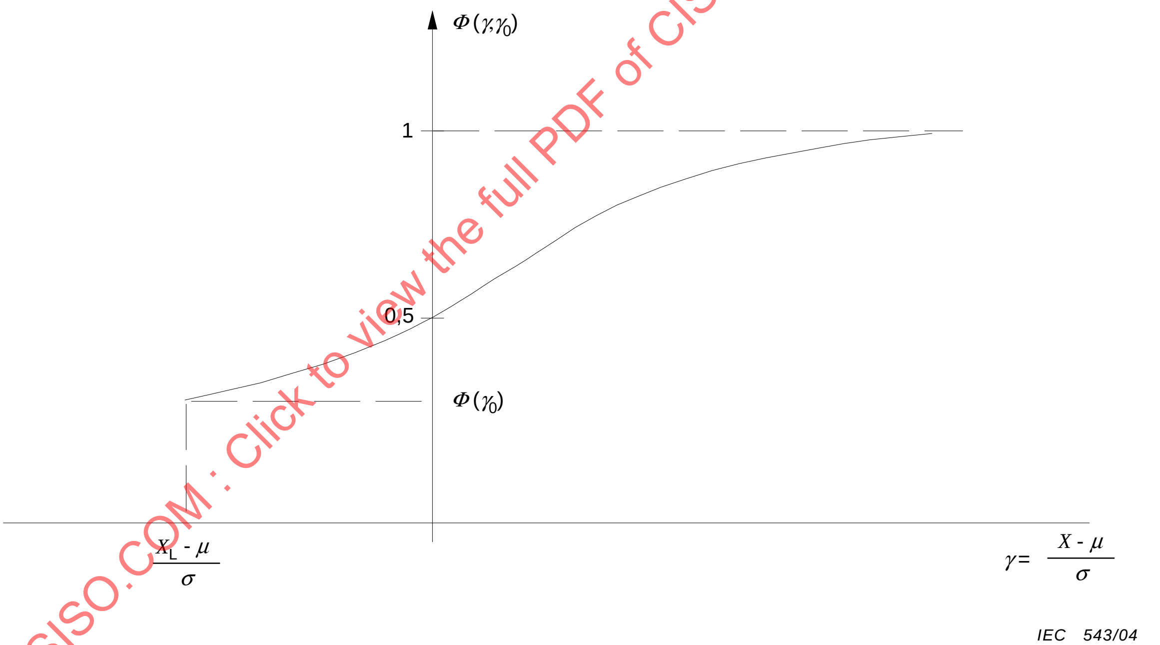


Figure B.2 – The truncated distribution function $\Phi(\gamma;\gamma_0)$

Annex C
(informative)

Test based on an additional acceptance limit

C.1 Mathematical theory of the method

This annex presents the mathematical basis of the test using an additional acceptance limit.

In mass production, control charts are used to identify changes in production, based on the results of samples. The aim of acceptance control charts is to recognize if production has changed to a degree where more than an acceptable percentage of the units are outside the specification. One of these control charts uses the largest value of each sample to reach its acceptance decision [2]. The standard deviation σ of the population (i.e. of the production in its normal state) is assumed as known. In the following, these ideas are adapted to the problem of RFI acceptance testing. Since in this situation the standard deviation σ of the population is not known, the maximum expected value σ_{max} that the standard deviation can reasonably have, is used instead. This is conservative. σ_{max} will depend on the type of product and measurement. In the following it will be shown that even with conservative values for σ_{max} the calculated additional margin will be reasonable for the practical application.

The basic idea of the test is to take a sample of n parts and determine their disturbance emission values $x1$, $x2$, …, xn. The test is passed if all n values are below an **additional acceptance limit** AL. AL is below the interference limit L. The difference between AL and L depends on the sample size n and the standard deviation σ and is calculated from the 80 %/80 % rule.

The 80 %/80 % rule requires, with an 80 % degree of confidence (i.e. α = 0,2), that at least 80 % of the appliances produced are below a specified radio interference limit L. This means that a sample from a population where exactly 80 % of the units are good has to be rejected with 80 % probability. Of course, samples from better populations will be rejected with a lower probability. The supplier will always try to reach a position where far more than 80 % of the units are good to achieve a low probability of rejection. 80 %/80 % is only one point of the operation characteristic of the test.

The following calculation assumes that the disturbance levels of the appliances are normally distributed with the known standard deviation σ. It consists of two parts:

1) What mean value μ^* (relative to L) of the population is required to get an 80 % acceptance rate?

2) What acceptance limit AL (relative to μ^*) will then lead to an 80 % rejection rate?

μ^* can then be eliminated to find out how far AL has to be below L (i.e. μ^* is only used for the calculation and has no further importance).

Figure C.1 shows that 80 % of the population is of acceptable quality if the mean value μ^* is sufficiently below the interference limit L:

With the assumption normalised with a standard deviation σ = 1 if

$$\frac{L-\mu^*}{\sigma} = u_{0,8} = 0{,}8416 = 80\% - \text{quantile of normal distribution}. \qquad \text{(C.1)}$$

where $u_{0,8}$ is the abscissa of the probability density 80 % quantile of the standardized normal distribution. If the limit is $L = 0$, μ^* is changed to –0,8416. As Figure C.1 shows for the probability density $g(x)$ and the cumulative probability distribution $G(x)$ for μ^* = –0,8416, the probability is that 80 % of the population totality is below the limit.

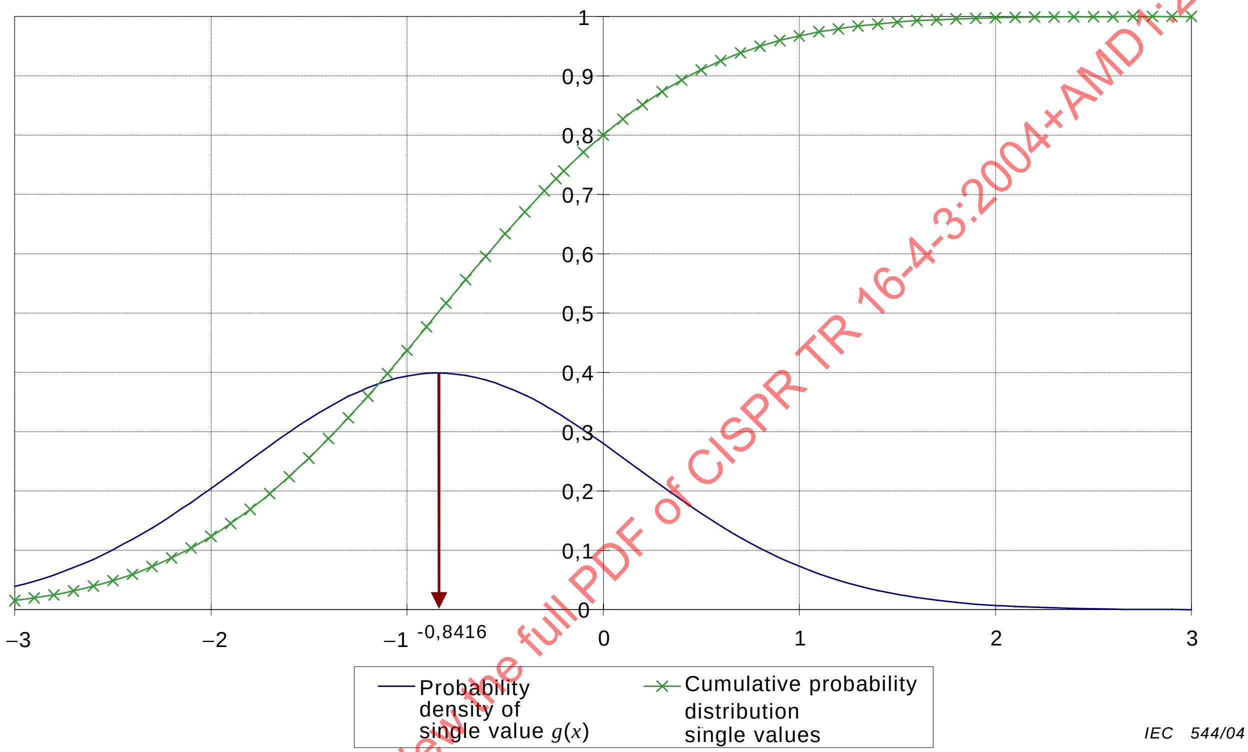


Figure C.1 – Probability density $g(x)$ and probability distribution $G(x)$ for μ = –0,8416 and σ = 1 with 80 % below the limit "0"

From this distribution, a sample of n parts is taken. Since the n values are independent of each other, the probability that all n are below x is $(G(x))^n$. This is the cumulative distribution function for the highest of n values. Figure C.2 shows this cumulative distribution for the example n = 5.

A confidence of 80 % (the second part of the 80 %/80 % rule) requires a test by the acceptance of a sample of the totality with α = 20 %. That means there is a 20 % probability that all measured values $x_1, x_2, x_3, \ldots x_n$ in the sample are below an acceptance limit AL. This gives a confidence of 80 % = 1 – α for rejection if not 80 % of the totality is below the limit. For the confidence to be valid, a rejection probability of 80 % (acceptance probability α = 0,2) is required for samples from a population that only just satisfies the first 80 % condition. This means that the additional acceptance limit AL chosen has to be so low that the probability that all n parts in the sample are below AL is only 20 %:

$$P((x_1 \le AL) \text{ and } (x_2 \le AL) \text{ and } (x_3 \le AL) \text{ and} \ldots (x_n \le AL)) = 0{,}2 = \alpha \qquad \text{(C.2).}$$

Since the individual values are independent of each other and from the same normal distribution, the distribution function with α = 0,2 is described by:

$$G(x_n) = (P(x_i \le AL))^n = 0{,}2 \qquad \text{(C.3)}$$

Under this condition, the following is valid for the probability distribution of the totality:

$$(G(AL))^n = 0{,}2 \qquad (C.4)$$

or

$$\frac{AL - \mu *}{\sigma} = u_{\sqrt[n]{0,2}} = \sqrt[n]{0{,}2} - quantile\ of\ normal\ distribution \qquad (C.5)$$

$$(P(x_1 \leq AL))^n = 0{,}2 \text{ or } P(x_1 \leq AL) = \sqrt[n]{0{,}2} \text{ or } \frac{AL - \mu *}{\sigma} = u_{\sqrt[n]{0,2}} \ . \qquad (C.6)$$

Combining the two equations (C.5) and (C.1) and eliminating μ* with the definition in Equation (C.1) given $\mu * = L - n_{0,8}$ gives

$$AL = L - u_{0,8} \cdot \sigma + u_{\sqrt[n]{0,2}} \cdot \sigma = L - k_E \cdot \sigma \text{ with } k_E = u_{0,8} - u_{\sqrt[n]{0,2}} \qquad (C.7)$$

where u are quantiles of the normal distribution. k_E values are tabulated in Table C.1.

Table C.1 – Values of k_E

Sample size *n*	Values of k_E
1	1,68
2	0,97
3	0,63
4	0,41
5	0,24
6	0,12
7	0,02

- Example

With the recommended value σ_{max} = 6 dB for the measurement of the disturbance voltage the following additional margins to the limit would have to be applied:

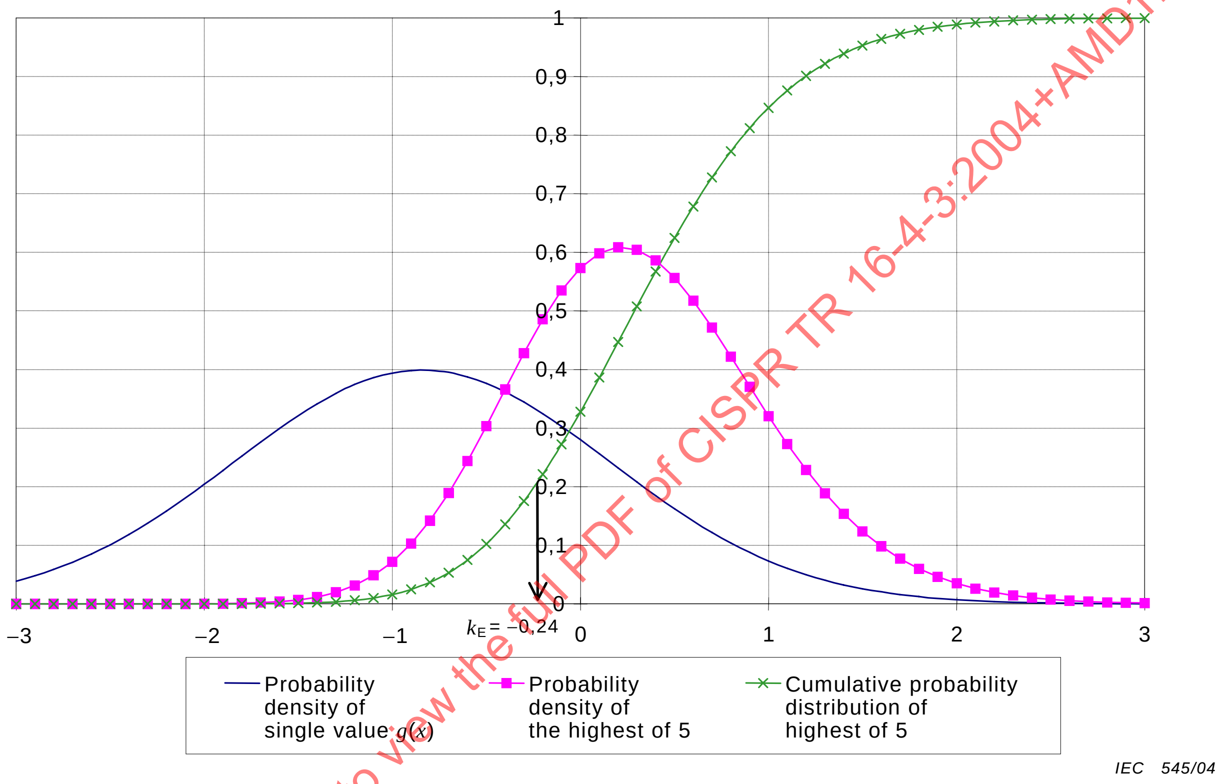
sample size	3	4	5	6
additional margin [dB]	3,8	2,5	1,5	0,7

For demonstration purposes, the probability density e. g. for a sample of 5 pieces has been calculated and the accessory cumulative probability distribution function is drawn.

The cumulative probability distribution function $G(x)$ is calculated by Equation (C.3). The probability density is calculated by using:

$$g(x) = \frac{d}{dx} \cdot G(x) \qquad \text{(C.8)}$$

Figure C.2 shows the determination of the additional acceptance limit AL. The intersection of the cumulative probability distribution for the sample with 5 appliances with α = 0,2 determines the additional acceptance limit AL for the highest expected single value of the sample. This gives a confidence of 80 %.



The cumulative probability distribution function indicates that for p = 0,2, u = –0,24 is valid. That means every value of the 5 pieces is expected to be below u = –0,24 if the parent population meets μ = –0,8416 and σ = 1.

Figure C.2 – Probability density of the highest of 5 pieces

The additional acceptance limit AL or the factor k_E can also be calculated by equation (C.5). The value $u_{0,8}$ = 0,8416 is known and $u_{\sqrt[n]{0,2}} = u_{\sqrt[5]{0,2}} = u_{0,7248} = 0,6$. Then k_E = 0,8416 – 0,6 = 0,24

C.2 Reference documents

[1] JOHNSON, NL. and LEONE, FC. *Statistics and Experimental Design /I*. Wiley and Sons, New York, 1964, p 298 – 348.

[2] WILRICH, P-Th. Qualitätsregelkarten bei vorgegebenen Grenzwerten. *Qualität und Zuverlässigkeit,* Munich-Vienna: Carl Hanser Verlag, 1979, 24 pp. 260-271.

[3] DETER et al. *New method for the statistical evaluation of RFI measurements.* EMC Zurich/2003.