European Radiocommunications Committee (ERC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

MONTE CARLO RADIO SIMULATION METHODOLOGY

Naples, February 2000

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INTRODUCTION

In this report background information on a Monte-Carlo Radio Simulation methodology is given. Apart from giving general information this text also constitutes a specification for the first generation of SEAMCAT software which implements the Monte-Carlo methodology applied to radicommunication scenarios.

1 GENERAL REMARKS

The problem of unwanted emissions, as a serious factor affecting the efficacy of radio spectrum use, is being treated in depth in various fora, internal and external to the CEPT. As the need to reassess the limits for unwanted emissions within RR-Appendix 8 is observed, it is widely recognised that a generic method is preferable for this purpose.

One of numerous reasons why generic methods are favoured is their a priori potential to treat new communication systems and technologies as they emerge. Other reason is that only generic method can aspire to become a basis for a widely recognised analysis tool.

The Monte-Carlo Radio Simulation tool described in this Report was developed, based on above considerations, within the ERC process.

2 SEAMCAT®

SEAMCAT® Radio Tool is the implementation of a Monte-Carlo Radio Simulation tool managed by the group of CEPT Administrations, ETSI members and international scientific bodies. SEAMCAT® is public domain software distributed by the CEPT European Radiocommunications Office, Copenhagen.

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Monte Carlo Radio Compatibility Tool

1. Background

In order to reassess the limits for unwanted emissions within RR - Appendix 8, it is desirable to develop an analytical tool to enable us to evaluate the level of interference which would be experienced by representative receivers. It has been agreed in the TG-1/3 that level of interference should be expressed in terms of the probability that reception capability of the receiver under consideration is impaired by the presence of an interferer. To arrive at this probability of interference, statistical modelling of interference scenarios will be required and this paper describes the methodology and offers a proposal for the tool architecture.

The statistical methodology described here and used for the tool development is best known as Monte-Carlo technique. The term "Monte-Carlo" was adopted by von Neumann and Ulan during World War II, as a codename for the secret work on solving statistical problems related to atomic bomb design. Since that time, the Monte-Carlo method has been used for the simulation of random processes and is based upon the principle of taking samples of random variables from their defined probability density functions. The method may be described as the most powerful and commonly used technique for analysing complex statistical problems.
Monte Carlo approach is seen not to have an alternative in development of a methodology for analysing unwanted emission interference. The approach is:

- generic - A diversity of possible interference scenarios can be handled by single model.
- flexible - The approach is very flexible, and may be easily devised in a such way to handle the composite interference scenarios.

2. Monte-Carlo Simulation Technique: An Overview

The Monte Carlo method can address virtually all radio-interference scenarios. This flexibility is achieved by the way the parameters of the system are defined. The input form of each variable parameter (antenna pattern, radiated power, propagation path,…) is its statistical distribution function. It is therefore possible to model even very complex situations by relatively simple elementary functions. Number of diverse systems can be treated, such as

- broadcasting (terrestrial and satellite)
- mobile (terrestrial and satellite)
- point to point
- point to multipoint
- etc.

The principle is best explained on a following example, which considers only unwanted emissions as the interfering mechanism. In general the Monte Carlo method addresses also other effects present in the radio environment such as out of band emissions, receiver blocking and intermodulation.

2.1 Illustrative example (only unwanted emissions, most influent interferer).

For interference to occur, it has been assumed that the minimum C/I is not satisfied at the receiver input. In order to calculate the C/I experienced by the receiver, it is necessary to establish both the wanted signal and unwanted signal levels. Unwanted emissions considered in this simulation are assumed to result from active transmitters. Moreover, only spurii falling into the receiving bandwidth have been considered to contribute towards interference. For the mobile to fixed interference scenario, an example is shown in figure 2.1.

Many potential mobile transmitters are illustrated. Only some of the transmitters are actively transmitting and still fewer emit unwanted energy in the victim receiver bandwidth. It is assumed that interference occurs as a result of unwanted emissions from the most influent transmitter with the lowest path loss (median propagation loss + additional attenuation variation + variation in transmit power) to the receiver.

An example of Monte-Carlo simulation process as applied to calculating probability of interference due to unwanted emission is given in figure 2.2. For each trial, a random draw of the wanted signal level is made from an appropriate distribution. For a given wanted signal level, the maximum tolerable unwanted level at the receiver input is derived from the receiver's C/I figure.

For the many interferers surrounding the victim, the isolation due to position, propagation loss (including any variations and additional losses) and antenna discrimination is computed. The lowest isolation determines the maximum unwanted level which may be radiated by any of the transmitters during this trial.

From many trials, it is then possible to derive a histogram of the unwanted levels and for a given probability of interference, then to determine the corresponding unwanted level.

By varying the values of the different input parameters to the model and given an appropriate density of interferers, it is possible to analyse a large spectra of interference scenarios.

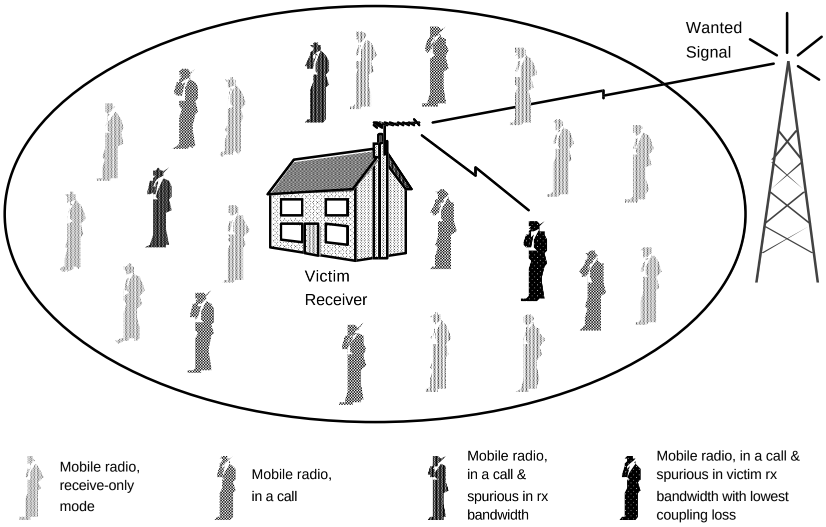


FIGURE 2.1

An example of interference scenario involving TV receiver and portable radios.

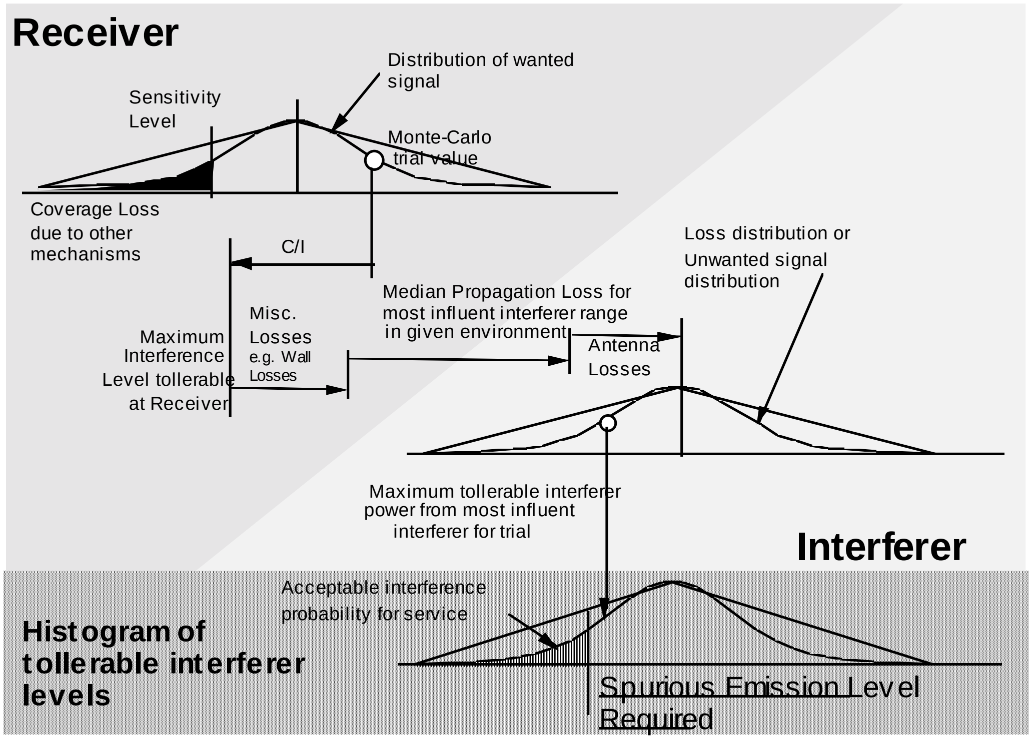


FIGURE 2.2

An example formulation of the Monte-Carlo evaluation process.

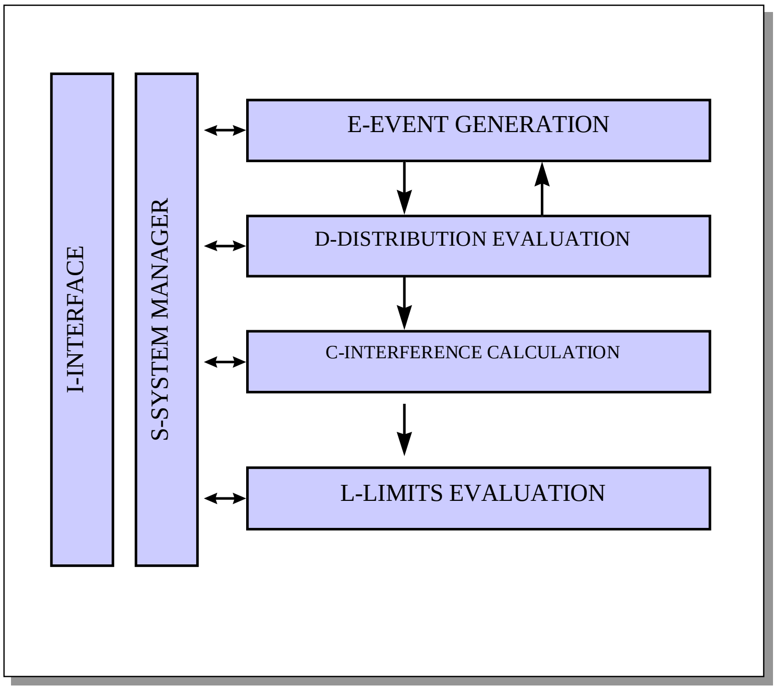
3. Architecture requirements

One of the main requirements is to select such an architectural structure for the simulation tool which would be flexible enough to accommodate analysis of composite interference scenarios in which a mixture of radio equipment sharing the same habitat and/or multiple sources of interference (e.g. out-of-band emission, spurious emission, intermodulation ..) are involved and can be treated concurrently.
Other requirements would be that the proposed architecture lend itself for modular development and is versatile enough to allow treatment of the composite interference scenarios.

The proposed Monte Carlo architecture which meets these constraints is presented in Fig. 3.1. The proposed architecture is basically of a sequential type and consists of four processing engines:

- event generation engine
- distribution evaluation engine
- interference calculation engine
- limits evaluation engine

The schematic view on the entire tool is on Figure 3.1.



The list of interference parameters and their relevance to one or more of the processing engines is shown in Appendix A.

3.1 Event Generation Engine

The event generation engine (EGE) takes the relevant parameters from the submitted interference scenario and generates information on the received signal strength of the desired as well as on the strength for each of the interfering signals included in the composite interference scenario. This process is repeated N times, where N is a number of trials which should be large enough to produce statistically significant results. Generated samples of the desired and all interfering signals are stored in separate data arrays of the length N.

The trials on parameters being common for desired and interfering radio paths are done concurrently in order to capture possible correlation between desired and interfering signals. Such an implementation will not cover only those seldom cases of interference in which one interference mechanism is excited by another interference (e.g. a strong transmitter mixes with spurious emission of the second transmitter and produce an intermodulation type of interference).

The flow chart description and detailed algorithm description for the EGE are presented in the ANNEX B.

List of potential sources of interference to be found in a radio habitat includes:

Transmitter interference phenomena:
- spurious emissions
- wideband Noise
- intermodulation
- adjacent Channel
- co-channel

Receiver interference phenomena:
- spurious radiation

Background noise:
- antenna noise
- man-made noise

Other receiver interference susceptibility parameters:
- blocking
- intermodulation rejection
- adjacent and Co-channel rejections
- spurious response rejection

All of the above sources can be classified into three generic interference mechanism categories: undesired emission, intermodulation and receiver susceptibility. Each of the above three categories requires a different model for physical processes being characteristic for that interfering mechanism. The man-made noise and the antenna temperature noise can be considered as an increase of the thermal noise level, decreasing thus the sensitivity of a receiver, and can be entered in the simulation when the criteria of interference is I/N or C/I+N.

3.2 Distribution Evaluation Engine

The distribution evaluation engine DEE takes arrays of the data generated by the EGE and processes the data with aims of:

- assessing whether or not the number of samples is sufficient to produce statistically stable results
- calculating correlation between the desired signal and interfering signal data and between different types of the interfering signal (e.g. blocking vs. Unwanted emissions)
- calculating a known "continuous" distribution function as the best fit to the RSS random variable.

First and third of the above points can be achieved using well known goodness-of-fit algorithms for general distributions such as the Kolmogorov-Smirnov test. Applicability of the «fit» to this specific task is to be further investigated when the first generation of software is available.

If DEE detect unacceptable variation in discrete distribution parameters estimated in two successive estimations using N and N+ΔN sample size, the EGE is instructed to generate another ΔN of additional samples. This test is repeated until a tolerable variation of the parameters is measured over the pre defined number of successive tests.

Three different kind of outputs are possible from the DEE engine:

- data arrays of the wanted and interfering signals. This is the output in the case that a high degree of correlation is detected between the wanted and any of the interfering signals.
- discrete distributions of the wanted and interfering signals are passed in the case of a weak correlation between the signals or in the case that there was no correlation between the signals but no «continuos» distribution approximation with satisfactory accuracy was possible.
- continuous distribution functions of the wanted and interfering signals are passed to ICE in the case that signals were decorelated and discrete distributions were successfully approximated with continuos distribution functions

The proposed flow chart and detailed algorithm specification is presented in ANNEX C.

3.3 Interference Calculation Engine

The interference calculation engine ICE is the heart of the proposed architecture. Here, information gathered by the EGE and processed by DEE are used to calculate probability of interference. Depending on which kind of information was passed from DEE to ICE three possible modes of calculating the probability of interference are identified, as shown in ANNEX D.

Mode 1: data arrays for dRSS and inRSS passed by DEE to the ICE, and vector representing the composite interfering signal I is calculated as a sum of the inRSS data vectors.

Mode 2: distribution function for the composite interfering signal is calculated by taking random samples for inRSS distributions and linearly adding them up.

Mode 3: The IRSS is calculated using numerical or analytical integration of the supplied distribution functions for each of the interference sources.

Mode 4: All signals are assumed to be mutually independent and the overall probability for interference is identified as the probability to be disturbed by at least one kind of interference.

Different criteria for calculation of interference probability can be accommodated within the processing engine. A cumulative probability functions can be calculated for C/N+I or N/N+I random variables.

The flow of information together with associated processes is shown in form of a flow chart in ANNEX D.

All interfering signal distributions are calculated with respect to reference levels or functions of unwanted (emission mask), blocking (receiver mask) or intermodulation attenuation. Interfering signal distributions for some other reference levels or functions can be derived by first order (unwanted or blocking) or third order (intermodulation) linear translation of the reference distributions (see ANNEX D).

3.4 Limits Evaluation Engine

The Limits Evaluation Engine (LEE) is envisaged to play a very important role in two aspects of the tool development:

- selection of optimal values for the limits
- verification of the tool

Output from the Interference Calculation Engine (ICE) is presented as a multi-dimensional surface characterising the dependance of the probability of interference versus the radio parameters.Two main features of the probability surface are:

- the same probability of interference is achieved by different sets of the limit values for the radio parameters under consideration.
- probability of interference parameter is not used in the radio system design and as such doesn't lend itself nicely for the validation through the system performance measurements. Instead, degradation in system coverage or traffic capacity seems to be more

appropriate to understand impact of a particular probability of interference to the radio system performance.

Flow chart for the LEE is shown in Annex E. The radio variables are transformed from the probabilistic space into a system performance space enabling us to evaluate the system performance degradation due to presence of interference. When the inter-system compatibility is analysed (e.g. unwanted emission) radio coverage and/or traffic capacity can be used to evaluate the impact of the radio parameters limits. For the case of intra-system compatibility study (e.g. out-of-band emission) spectrum efficiency should be used to derive appropriate values for the radio parameters.
The limit values are derived by means of an optimisation algorithm. For optimisation to work a criteria needs to be set. The criteria is usually termed the «cost» function and optimisation process has for a task to minimise this «cost» function. The «cost» function is a function of all radio parameters and their significance to the «cost» can be altered by means of the weight coefficients. The weight coefficients can integrate any of the following aspects into optimisation process:

- system availability
- traffic capacity
- spectrum utilisation
- technological limitations
- economic constraints

The set of radio parameters values for which the «cost» function is minimised represents the optimal solution for the limit values.

The role of LEE is very important within the tool. However, since its various elements are still under consideration and it will not be possible to include LEE into the first phase of the implementation.

ANNEX A

LIST OF PARAMETERS
with suggested links to one or more of the processing engines

1. Parameters for the Wanted Transmitter

Note: Parameters 1.1 to 1.19 are not required if parameters 2.23 and 2.24 are specified

	Parameters	Link with engine(s)	Units	Included in this version of the tool
1.1	Max. power supplied to the antenna	EGE	dBm	yes
1.2	Max power level distribution	EGE	1/dBm	yes
1.3	Power control threshold	EGE	dBm	no
1.4	Power control dynamic range	EGE	dB	no
1.5	Power control step range	EGE	dB	no
1.6	Maximum antenna gain	EGE	dBi	yes
1.7	Antenna pattern within operating bandwidth	EGE	dB (θ,φ)	yes
1.8	Polarisation	ICE		no
1.9	Antenna height	EGE	m	yes
1.10	Antenna height distribution	EGE	1/m	yes
1.11	Frequency	EGE	MHz	yes
1.12	Transmitting mask	ICE	dBm/Hz	yes
1.13	Density	EGE,LEE	/km^2	yes
1.14	Density spatial distribution	DEE,EGE		no
1.15	Movement	ICE	m/s	no
1.16	Probability of transmission	ICE	%	no
1.17	Temporal activity variation with time of the day	ICE	1/h	no
1.18	Duty cycle (TDMA applications & voice activity)	ICE	%	no
1.19	Call length distribution	ICE	1/s	no

2. Parameters for the Receiver (victim)

2.1	Sensitivity	EGE,ICE	dBm	yes
2.2	Sensitivity distribution	ICE	1/dBm	yes
2.3	Protection ratio	ICE	dB	yes
2.4	Maximum antenna gain	EGE	dBi	yes
2.5	Antenna pattern within operating bandwidth	EGE	dB	yes
2.6	Polarisation	ICE		no
2.7	Antenna height	EGE	m	yes
2.8	Antenna height distribution	EGE	1/m	yes
2.9	Noise floor	ICE	dBm	yes
2.10	Tolerable level of interference	LEE	%	no
2.11	Receiver frequency response	EGE	dB (Δf)	yes
2.12	Receiver intermodulation response	EGE	dB(Δf)	yes
2.13	Frequency	EGE,ICE	MHz	yes
2.14	Bandwidth	ICE	kHz	yes
2.15	Density	LEE	/km^2	no
2.16	Spatial density distribution	LEE		no
2.17	Movement	ICE	m/s	no
2.18	Probability of being in receiving mode	LEE	%	no
2.19	Temporal variation	ICE	1/h	no
2.20	Duty cycle	ICE	%	no
2.21	Call length distribution	LEE	s	no

2.22	Distribution of Rx channel	LEE	1/MHz	no
2.23	Fast fading distribution	ICE	1/dB	no
2.24	Wanted signal strength	DEE	dBm	yes
2.25	Wanted signal strength distribution	DEE	1/dBm	yes

3. Parameters for the interfering transmitter

3.1	Power supplied to the antenna	EGE	dBm	yes
3.2	Power level distribution	EGE	1/dBm	yes
3.3	Power control threshold	EGE	dBm	yes
3.4	Power control dynamic range	EGE	dB	yes
3.5	Power control step range	EGE	dB	yes
3.6	Maximum antenna gain	EGE	dBi	yes
3.7	Antenna pattern function of frequency	EGE	dB	yes
3.8	Polarisation	ICE		no
3.9	Antenna height	EGE	m	yes
3.10	Antenna height distribution	EGE	1/m	yes
3.11	Frequency	ICE	MHz	yes
3.12	Transmitting mask	ICE	dBm/Hz	yes
3.13	Density	EGE	$/km^2$	yes
3.14	Spatial density distribution	LEE		no
3.15	Movement	LEE	m/s	no
3.16	Probability of transmission	EGE	%	yes
3.17	Temporal activity variation with time f the day	EGE	1/h	yes
3.18	Duty cycle (TDMA applications & voice activity)	EGE	%	no
3.19	Call length distribution	LEE	s	no
3.20	Distribution of fixed discrete emissions	ICE	1/ HzdBm	yes
3.21	Distribution of discrete emissions which are dependent on carrier frequency	ICE	1/ HzdBm	yes
3.22	Distribution of wide-band noise relative to carrier	ICE	1/ HzdBm	yes
3.23	Manufacturing tolerance modelling	LEE	1/dB	no

4. Environmental and Propagation Parameters

4.1	Environment	EGE		yes
4.2	Slow fading distribution	EGE	1/dB	yes
4.3	Clutter losses	EGE	dB	yes
4.4	Path loss	EGE	dB	yes

1.1 Power supplied to the antenna

Transmitting power supplied to the antenna at the transmitter frequency in the transmitter bandwidth.

1.2 Power level distribution

1.3 Power control threshold

Power (supplied to the antenna) under which no power control can be applied

1.4 Power control dynamic range

Range upon which of the power control applies

1.5 Power control step range
Step size of the power control

1.6 Maximum antenna gain
Antenna gain in direction of the highest directivity

1.7 Antenna pattern within operating bandwidth
Antenna gain dependence as a function of the spherical coordinate angles for frequencies falling in the operating bandwidth.

1.8 Polarisation
Orientation of the electric field component in the transversal cross-section of a electromagnetic wave.

1.9 Antenna height
Antenna height above ground level.

1.10 Antenna height distribution
Statistical description of the variations in antenna height

1.11 Frequencies used within transmission band for trnasmission of the wanted signal

1.12 Transmitting mask
Power spectral mask of the transmitter

1.13 Density
Number of transmitting units per unit of geographical area

1.14 Density spatial distribution
Statistical description of the transmitter density variation over geographical area of interest.

1.15 Movement
Information on the changes in the transmitter position over a specified time interval.

1.16 Temporal utilisation distribution (probability of transmission)
Statistical description of the transmitter activities averaged over large number of users and long period of time.

1.17 Temporal activity variation with time of the day
Statistical description of the transmitter activities with time of the day

1.18 Duty cycle (for TDMA applications & voice activity)
Time compression factor in the transmission activity.

1.19 Call length distribution
Statistical description of variations in the call duration.

2.1 Sensitivity

Minimum signal strength at the receiver input needed to detect desired signal with required quality under specified conditions.

2.2 Sensitivity distribution
Statistical description of variations in the receiver minimum usable sensitivity.

2.3 Protection ratio
Signal to noise plus interference at the receiver input needed to detect desired signal with required quality under specified conditions.

2.4 Maximum antenna gain
see 1.6

2.5 Antenna pattern within the operating bandwidth
see 1.7

2.6 Polarisation
see 1.8

2.7 Antenna height
see 1.9

2.8 Antenna height distribution
see 1.10

2.9 Noise floor
Thermal noise power captured by the receiver bandwidth

2.10 Acceptable level of interference
Percentage of time and locations service coverage allowed to be lost due to interference

2.11 Receiver frequency response
Receiver susceptibility characteristic expressed as a ratio between desired and interfering signal levels producing unacceptable receiver performance and given as a function of frequency separation between the two signals.

2.12 Receiver intermodulation response
The intermodulation response is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of two unwanted signals with a specific frequency relationship to the wanted signal frequency.

2.15 Density
see 1.13

2.16 Spatial density distribution
see 1.14

2.17 Movement

see 1.15

2.18 Temporal utilisation description (Probability of being in receiving mode)
Statistical description of the receiver activities averaged over large number of users and long period of time.

2.19 Temporal activity variation with time of the day
see 1.17

2.20 Duty cycle
see 1.18

2.21 Call length distribution
see 1.19

2.22 Distribution of receiving channel within allocated bandwidth
Statistical description on variation in the receiving channel assignment within allocated spectrum

2.23 Fast fading distribution
Statistical description on fast changes in received signal envelope.

2.24 Wanted signal power at the the victim

2.25 Statistical description of the wanted signal power at the victim receiver

3.1 - 3.10 : see 1.1 - 1.10

3.11 Frequencies carrying interfering power which falls into the victim receiver band

3.12 Transmitting mask
Transmitter spectral power mask

3.13 Density
Number of transmitting units per unit of geographical area

3.14 Spatial density distribution
see 1.14

3.15 Movement
see 1.15

3.16 Temporal utilisation distribution (probability of transmission)
see 1.16

3.17 Temporal activity variation with time of the day
see 1.17

3.18 Duty cycle (for TDMA applications & voice activity)
see 1.18

3.19 Call length distribution
see 1.19

3.20 Distribution of fixed discrete emissions
Statistical description of spectral density of discrete emissions which are independent of carrier frequency.

3.21 Distribution of discrete emissions dependant on carrier frequency
Statistical description of spectral density of discrete emissions which are independent of carrier frequency.

3.22 Distribution of wide-band noise relative to carrier
Statistical description of spectral power density given relative to the carrier frequency

3.23 Manufacturing tolerance modelling
Statistical description of variation in difference between the specified limit level and the emission levels.

4.1 Environment
The type of environment, e.g. urban, suburban or rural case

4.2 Slow fading distribution
Statistical description of the slow variations in a signal envelope.

4.3 Clutter loss
Additional attenuation due to indoor propagation

4.4 Path loss
Mathematical description of the propagation loss between transmitter and receiving ends.

ANNEX B
Event Generation Engine

Introduction

In this annex we describe how to construct signals that are used in the interfering scenarios: the desired signal and the interfering signals due to unwanted emission, blocking and intermodulation. The calculated signals are the stored in an array which serves as input to the DEE as shown in Figure B.1.

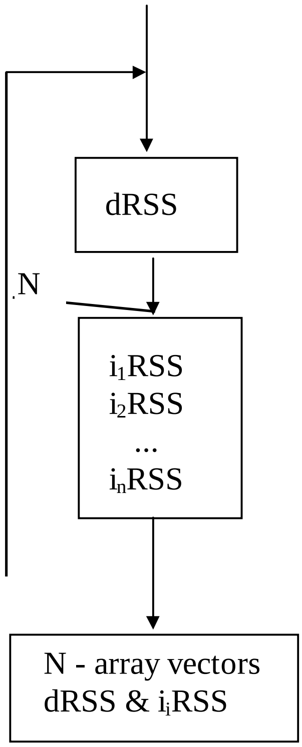


Fig. B.1. General flowchart of the EGE

Inputs:

The input parameters are defined in Annex A.
They have been defined using the following rules:L
- a capital letter is used for a distribution function,
- a small letter is a variable (result of a calculation or a trial),
- the index refers to a "player": wanted transmitter, victim receiver, wanted receiver and interfering transmitter. The different players are shown in Figure B.2:

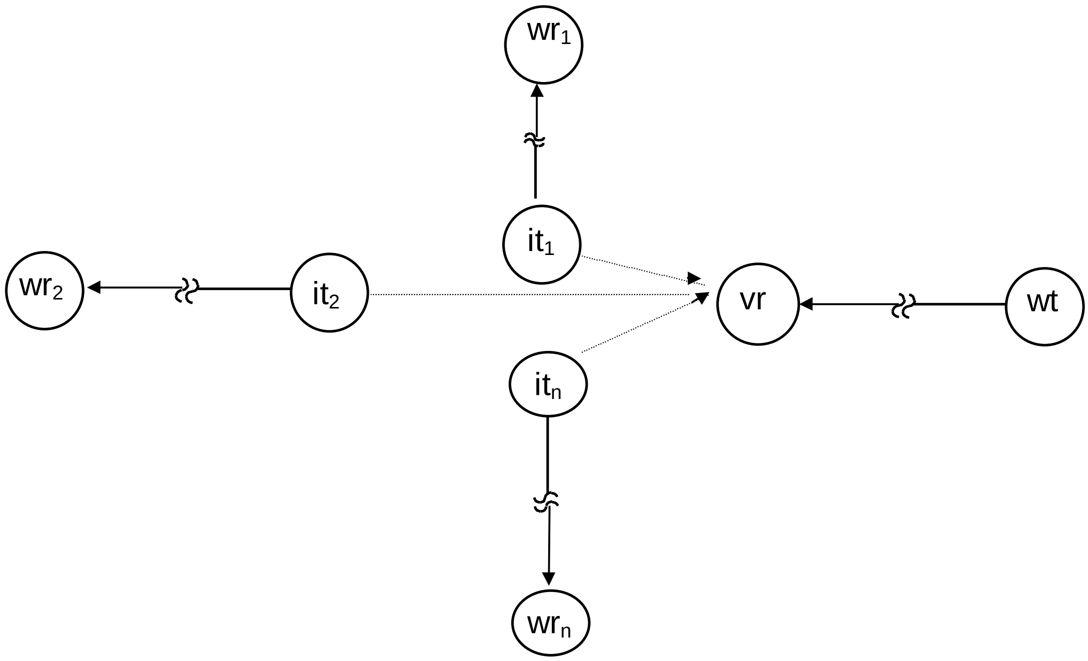


Figure B.2. Different players participating in the EGE.

<u>Parameters for the wanted transmitter:</u>

$P_{wt}^{supplied}$ = maximum power level distribution
g_{wt}^{max} = maximum antenna gain
$pattern_{wt}$ = normalised antenna pattern within operating bandwidth (supplied as a function or a look-up table)
H_{wt} = antenna height distribution
R_{wt}^{max} = radius of the wanted transmitter coverage

<u>Parameters for the victim receiver:</u>

C/I = protection ratio
g_{vr}^{max} = maximum antenna gain
$pattern_{vr}$ = normalised antenna pattern within operating bandwidth (supplied as a function or a look-up table)
H_{vr} = antenna height distribution
$block$ = receiver frequency response
$intermod$ = receiver intermodulation response
f_{vr} = frequency
a_{vr} = attenuation of victim receiver
$sens_{vr}$ = sensitivity of victim receiver
$dRSS_{max}$ = maximum received signal at the receiver input

b = bandwidth of victim receiver

Parameters for the interfering transmitter:

$P_{it}^{supplied}$ = maximum power level distribution
$pc_{it}^{t\_hold}$ = power control threshold
$pc_{it}^{dyc\_rg}$ = power control dynamic range
$pc_{it}^{st\_rg}$ = power control step range
g_{it}^{max} = maximum antenna gain
R_{it}^{max} = radius of the interfering transmitter coverage
R_{simu} = radius of the area where interferers are spread
$pattern_{it}$ = normalised antenna pattern function of frequency
(supplied as a function or a look-up table)
H_{it} = antenna height distribution
$spur$ = unwanted emissions
$spur_0$ = unwanted emissions floor (unwanted emissions which would be emitted with the lowest possible power of the transmitter)
f_{it} = frequency
$dens_{it}$ = density
p_{it}^{tx} = probability of transmission
$temp_{it}$ = normalised temporal activity variation function of time of the day

Parameters for the wanted receiver of the interfering system:

g_{wr}^{max} = maximum antenna gain
$pattern_{wr}$ = normalised antenna pattern within operating bandwidth
(supplied as a function or a look-up table)
H_{wr} = antenna height distribution
$sens_{wr}$ = dynamic sensitivity of wanted receiver, taking into account margin for fast-fading and intra-system interference.

Environmental and Propagation Parameters:

f_{propag} = propagation law (median loss + variation) (given in annex B.a)
f_{median} = propagation law (median loss only) (given in annex B.a)

env = environment type (indoor/outdoor, urban/suburban/open area) additional information on environment type are necessary for indoor/indoor and indoor/outdoor propagation models and are described in details in annex B.a.

Outputs:

dRSS = desired Received Signal Strength (in dBm)
$iRSS_{spur}$ = interfering Received Signal Strength due to unwanted emissions (in dBm)
$iRSS_{block}$ = interfering Received Signal Strength due to blocking (in dBm)
$iRSS_{intermod}$ = interfering Received Signal Strength due to intermodulation (in dBm)

Calculation:

In this section,
- T represents a trial from a given distribution (algorithm described in annex B.d).
- Distributions $U(0,1)$, $G(\sigma)$ and $R(\sigma)$ are defined in annex B.c.
- Flow charts of dRSS and iRSS calculation are given respectively in annexes B.e, B.f and B.h.

a) <u>*dRSS* calculation</u>:

Case of variable distance:

$$dRSS = f(p_{wt}^{\text{supplied}}, g_{wt->vr}, pl_{wt\leftrightarrow vr}, g_{vr->wt}) = p_{wt}^{\text{supplied}} + g_{wt\rightarrow vr}(f_{vr}) - pl_{wt\leftrightarrow vr}(f_{vr}) + g_{vr\rightarrow wt}(f_{vr})$$

if the received signal can not exceed a given value (i.e. if depending on the power control implemented in the victim system) :

$$dRSS = \min(dRSS, dRSS_{\max})$$ using *dRSS* as calculated before

where

- $p_{wt}^{supplied}$ = maximum power supplied to the wanted transmitter antenna
  $p_{wt}^{supplied} = T(P_{wt}^{supplied})$

$pl_{wt\leftrightarrow vr}$ = path loss between the wanted transmitter and the victim receiver (propagation loss, slow fading and clutter losses taken into account). Depending on whether the criteria of interference will apply to the instantaneous dRSS (rayleigh fading excluded) or to the mean dRSS :

$$pl_{wt\leftrightarrow vr} = f_{propag}(f_{vr}, h_{vr}, h_{wt}, d_{wt\leftrightarrow vr}, env)$$

or

$$pl_{wt\leftrightarrow vr} = f_{median}(f_{vr}, h_{vr}, h_{wt}, d_{wt\leftrightarrow vr}, env)$$

where

h_{vr} = victim receiver antenna height

$h_{vr} = T(H_{vr})$

e. g. $h_{vr} = T(U(h_{vr}^{min}, h_{vr}^{max})) = h_{vr}^{min} + (h_{vr}^{max} - h_{vr}^{min}) \times T(U(0,1))$

h_{wt} = wanted transmitter antenna height

$h_{wt} = T(H_{wt})$

e. g. $h_{wt} = T(U(h_{wt}^{min}, h_{wt}^{max})) = h_{wt}^{min} + (h_{wt}^{max} - h_{wt}^{min}) \times T(U(0,1))$

$d_{wt\leftrightarrow vr}$ = distance between the victim receiver and the wanted transmitter.

$d_{wt\leftrightarrow vr} = T\left(R_{\max}^{wt}\right)$ (e.g. $d_{wt\leftrightarrow vr} = R_{\max}^{wt}\sqrt{T(U(0,1))}$)

Three different choices for R_{max}^{wt} are considered:

1) Given distance R_{max}^{wt}

2) Noise limited network

R_{max}^{wt} is determined by the following equation :

$f_{median}\left(f_{vr}, h_{wt}, h_{vr}, R_{\max}^{wt}, env\right) + f_{slowfading}(X\%) = P_{wt}^{supplied} + g_{wt}^{\max} + g_{vr}^{\max} - sens_{vr}$

f_{median} = propagation loss not including slow fading

$f_{slowfading}(X\%)$ = fading margin to be used for 1-X% coverage loss

In the case of lognormal fading and a 95% coverage loss at the edge of the coverage, for large distances, the value $f_{slowfading}$ is the well known 1.64 times the standard deviation of the propagation loss.

3) Traffic limited network

$$R_{max}^{wt} = \sqrt{\frac{n_{channels} \times n_{userperchannel}}{\pi \times dens_{max} \times cluster_{frequency}}}$$

- $g_{wt\rightarrow vr}$ = wanted transmitter antenna gain in the victim receiver direction.

$g_{wt\rightarrow vr} = f(g_{wt}^{\max}, pattern_{wt}) = g_{wt}^{\max} \times pattern_{wt}(\theta_{wt\rightarrow vr}, \varphi_{wt\rightarrow vr}, f_{vr})$

where

$(\theta_{wt\rightarrow vr}, \varphi_{wt\rightarrow vr})$ = azimuth and elevation angles between the top of the wanted transmitter antenna and the top of the victim receiver antenna

e.g. :

$\theta_{wt\rightarrow vr} = T(U(0, 2\pi)) = 2\pi \times T(U(0,1))$

$$\varphi_{wt\rightarrow vr} = T\left(U\left(-\frac{\pi}{2}, \frac{\pi}{2}\right)\right) = \pi \times T(U(0,1)) - \frac{\pi}{2}$$

- $g_{vr \to wt}$ = victim receiver antenna gain in the wanted transmitter direction.

  $g_{vr\to wt} = f\left(g_{vr}^{\max}, pattern_{vr}\right) = g_{vr}^{\max} \times pattern_{vr}\left(\theta_{wt\to vr}+\pi, -\varphi_{wt\to vr}, f_{vr}\right)$

Case of fixed distances:

$P_{wt}^{nominal}$ = nominal power distribution

$f_{fading\ ,\ fixed\ link}$ = fading distribution

$$dRSS = f(P_{\mathrm{wt}}^{\mathrm{nominal}}, f_{\mathrm{fading,\ fixed\ link}}) = T(P_{\mathrm{wt}}^{\mathrm{nominal}}) - T(f_{\mathrm{fading,\ fixed\ link}})$$

Case of given dRSS: distribution to be given by the user.

b) $iRSS_{block}$ calculation:

$$iRSS_{block} = \sum_{i=1}^{n_{\text{interferers}}} f\left(P_{it}^{\sup plied}, g_{it}^{PC}, g_{it\to vr}, pl_{it\leftrightarrow vr}, a_{vr}, g_{vr\to it}\right)_i$$

$$= 10\log \sum_{i=1}^{n_{\text{interferers}}} 10^{i_{block_i}/10}$$

where the i-th interferer signal is given by

$$i_{block_i} \equiv \left(P_{it}^{\sup plied} + g_{it}^{PC} + g_{it\to vr}\left(f_{it}\right) - pl_{it\leftrightarrow vr} - a_{vr} + g_{vr\to it}\left(f_{it}\right)\right)_i$$

where for each interferer:

- f_{it} = interferer transmitting frequency

  $f_{it} = T(f_{it})$

- $p_{it}^{\mathrm{supplied}}$ = maximum power supplied to the interfering transmitter antenna (before power control)

  $p_{it}^{supplied} = T(P_{it}^{supplied})$

- g_{it}^{PC} = power control gain for the interfering transmitter

  $g_{it}^{pc} = f_{pc}\left(p_{it}^{\sup plied}, g_{it\to wr}, pl_{it\leftrightarrow wr}, g_{wr\to it}, pc_{it}^{t\_hold}, pc_{it}^{dyc\_rg}, pc_{it}^{st\_rg}\right)$

  where

  f_{pc} = power control function (given in annex B.b)

  $pl_{it\leftrightarrow wr}$ = path loss between the interfering transmitter and the wanted receiver (propagation loss, slow fading and clutter losses taken into account).

Depending on the power control implementation, this can be either mean path loss or instantaneous path loss (rayleigh fading excluded)

$$pl_{it \leftrightarrow wr} = f_{propag}\left(f_{it}, h_{wr}, h_{it}, d_{it \leftrightarrow wr}, env\right) + f_{clutter}(env)$$

or

$$pl_{it \leftrightarrow wr} = f_{mean}\left(f_{it}, h_{wr}, h_{it}, d_{it \leftrightarrow wr}, env\right) + f_{clutter}(env)$$

where

h_{wr} = antenna height of wanted receiver

$h_{wr} = T(h_{wr})$

e. g. $h_{wr} = T\left(U\left(h_{wr}^{\min}, h_{wr}^{\max}\right)\right) = h_{wr}^{\min} + \left(h_{wr}^{\max} - h_{wr}^{\min}\right) \times T\left(U(0,1)\right)$

h_{it} = interfering transmitter antenna height

$h_{it} = T(H_{it})$

e. g. $h_{it} = T(U(h_{it}^{min}, h_{it}^{max})) = h_{it}^{min} + (h_{it}^{max} - h_{it}^{min}) \times T(U(0,1))$

$d_{it \leftrightarrow wr}$ = distance between the interfering transmitter and the wanted receiver

$d_{it \leftrightarrow wr} = T\left(R_{\max}^{it}\right)$ (e.g: $d_{it \leftrightarrow wr} = R_{\max}^{it} \sqrt{T\left(U(0,1)\right)}$)

Three different choices for R_{max}^{it} are considered:

1) Given distance R_{max}^{it}

2) Noise limited network

R_{max}^{it} is determined by the following equation :

$$f_{median}\left(f_{vr}, h_{vr}, h_{it}, R_{\max}^{it}, env\right) + f_{slowfading}(X\%) = P_{it}^{supplied} + g_{it}^{\max} + g_{vr}^{\max} - sens_{vr}^{\max}$$

f_{median} = propagation loss not including slow fading

$f_{slowfading}(X\%)$ = fading margin to be used for 1-*X*% coverage loss

In the case of lognormal fading and a 95% coverage loss at the edge of the coverage, for large distances, the value is the well known 1.64 times the standard deviation of the propagation loss.

3) Traffic limited network

$$R_{max}^{it} = \sqrt{\frac{n_{channels} \times n_{usersperchannel}}{\pi \times dens_{max} \times cluster_{frequency}}}$$

$g_{it \rightarrow wr}$ = interfering transmitter antenna gain in the direction of the closest base station.

$$g_{it \rightarrow wr} = f\left(g_{it}^{\max}, pattern_{it}\right) = g_{it}^{\max} \times pattern_{it}\left(\theta_{it \rightarrow wr}, \varphi_{it \rightarrow wr}, f_{it}\right)$$

where

$\left(\theta_{it\to wr}, \varphi_{it\to wr}\right)$ = azimuth and elevation angles between the top of the interfering transmitter antenna and the top of the wanted receiver antenna.

e.g.

$$\theta_{it\to wr} = T\left(U\left(0,2\pi\right)\right) = 2\pi \times T\left(U\left(0,1\right)\right)$$

$$\varphi_{it\to wr} = T\left(U\left(-\frac{\pi}{2},\frac{\pi}{2}\right)\right) = \pi \times T\left(U\left(0,1\right)\right) - \frac{\pi}{2}$$

$g_{wr\to it}$ = base station antenna gain in the interfering transmitter direction

$$g_{wr\to it} = f\left(g_{wr}^{\max}, pattern_{wr}\right) = g_{wr}^{\max} \times pattern_{wr}\left(\theta_{it\to wr} + \pi, -\varphi_{it\to wr}, f_{it}\right)$$

- $pl_{it\leftrightarrow vr}$ = path loss between the interfering transmitter i and the victim receiver (propagation loss, slow fading and clutter losses taken into account)

$pl_{it\leftrightarrow vr} = f_{propag}\left(f_{it}, h_{vr}, h_{it}, d_{it\leftrightarrow vr}, env\right) + f_{clutter}\left(env\right)$ or

$$pl_{it\leftrightarrow vr} = f_{mean}\left(f_{it}, h_{vr}, h_{it}, d_{it\leftrightarrow vr}, env\right) + f_{clutter}\left(env\right)$$

The choice between f_{mean} and f_{propag} would depend on the criteria of interference, and is closely related to the choice made for assessment of dRSS, e.g. whether ICE will evaluate :

$$\frac{dRSS_{mean}}{iRSS_{mean}};\frac{dRSS_{propag}}{iRSS_{propag}};\frac{dRSS_{mean}}{iRSS_{propag}}\ldots$$

where

h_{vr} = victim receiver antenna height (defined in the dRSS calculation)

h_{it} = interfering transmitter antenna height (defined previously)

$d_{it\leftrightarrow vr}$ = distance between the victim receiver and the interfering transmitter

Two different ways to choose $d_{it\leftrightarrow vr}$:

1) The most common case is when there is no spatial correlation between the elements of the victim system and the elements of the interfering system.

Then $d_{it\leftrightarrow vr}$ is a result of a trial:

$$d_{it\leftrightarrow vr} = R_{simu}\sqrt{T\left(U\left(0,1\right)\right)}$$

R_{simu} = radius of the area where interferers are spread

$$R_{simu} = \sqrt{\frac{n^{active}}{\pi \times dens_{it}^{active}}}$$

where

n^{active} = number of active interferers considered in the simulation. n^{active} should be sufficiently large so that the n+1 interferer would bring a negligible additional interfering power.

$$dens_{it}^{active} = dens_{it} \times p_{it}^{tx} \times temp_{it}(time)$$

2) This case deals with the situation where the victim system and the interfering system are geographically correlated (e.g. co-located base stations).

This correlation is assumed to be only between one element (victim or wanted transmitter) of the victim system and one element (interferer or wanted receiver) of the interfering system.

A trial (if the distance is not fixed) of the distances and angles between the two correlated elements is made (e.g. $d_{wr\leftrightarrow vr}, \theta_{wr\leftrightarrow vr}$). The knowledge of $d_{it\leftrightarrow wr}, d_{vr\leftrightarrow wt}, \theta_{it\leftrightarrow wr}, \theta_{vr\leftrightarrow wt}$ enables to derive the missing coordinates (e.g. $d_{it\leftrightarrow vr}, \theta_{it\leftrightarrow vr}$)

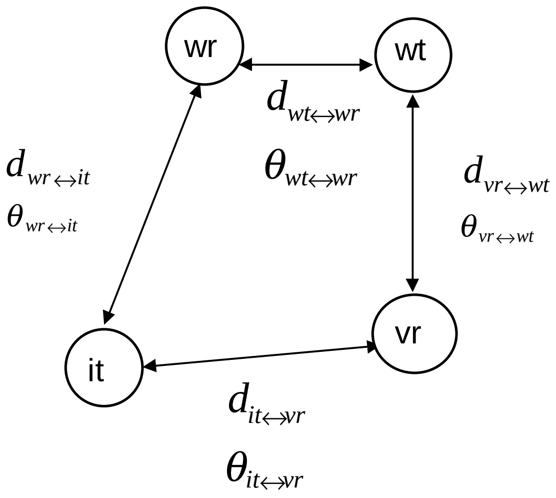


Fig. B.3. Interfering scenario with a geographical correlation between the victim and the interfering systems

- $g_{it\to vr}(f_{it})$ = interfering transmitter antenna gain in the victim receiver direction.

$$g_{it\to vr}(f_{it}) = (g_{it}^{\max}, pattern_{it}) = g_{it}^{\max} \times pattern_{it}(\theta_{it\to vr}, \varphi_{it\to vr}, f_{it})$$

where

$(\theta_{it\rightarrow vr}, \varphi_{it\rightarrow vr})$ = azimuth and elevation angles between the top of the closest interfering transmitter antenna and the top of the victim receiver antenna

e.g.

$$\theta_{it\rightarrow vr} = T(U(0,2\pi)) = 2\pi \times T(U(0,1))$$

$$\varphi_{it\rightarrow vr} = T\left(U\left(-\frac{\pi}{2},\frac{\pi}{2}\right)\right) = \pi \times T(U(0,1)) - \frac{\pi}{2}$$

- $a_{vr}(f_{it}, f_{vr})$ = attenuation of the victim receiver

Three possible ways are considered for calculating this attenuation:

1) a_{vr} is given by the user

2) blocking is given in terms of blocking attenuation or protection ratio. For a wanted signal 3 dB above the sensitivity, the attenuation a_{vr} can be derived from the following equation (see annex B.g) :

$$a_{vr} = f\left(\frac{C}{N+I}, block_{att}\right) = 3 + \frac{C}{N+I} + block_{att}(f_{it}, f_{vr})$$

3) blocking is given in terms of absolute level of blocking.

$$a_{vr} = f\left(\frac{C}{N+I}, block_{abs}\right) = \frac{C}{N+I} + block_{abs}(f_{it}, f_{vr}) - sens_{vr}$$

Two cases are envisaged:

1) *block* is a mask which is a function of $\Delta_f = (f_{it} - f_{vr})$. It is introduced to enable calculations of interference between systems in adjacent band.

2) *block* is a fixed value (e.g. 80 dBm). It is used to derive generic limits.

- $g_{vr\rightarrow it}(f_{it})$ = victim receiver antenna gain in the interfering transmitter direction

$$g_{vr\rightarrow it}(f_{it}) = f\left(g_{vr}^{\max}, pattern_{vr}\right) = g_{vr}^{\max} \times pattern_{vr}\left(\theta_{it\rightarrow vr} + \pi, -\varphi_{it\rightarrow vr}, f_{it}\right)$$

c) <u>$iRSS_{spur}$ calculation:</u>

$$IRSS_{spur} = f\left(spur, g_{it}^{pc}, g_{it\rightarrow vr}, pl_{it\leftrightarrow vr}, g_{vr\rightarrow it}\right)$$

$$= 10\log \sum_{i=1}^{n_{\text{interferers}}} 10^{i_{spur_i}/10}$$

where the i-th interferer signal is defined as

$$i_{spur_i} \equiv \left(spur(f_{it}, f_{vr}) + g_{it\rightarrow vr}(f_{vr}) - pl_{it\leftrightarrow vr}(f_{vr}) + g_{vr\rightarrow it}(f_{vr})\right)_i$$

- f_{it} = interferer transmitting frequency (defined in section b)

- $spur(f_{it}, f_{vr}, g_{pc})$ = unwanted emission by the interfering transmitter

  Two cases are envisaged :

  1) *spur* is a mask which is a function of $\Delta_f = (f_{it} - f_{vr})$. It is introduced to enable calculations of interference between systems in adjacent band.
  2) *spur* is a fixed value (e.g. -36 dBm). It is used to derive generic limits.

$spur(f_{it}, f_{vr}, g_{pc})$ generally depends on the effect of the power control. Either :

$$spur(f_{it}, f_{vr}, g_{pc}) = \max(spur_0(f_{it}, f_{vr}), spur(f_{it}, f_{vr}) - g_{pc})$$

or

$spur(f_{it}, f_{vr}, g_{pc})$ is defined as a function of $\Delta_f = (f_{it} - f_{vr})$ for each possible steps of the power control.

- g_{it}^{PC} = power control gain for the interfering transmitter (defined in section b)

- $pl_{it \leftrightarrow vr}$ = path loss between the interfering transmitter and the victim receiver (propagation loss, slow fading and clutter losses taken into account)

$$pl_{it \leftrightarrow vr} = f_{propag}(f_{vr}, h_{vr}, h_{it}, d_{it \leftrightarrow vr}, env) + f_{clutter}(env)$$

where

h_{vr} = victim receiver antenna height (defined in dRSS calculation)

h_{it} = interfering transmitter antenna height (defined in section b)

$d_{it \leftrightarrow vr}$ = distance between the victim receiver and the interfering transmitter (defined in section b)

- $g_{it \to vr}(f_{vr})$ = interfering transmitter antenna gain in the victim receiver direction.

$$g_{it \to vr}(f_{vr}) = (g_{it}^{\max}, pattern_{it}) = g_{it}^{\max} \times pattern_{it}(\theta_{it \to vr}, \varphi_{it \to vr}, f_{vr})$$

where

$(\theta_{it \to vr}, \varphi_{it \to vr})$ = azimuth and elevation angles between the top of the closest interfering transmitter antenna and the top of the victim receiver antenna (defined in section b)

- $g_{vr \to it}(f_{vr})$ = victim receiver antenna gain in the interfering transmitter direction

$$g_{vr \to it}(f_{vr}) = f(g_{vr}^{\max}, pattern_{vr}) = g_{vr}^{\max} \times pattern_{vr}(\theta_{it \to vr} + \pi, -\varphi_{it \to vr}, f_{it})$$

d) $iRSS_{intermod}$ calculation:

$$iRSS_{intermod} = f\left(p_{it,k}^{supplied}, g_{it,k}^{pc}, g_{it,k\to vr}, pl_{it,k\leftrightarrow vr}, g_{vr\to it,k}, sens_{vr}, intermod\right) \text{ with k} = i, j$$

$$= 10\log\left(\sum_{i=1}^{n}\sum_{j=1,\, j\neq i}^{n} 10^{i_{i,j}RSS_{intermod}/10}\right)$$

where

- $i_{i,j}RSS_{intermod}$ = intermodulation product of third order at the frequency f_0

  $i_{i,j}RSS_{intermod} = 2i_iRSS_{int} + i_jRSS_{int} - 3intermod - 3sens_{vr} - 9\text{dB}$

  The interferer i transmits at the frequency $f_{it,i} = f_{it}$ and the interferer j at the frequency $f_{it,j}$ (see section b) , which defines $\Delta f = f_{it,j} - f_{it}$ and yields $f_0 = f_{it} - \Delta f = 2 f_{it} - f_{it,j}$. Assuming an ideal filter (roll off factor 0) the intermodulation product has to be considered only for the bandwidth b

  $$f_{vr} - b/2 \leq f_0 \leq f_{vr} + b/2 \quad .$$

  For all other cases the intermodulation product can be neglected.
- i_kRSS_{int} = received power in the victim receiver due to interferer $k=i$ at f_{it} or or interferer $k=j$ at $f_{it,j}$.

  $i_kRSS_{int} = p_{it,k}^{supplied} + g_{it,k}^{pc} + g_{it,k\to vr} - pl_{it,k\leftrightarrow vr} + g_{vr\to it,k}$

  The various parameters are defined in the previous sections a)-c). For the computation of i_iRSS_{int} the same algorithms as given in Sub-annex B.f can be used because i_iRSS_{int} corresponds to $i_iRSS_{block} + a_{vr}(f_{it}, f_{vr})$.
- $intermod$ = receiver intermodulation response for a wanted signal 3 dB above the sensitivity

  2 cases are envisaged:
  1) $intermod$ is given by the user, e.g. typical values are 70 dB for base station equipment and 65 dB for mobile and handportable equipment. It is used to derive generic limits.
  2) $intermod(\Delta f)$ is measured as a function of Δf refered to f_{vr} (see annex B.i)
- $sens_{vr}$ = sensitivity of victim receiver

Sub-annex B.a (Reference [3])

Propagation model

A number of propagation models are provided in the tool. They are depending on the environment chosen for the scenarios :

- general environment : open area, suburban or urban area,

- environment for the interferers : indoor or outdoor,

- environment for the victim receiver : indoor or outdoor.

The domain of validity for the models is described in the table below :

Below 30 MHz	No model available. Curves of Rec. ITU-R P368 is suited for high power transmitters and large distances and is therefore not adapted to interference calculations.
Between 30 MHz and 3 GHz	Modified Hata model available for outdoor-outdoor path loss calculations. Care should be taken when propagation distances are expected to be above 20 km. Indoor-indoor and indoor-outdoor models also suitable.
Above 3 GHz	Modified Hata model not advised. Spherical diffraction model is suitable for open area environment. No model available for suburban and urban environment. Indoor-indoor and indoor-outdoor models also suitable.

To improve the flexibility of the tool, a "generic" model (L=A + Blog(d) + Cd) both for the wanted signal path and the interfering path can also be entered by the user. The user of the tool is then to enter the parameters A, B, C of the median attenuation formula and the distribution of the variation in path loss Dv. As a default distribution, a lognormal distribution is to be proposed with a standard deviation to be entered by the user. Then we have :

$f_{propag}(d) = L + T(Dv)$

Also, more elaborate models can be implemented by the user using a simple script.

B.a.1. Modified Hata model

$$f_{propag}(f, h_1, h_2, d, env) \quad = L + T(G(\sigma))$$

L	= median propagation loss (dB)
σ	= deviation of the slow fading distribution
f	= frequency (MHz)
H_m	= $\min(h_1, h_2)$
H_b	= $\max(h_1, h_2)$
d	= distance (km), preferably less than 100 km.
env	= (outdoor/outdoor), (rural, urban or suburban), (propagation above or below roof)

If H_m and/or H_b are below 1 m, a value of 1 m should be used instead. Antenna heights above 200 m might also lead to significative errors.
Propagation below roof means that both H_m and H_b are above the height of roofs. Propagation is above roof in other cases (H_b above the height of roofs).

Calculation of the median path loss L :

Case 1: $d \le 40\,m$

$$L = 32.4 + 20\log(f) + 10\log\left[d^2 + (H_b - H_m)^2/10^6\right]$$

Case 2: $d \ge 100\,m$

$$a(H_m) = (1.1\log(f) - 0.7)\cdot\min\{10; \mathrm{H_m}\} - (1.56\log(\mathrm{f}) - 0.8) + \max\{0; 20\log(\mathrm{H_m}/10)\}$$

$$b(H_b) = \min\{0; 20\log(H_b/30)\}$$

$$\alpha = \begin{cases} \alpha = 1 & \text{d} \le \text{20 km} \\ \alpha = 1 + (0.14 + 1.87x10^{-4}\,xf\ + 1.07x10^{-3}\,H_b)(\log\dfrac{d}{20})^{0.8} & \text{20 km} < \text{d} < \text{100 km} \end{cases}$$

Subcase 1: Urban

- $30\ \text{MHz} < f \le 150\ MHz$

$$\begin{aligned} L = {} & 69.6 + 26.2\log(150) - 20\log(150/f) \\ & -13.82\log(\max\{30; H_b\}) + \alpha.\left[44.9 - 6.55\log(\max\{30; H_b\})\right]\log(d) \\ & -a(H_m) - b(H_b) \end{aligned}$$

- $150\ MHz < f \le 1500\ MHz$

$$\begin{aligned} L = {} & 69.6 + 26.2\log(f) \\ & -13.82\log(\max\{30; H_b\}) + \alpha.\left[44.9 - 6.55\log(\max\{30; H_b\})\right]\log(d) \\ & -a(H_m) - b(H_b) \end{aligned}$$

- $1500\ MHz < f \leq 2000\ MHz$

$$L = 46.3 + 33.9\log(f)$$
$$-13.82\log\left(\max\{30; H_b\}\right) + \alpha.\left[44.9 - 6.55\log\left(\max\{30; H_b\}\right)\right]\log(d)$$
$$-a(H_m) - b(H_b)$$

- 2000 MHz < f < 3000 MHz

$$L = 46.3 + 33.9\log(2000) + 10\log(f / 2000)$$
$$-13.82\log\left(\max\{30; H_b\}\right) + \alpha.\left[44.9 - 6.55\log\left(\max\{30; H_b\}\right)\right]\log(d)$$
$$-a(H_m) - b(H_b)$$

Subcase 2 : Suburban

$$L = L(\text{urban})$$
$$-2 \cdot \left\{\log\left[\left(\min\left\{\max\{150; f\};2000\right\}\right) / 28\right]\right\}^2 - 5.4$$

Subcase 3: Open area

$$L = L(\text{urban})$$
$$-4.78 \cdot \left\{\log\left[min\{max\{150; f\};2000)\}\right]\right\}^2 + 18.33 \cdot \log\left[min\{max\{150; f\};2000\}\right]$$
$$-40.94$$

Case 3: $40\,m < d < 100\,m$

$$L = L(40) + \frac{[\log(d) - \log(40)]}{[\log(100) - \log(40)]} \times [L(100) - L(40)]$$

When L is below the free space attenuation for the same distance, the free space attenuation should be used instead.

Assessment of the standard deviation for the lognormal distribution

Case 1: $d \leq 40\,m$:

$$\sigma = 3.5$$

Case 2: $40m < d \leq 100\,m$:

$\sigma = 3.5 + \dfrac{(12 - 3.5)}{100 - 40} \times (d - 40)$ for propagation above roofs,

$\sigma = 3.5 + \dfrac{(17 - 3.5)}{100 - 40} \times (d - 40)$ for propagation below roofs,

Case 3: $100\,m < d \leq 200\,m$:

$\sigma = 12$ for propagation above roofs,
$\sigma = 17$ for propagation below roofs

Case 4: $200m < d \leq 600\,m$:

$$\sigma = 12 + \frac{(9-12)}{(600-200)}(d-200) \quad \text{for propagation above roofs,}$$

$$\sigma = 17 + \frac{(9-17)}{(600-200)}(d-200) \quad \text{for propagation below roofs}$$

Case 5: $600\,m < d$:

σ = 9 dB

B.a.2 Spherical diffraction model

This model is not advised in urban or suburban environment.

General explanation on the application of the diffraction models can be found in § 4.3 of Rec. ITU-R P.452 (452-7 under revision), with the exception that, in absence of terrain database, the reference to the § 4.5 in Rec.ITU-R P.526 (last version 526-4 in 1995) is to be replaced by the reference to § 3.1.2.

For frequencies under interest (above 3 GHz), the effect of the ground can be neglected in § 3.1.2 of Rec. ITU-R 452-7, so that the inputs for the model are the same as for the modified hata model.

The term A_g in § 4.3 of Rec. ITU-R P.452 is to be calculated using § 4.2 of Rec. ITU-R P.452 and Rec. ITU-R P.676.

The variation in path loss is explicitely provided in § 4.3 of Rec. ITU-R P.452 in particular through the variability of the equivalent earth radius.

B.a.3. Indoor-outdoor propagation model

Case 1 : Use of the modified Hata model for outdoor-outdoor propagation

$$f_{propag}(f, h_1, h_2, d, env) = L + T(G(\sigma))$$

f, h_1,, h_2, and d defined as previously

env = (indoor,outdoor), (L_{we} = attenuation due to external walls), (σ_{add} = additional standard deviation of the signal)

Median attenuation L :

L(indoor-outdoor) = L_{hata}(outdoor-outdoor) + L_{we}

L_{we} = Attenuation due to external wall (default value = 10 dB)

Variation in path loss :

The standard deviation of the lognormal distribution is increased, compared to the outdoor-outdoor scenario due to additional uncertainty on materials and relative location in the building.

$$\sigma(indoor - outdoor) = \sqrt{\sigma(outdoor - outdoor)^2 + \sigma_{add}{}^2}$$

σ_{add} is to be entered by the user (default value : 5 dB).

<u>Case 2 : Use of the Spherical diffraction model for the outdoor-outdoor propagation</u>

f_{propag}(indoor-outdoor) = $f_{propag\text{-}spherical\ diff.}$(outdoor-outdoor) + L_{we}

L_{we} = Attenuation due to external wall (default value = 10 dB)

The variation in path loss in this case is already partially taken into account in the calculation of the spherical diffraction attenuation. An additional variations is due to the variation in building materials and is to be reflected by an additional lognormal distribution trial using the above σ_{add}.

<u>B.a.4. Indoor-indoor propagation model</u>

The first step is to determine whether the indoor-indoor scenario corresponds to an interferer and a victim in the same building or not. This is done by the calculation of the variable SB (Same Building).

<u>Trial of the condition SB (Same Building) :</u>

<u>case 1 :</u> d < 20 m :

SB = Yes

<u>case 2 :</u> 20 m < d < 50 m :

P(SB=Yes) = (50-d)/30

P(SB=No) = (d-20)/30

<u>case 3 :</u> d > 50 m

SB = No

If SB = No

<u>Case 1 : Use of the modified Hata model for outdoor-outdoor propagation</u>

$$f_{propag}(f, h_1, h_2, d, env) = L + T(G(\sigma))$$

f, h_1, h_2, and d defined as previously

env = (indoor,indoor), (L_{we} = attenuation due to external walls), (σ_{add} = additional standard deviation of the signal)

Median attenuation L :

L(indoor-indoor) = L_{hata}(outdoor-outdoor) + 2xL_{we}

L_{we} = Attenuation due to external wall (default value = 10 dB)

Variation in path loss :

The standard deviation of the lognormal distribution is increased, compared to the outdoor-outdoor scenario due to additional uncertainty on materials and relative location in the building.

$$\sigma(indoor - outdoor) = \sqrt{\sigma(outdoor - outdoor)^2 + 2.\sigma_{add}^{\ 2}}$$

σ_{add} is to be entered by the user (default value : 5 dB).

<u>Case 2 : Use of the Spherical diffraction model for the outdoor-outdoor propagation</u>

f_{propag}(indoor-indoor) = $f_{propag\text{-}spherical\ diff.}$(outdoor-outdoor) + 2.$L_{we}$

L_{we} = Attenuation due to external wall (default value = 10 dB)

The variation in path loss in this case is already partially taken into account in the calculation of the spherical diffraction attenuation. An additional variations is due to the variation in building materials and is to be reflected by an additional lognormal distribution trial using a standard deviation of $\sqrt{2}\,\sigma_{add}$.

If SB = Yes

$$f_{propag}(f, h_1, h_2, d, env) = L + T(G(\sigma))$$

f, h_1, h_2, and d defined as previously

env = (indoor,indoor), (σ = standard deviation of the signal), (L_{wi}, k_f, L_f, b, d_{room}, h_{floor} defined below)

$$L(indoor - indoor) = -27.6 + 20\log(d) + 20.\log(f) + fix(\frac{d}{d_{room}}).L_{wi} + k_f^{\left[\frac{k_f+2}{k_f+1} - b\right]}.L_f$$

$$k_f = fix(\frac{|h_2 - h_1|}{h_{floor}})$$

L_{wi} = loss of wall (default value = 5 dB)

L_f = loss between adjacent floor (default value = 18.3 dB)

b = empirical parameter (default value = 0.46)

d_{room} = size of the room (default value = 4 m)

h_{floor} = height of each floor (default value = 3 m)

The lognormal distribution trial is made using a standard deviation entered by the user and covering the variation in building design, in furniture of the rooms ...
The default value is σ = 10 dB.

Sub-annex B.b

Power control function

$$g_{it}^{pc} = f_{pc}\left(p_{it}^{\sup plied}, g_{it\to wr}, pl_{it\leftrightarrow wr}, g_{wr\to it}, pc_{it}^{t\_hold}, pc_{it}^{dyc\_rg}, pc_{it}^{st\_rg}\right)$$

P = power received by the wanted receiver, e.g. closest base station, of the interfering system.

$$P = f\left(p_{it}^{\sup plied}, g_{it\to wr}, pl_{it\leftrightarrow wr}, g_{wr\to it}\right) = p_{it}^{\sup plied} + g_{it\to wr} - pl_{it\leftrightarrow wr} + g_{wr\to it}$$

where $p_{it}^{sup plied}$, $g_{it\to wr}$, $g_{wr\to it}$ and $pl_{it\leftrightarrow wr}$ are defined in the iRSS calculation section.

Case 1: $P \le pc_{it}^{t\_hold}$:

$$p_{it}^{supplied\ \_PC} = p_{it}^{supplied}$$
$$g_{it}^{PC} = 0$$

Case (i+1): $pc_{it}^{t\_hold} + (i-1)\cdot pc_{it}^{st\_rg} \le P < pc_{it}^{t\_hold} + i\cdot pc_{it}^{st\_rg}$

$$p_{it}^{supplied\ \_PC} = p_{it}^{supplied} - (i-1)\cdot pc_{it}^{st\_rg}$$
$$g_{it}^{PC} = -(i-1)\cdot pc_{it}^{st\_rg}$$

where i is an integer ranging from 1 to n_steps = $\dfrac{pc_{it}^{dyc\_rg}}{pc_{it}^{st\_rg}}$

Case (n_steps +2): $P \ge pc_{it}^{t\_hold} + pc_{it}^{dyc\_rg}$:

$$p_{it}^{supplied\ \_PC} = p_{it}^{supplied} - pc_{it}^{dyc\_rg}$$
$$g_{it}^{PC} = -pc_{it}^{dyc\_rg}$$

Sub-annex B.c

Distribution definitions

- Uniform distribution: $U(0,1)=\begin{cases}1 & \text{if } 0\le x\le 1\\ 0 & \text{otherwise}\end{cases}$

- Gaussian distribution: $G(\sigma)=\dfrac{1}{\sqrt{2\pi}\sigma}\exp\left(-\dfrac{x^2}{2\sigma^2}\right)$

- Rayleigh distribution: $R(\sigma)=\dfrac{r}{\sigma^2}\exp\left(-\dfrac{r^2}{2\sigma^2}\right)$

- User defined distribution: The option to include an User-defined distribution in the tool should be considered.

Sub-annex B.d

<u>Pseudo-random number generation</u> (References [3], [4])

- From a uniform distribution $U(0,1)$

$$u_{i+1} = T(U(0,1)) = \frac{x_{i+1}}{m}$$

where
$x_{i+1} = (a \cdot x_i) \pmod{m}$
a = multiplier e. g. $a = 16{,}807$ or $397{,}204{,}094$ or $950{,}706{,}376$
m = modulus e. g. $m = 2^{31} - 1 = 2{,}147{,}483{,}647$
x_0 = seed, integer variable taking a value between 1 and (m-1)

- From a Gaussian distribution $G(\sigma)$

$$T(G(\sigma)) = v_1 \sqrt{\frac{-2 \cdot \ln(s)}{s}}$$

where

$$\text{while } s \geq 1, \text{ do } \begin{cases} v_1 = 2 \cdot T_{seed\,1}(U(0,1)) - 1 \\ v_2 = 2 \cdot T_{seed\,2}(U(0,1)) - 1 \\ s = v_1^2 + v_2^2 \end{cases}$$

v_1 and v_2 are two independent random variables (using two different seeds) uniformly distributed between -1 and +1.

- From a Rayleigh distribution $R(\sigma)$

$$T(R(\sigma)) = \sqrt{\left(v_1^2 + v_2^2\right) \cdot \frac{-2 \cdot \ln(s)}{s}}$$

where

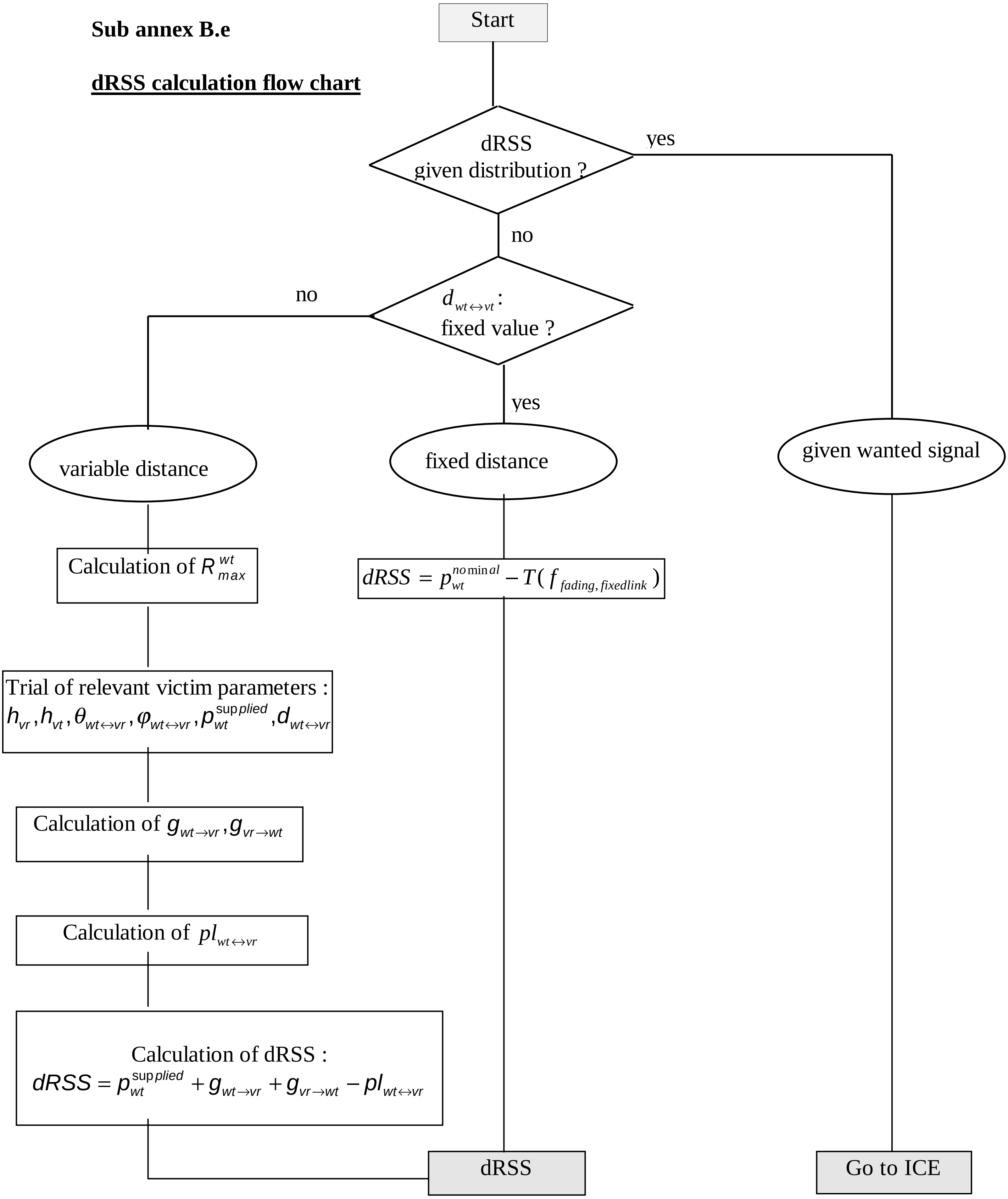
$$\text{while } s \geq 1, \text{ do } \begin{cases} v_1 = 2 \cdot T_{seed1}(U(0,1)) - 1 \\ v_2 = 2 \cdot T_{seed2}(U(0,1)) - 1 \\ s = v_1^2 + v_2^2 \end{cases}$$

v_1 and v_2 are two independent random variables (using two different seeds) uniformly distributed between -1 and +1.

- From any type of distribution with a given cumulative distribution function, cdf
$T(distribution) = cdf^{-1}(p)$
where
$p = T(U(0,1))$

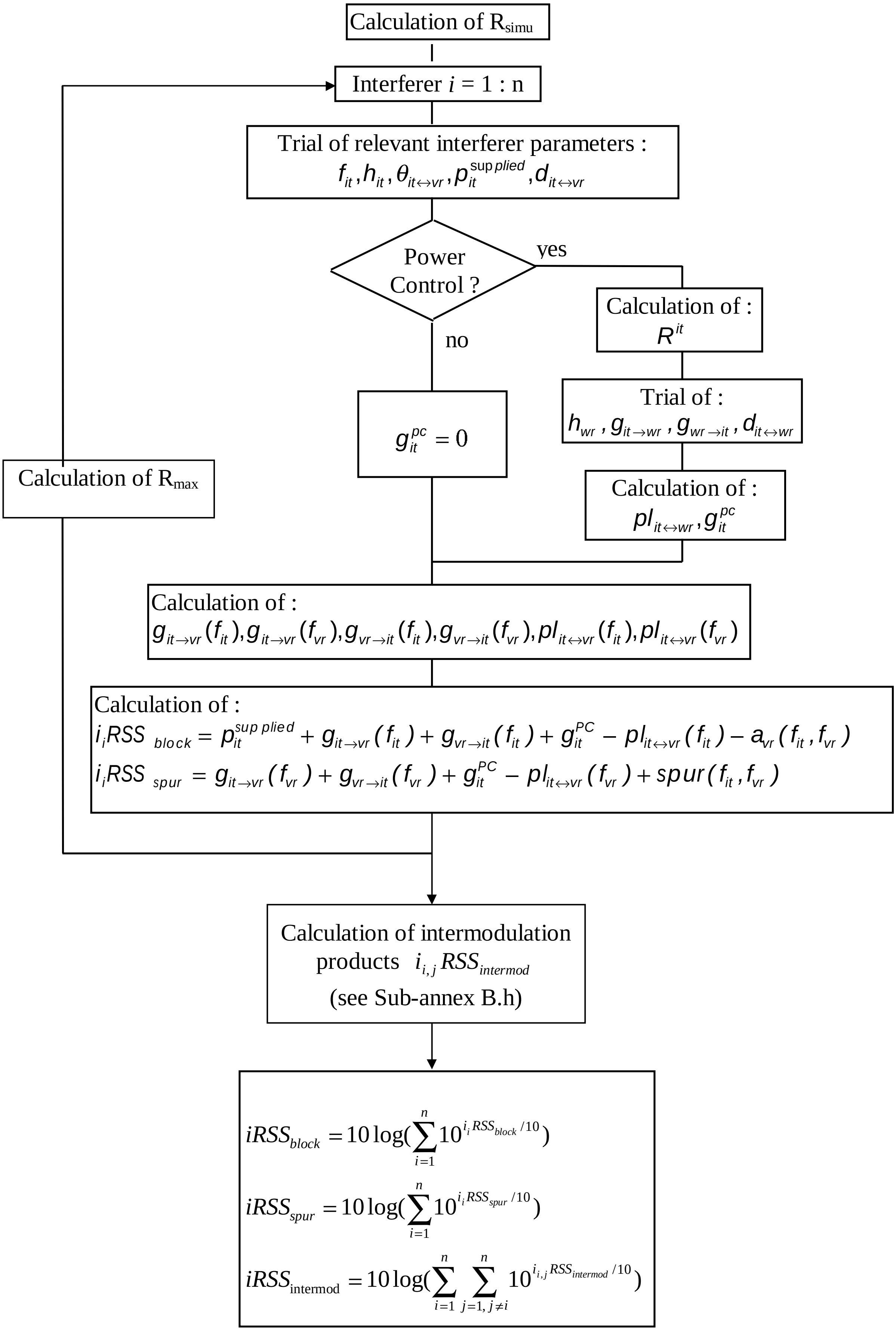
Sub annex B.e

dRSS calculation flow chart



Sub-annex B.f

iRSS due to unwanted and blocking calculation



Sub-annex B.g

Receiver Blocking

1. Basic concept

The receiver is capturing some unwanted signal because its filter is not ideal.

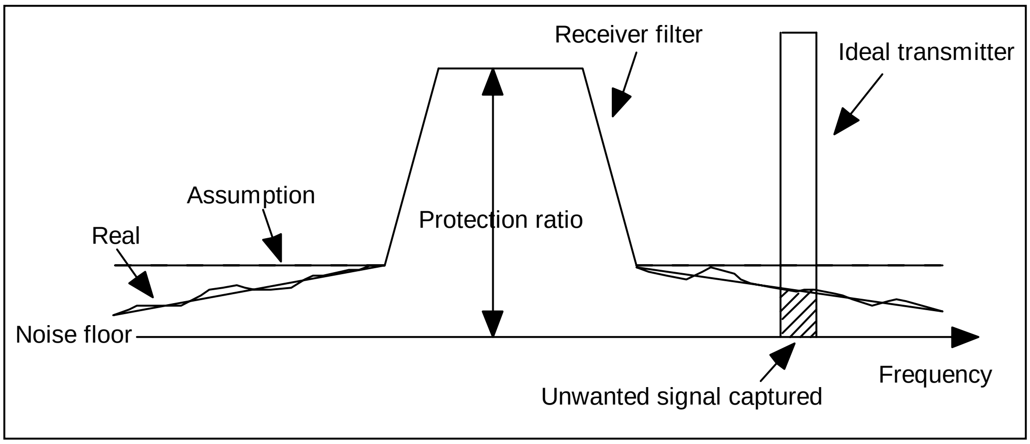


Figure 1. Basic concept

Definition: Blocking is a measure of the capability of the receiver to receive a modulated wanted input signal in the presence of an unwanted input signal on frequencies other than those of the spurious responses or the adjacent channels, without these unwanted input signals causing a degradation of the performance of the receiver beyond a specified limit (Document I-ETS 300 113:1992).

2. Blocking level measurements

- Adjust the desired signal at the BER limit level,
- Increase this desired signal by 3 dB and add the interfering signal which is increased until the same BER is obtained,
- The ratio (int. signal / des. signal) is the value of the Receiver blocking.

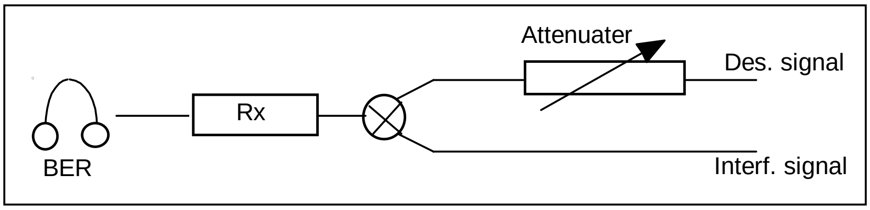


Figure 2. Measurement procedure.

3. Attenuation of the receiver

During the measurement procedure, the three following equations are valid:

Noise Floor + Protection ratio + 3 dB = Desired Signal Level,

Desired Signal Level + Blocking = Interfering Signal Level,

Interfering Signal Level - Attenuation = Noise Floor,

Hence,

Attenuation = 3 dB + Protection ratio + Blocking

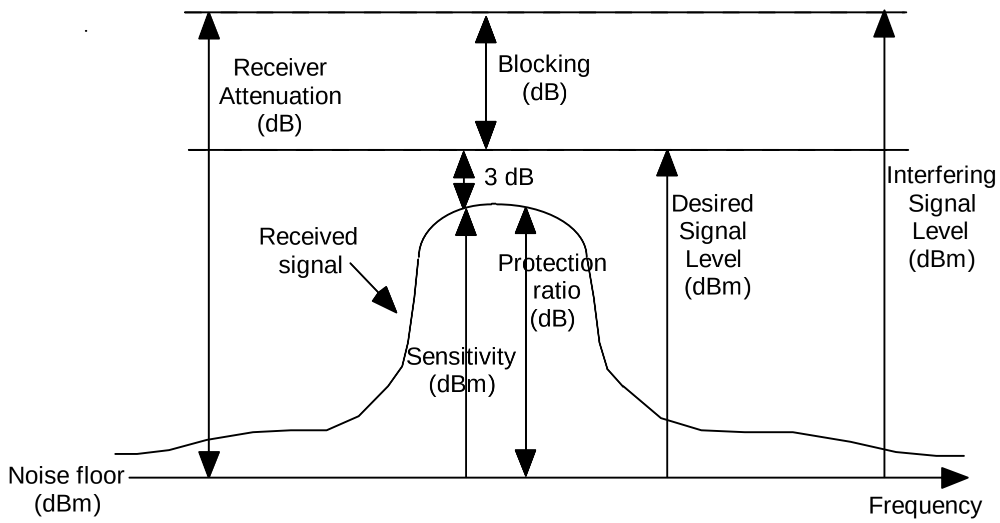


Figure 3.

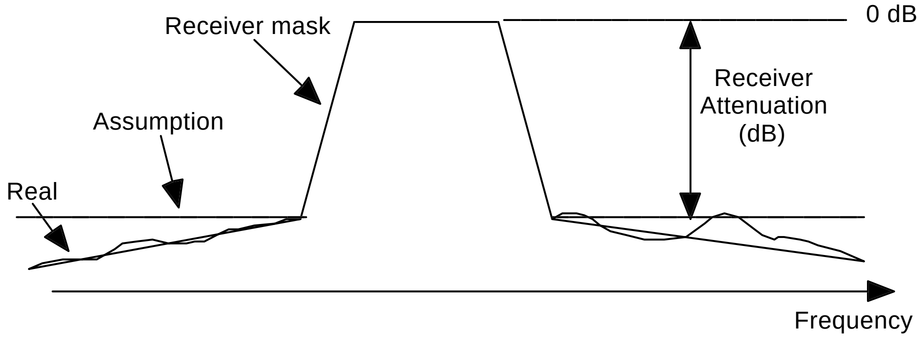
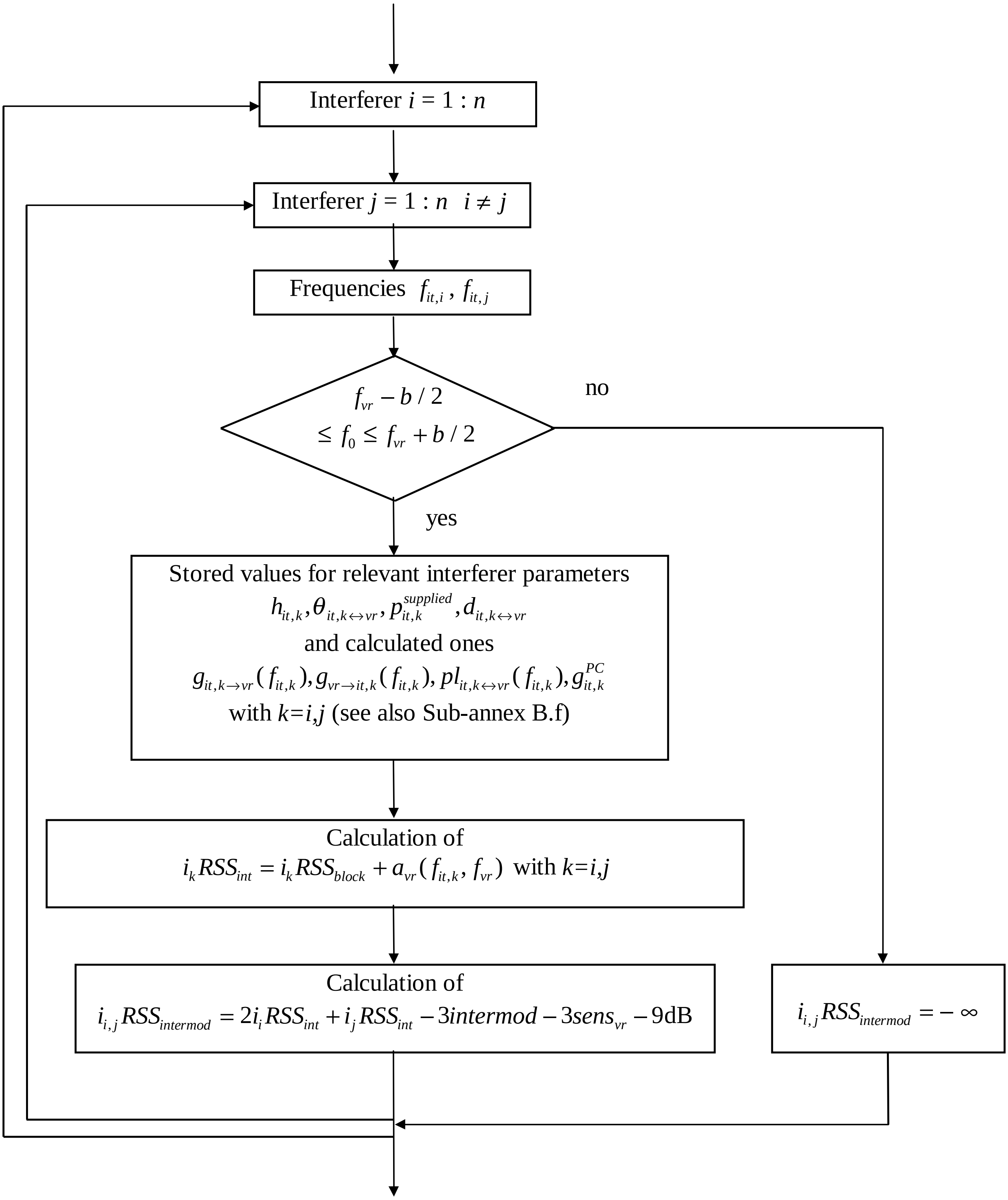


Figure 4. Receiver mask.

Sub-annex B.h

iRSS due to intermodulation

This flow chart is part of the flow chart given in Sub-annex B.f.



Sub-annex B.i

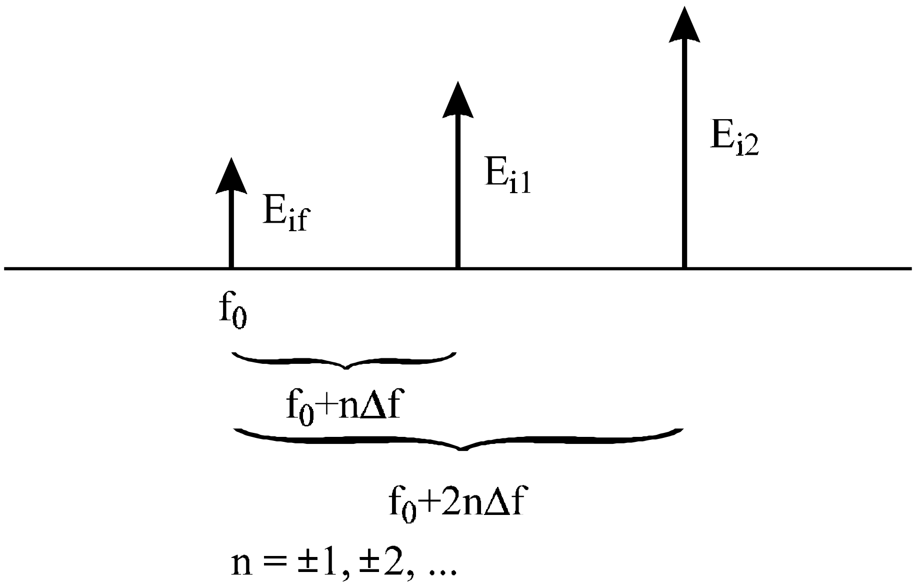
Intermodulation in the Receiver

The main contribution to Intermodulation Interference originates from interfering signals in neighbouring channels due to the frequency selectivity of the antennas and the receiver equipment. We consider a service with a desired signal at frequency f_0, a channel separation Δf and interfering signals E_{i1} and E_{i2} at frequencies $f_0+n\Delta f$ and $f_0+2n\Delta f$, respectively. The receiver nonlinearities produce an intermodulation product E_{if} of third order at the frequency

$$f_0 = 2\left(f_0 + n\Delta f\right) - \left(f_0 + 2n\Delta f\right) \quad n = \pm 1, \pm 2, ... \qquad (1)$$

(see Fig. 1).

Fig. 1



The signal strength E_{if} of the intermodulation product is given by

$$E_{if} = k\ E_{i1}^2\ E_{i2}\ , \qquad (2)$$

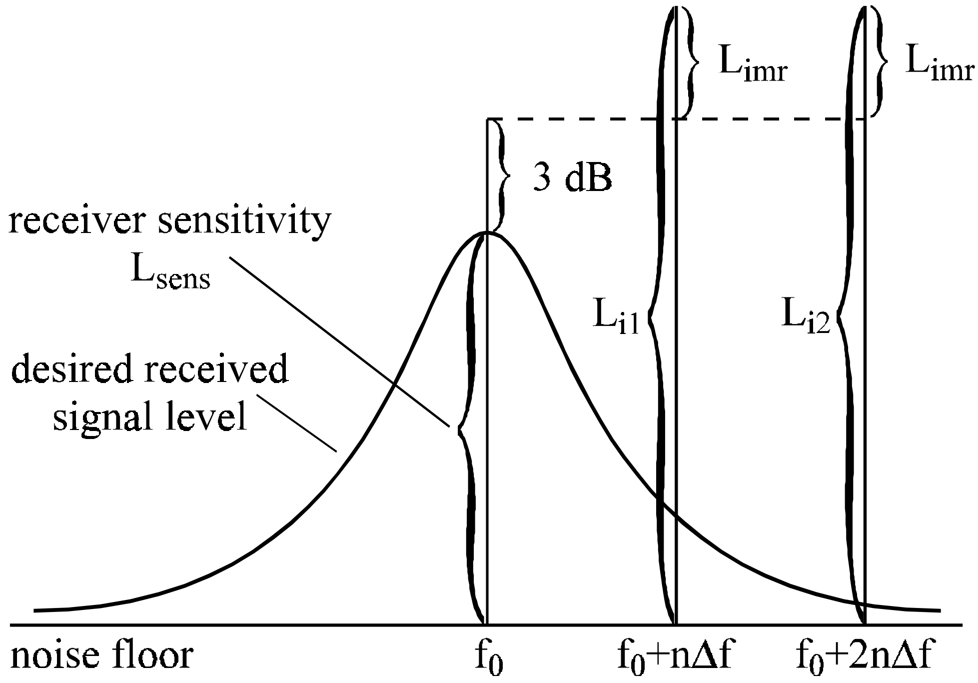
with some constant k to be determined. For signal levels (measured in dB) the eq. (2) reads

$$L_{if} = 2L_{i1} + L_{i2} + 20\log k\ . \qquad (3)$$

The constant 20log k in eq. (3) can be found from the measurement procedure which is described in the ETSI standard ETS 300-113, clause 8.8. The method is similar to the contribution in annex B.g for blocking interference.

ETS 300-113 defines via the intermodulation response L_{imr} the interfering signal levels $L_{i1} = L_{i2}$ at which bit errors due to intermodulation just start to be recorded (see Fig. 2) .

Fig. 2



This means, for L_{i1} and L_{i2} as in Fig. 2, we have an intermodulation product L_{if} just at the noise floor (0 dB). Introducing L_{i1} and L_{i2} from Fig. 2 into eq. (3) we obtain

$$0 = 2\left(L_{imr} + 3\ dB + L_{sens}\right) + \left(L_{imr} + 3\ dB + L_{sens}\right) + 20\log k \qquad (4)$$

With the value of k from eq. (4), the eq. (3) becomes

$$L_{if} = 2L_{i1} + L_{i2} - 3L_{imr} - 3L_{sens} - 9\,dB\ . \qquad (5)$$

Sub-annex B.j

Influence of different bandwidths

a) Wanted Path

The wanted transmitter transmits its power p_{wt} (dBm) at the frequency f_{vr} within a given bandwidth b_{vr} . This bandwidth is also used for the determination of the intermodulation products (see Sub-annex B.h).

b) Interfering Transmitter

For the interfering transmitter, an unwanted transmission mask p_{mi} as function of $\Delta f = f - f_{it}$ should be defined as maximum power levels $p_{mi}(\Delta f)$ in reference bandwidth $b_s(\Delta f)$ as specified by the user.

The interfering transmitter power p_{it} (dBm) at f_{it} is used for evaluating the link budget with the wanted receiver (i.e. power control).

If no mask is defined, the unwanted emission bandwidth b_{it} should be defined and the transmitted power should be assumed to spread uniformly over b_{it} with no emission outside b_{it} .

Note : This approach provides a clear splitting between the case where no mask is needed (i.e. co-channel) and the case where a mask is given, which assumes that the mask is also specified within the transmitter bandwidth (no systematic assumption can be done here since we need to envisage non-flat spectrum). b_{it} *is not used by the tool in the case of the user-defined mask.*

c) Determination of interfering power

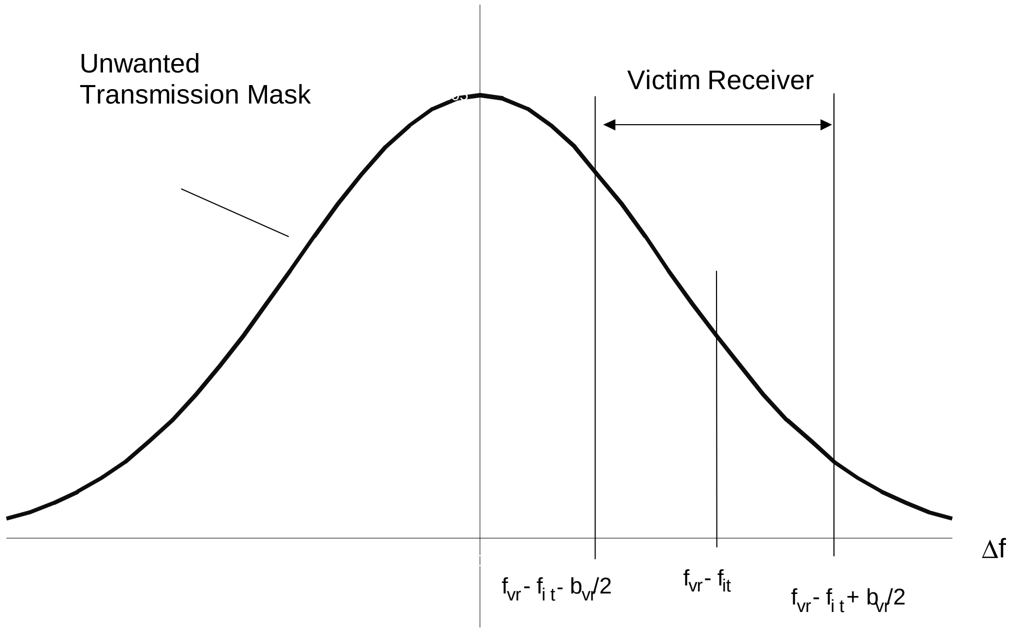


Fig.1: Principle of determination of interfering power

The Figure shows the principle of the determination of the interfering power $spur(f_{it}, f_{vr})$. If $f_{it} = f_{vr}$ then the interfering frequencies falls exactly in the receiving band of the victim receiver (co-channel interference).

For simplification within the algorithms the mask function p_{mi} is normalised to 1 Hz reference bandwidth:

$$p_{ni} = p_{mi}(\Delta f) - 10\log\frac{b}{1\text{Hz}}$$

The bandwidth b is the bandwidth used for deriving p_{mi}. If no mask was provided, $b = b_{it}$ and $p_{mi} = p_{it}$ (assuming flat spectrum). If a mask has been specified, $b = b_s$ and $p_{mi} = spur(\Delta f)$.

The total received interfering power $spurtot$ can easily calculated by integration over the receiver bandwidth from $a = f_{vr} - f_{it} - b_{vr} /$ to $b = f_{vr} - f_{it} + b_{vr} / 2$

$$spurtot = 10\log\left\{\int_a^b 10\wedge(p_{ni}(\Delta f)/10)\, d\Delta f\right\}$$

with p_{ni} denoting the normalised mask in dBm/Hz. Using 1 Hz reference bandwidth the integral can be replaced by a summation

$$spurtot = 10\log\left\{\sum_{i=a}^{b} 10\,\hat{}\,(p_{ni}(\Delta f_i)/10)\right\}$$

where $spurtot$ is given in dBm.

d) Conclusion

The interfering power of a radio system having a different bandwidth can be estimated by the aforementioned algorithms. This calculation is only required for the interference due to unwanted emissions but not for blocking and intermodulation.

The application of this approach requires that the different bandwidths used in the wanted radio path b_{vr} , the interfering transmitter b_{it} and for reference of the unwanted transmission mask b_s are provided via the input list.

References for Annex B

[1] Annex B of document SE21(94)/68. Subject: *An Objective Derivation of Isolation Distance.* Source: Motorola.

[2] France, ITU Radio communication Study Group, Document 1-3/ 31 rev1 -E. Subject: *Proposal for a Propagation Model to be used in Models for Calculating Spurious Emission Interference*, May 1995

[3] Knuth, D. E., *The Art of Computer Programming*, Vol. 2, *Seminumerical Algorithms*, Addison-Wesley, Reading, Massachusetts, 1969.

[4] Reuven Y. Rubinstein, *Simulation and the Monte Carlo Method*, Haifa, Israel, 1981.

ANNEX C

Distribution Evaluation Engine

Flow chart for DEE is shown in Fig. C.1. Fit-of-goodness test is performed using the chi-squared algorithm, described in Annex A
The algorithm basically tests if a random sample of observations conform to a pre-specified cumulative distribution. The pre-defined distribution can be continuous, discrete or hybrid. Thus, chi-squared method is very versatile and single algorithm is proposed for use within DEE for testing all possible types of probability distribution functions.
An array of samples on RSS random variable is passed to DEE. Firstly DEE test if the array length, N (number of samples), is long enough to produce a stable distribution. This is accomplished by using N-dN samples to establish an initial discrete distribution function and calculate the corresponding cumulative distribution function (cdf). This cdf is then used as a reference in the chi-squared test performed now on the complete population of N samples. Should the test show that two discrete distribution differs more than an acceptable and prespecified value, a message is send back to EGE to generate some extra samples. On contrary, if the chi-squared criteria is satisfied DEE proceed with testing whether or not a continuous probability density function can be used.
The flow-chart in Fig.C.1, as an example, shows Gaussian distribution test. The chi-squared algorithm is equally applicable to any other continuous distribution that might be representative of RSS random variable. A continuous distribution function enables a closed form expression for probability calculation in ICE what in return warrants a numerically efficient calculation. If no continuous pdf fits the sample population with the adequate accuracy, discrete pdf representation and numerical probability calculation is the only way forward.

The flow chart in Fig.C.2 presents one of many different possibilities to form the discrete pdf for a random variable.

Notation used:

<RSS>	- random variable population
N	- sample population size
I	- counter internal to result stability testing
dN	- portion of population size (e.g. dN=0.1N)
Y	- chi-squared test criteria (see Annex C.a)
$\chi_{1-\alpha}$	- `quantile` - reference level for chi-squared test
n	- total sample counter
<C>	- discrete cdf coefficient array

Fig.C.1. DEE algorithm- flow chart representation

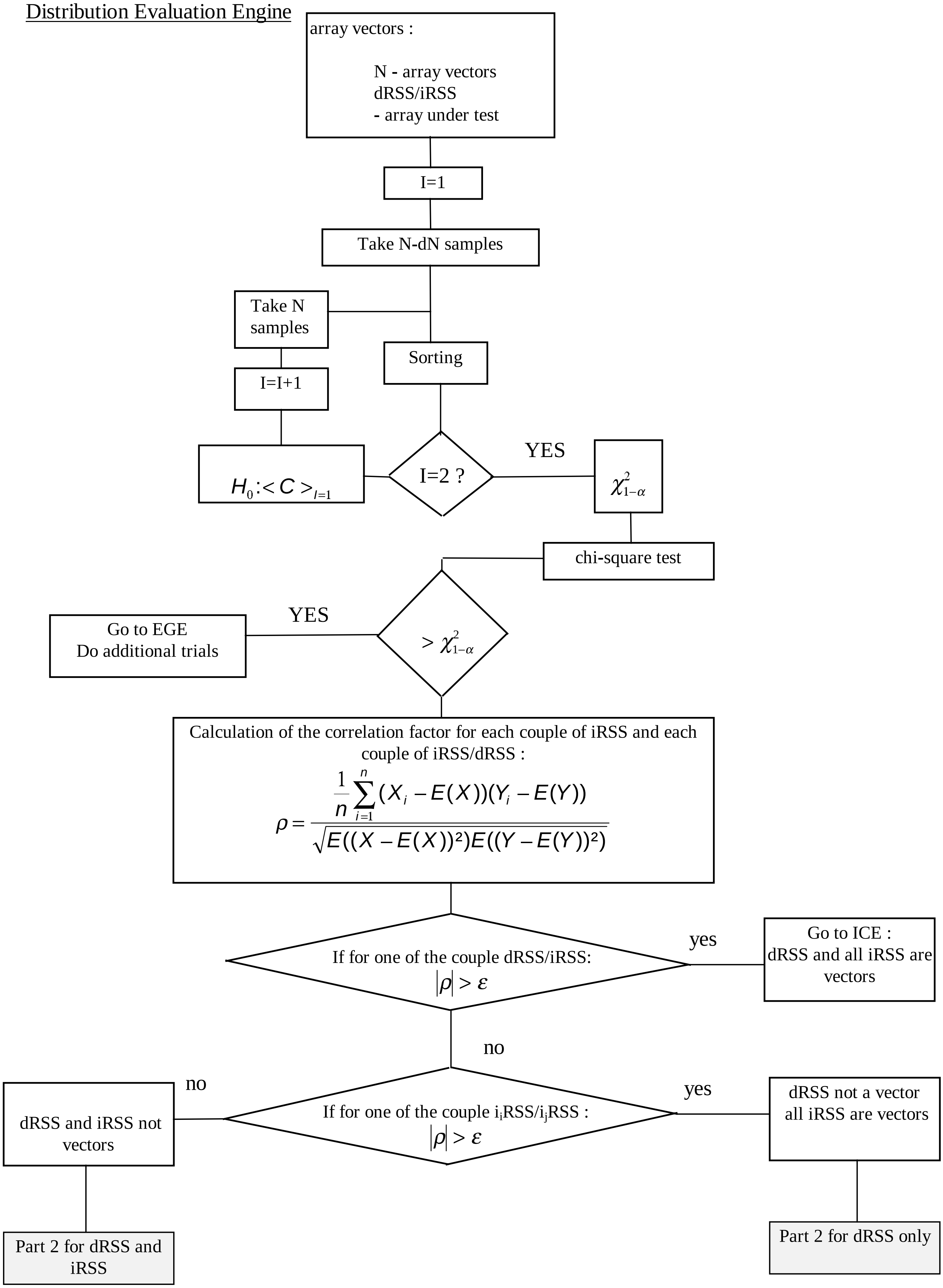
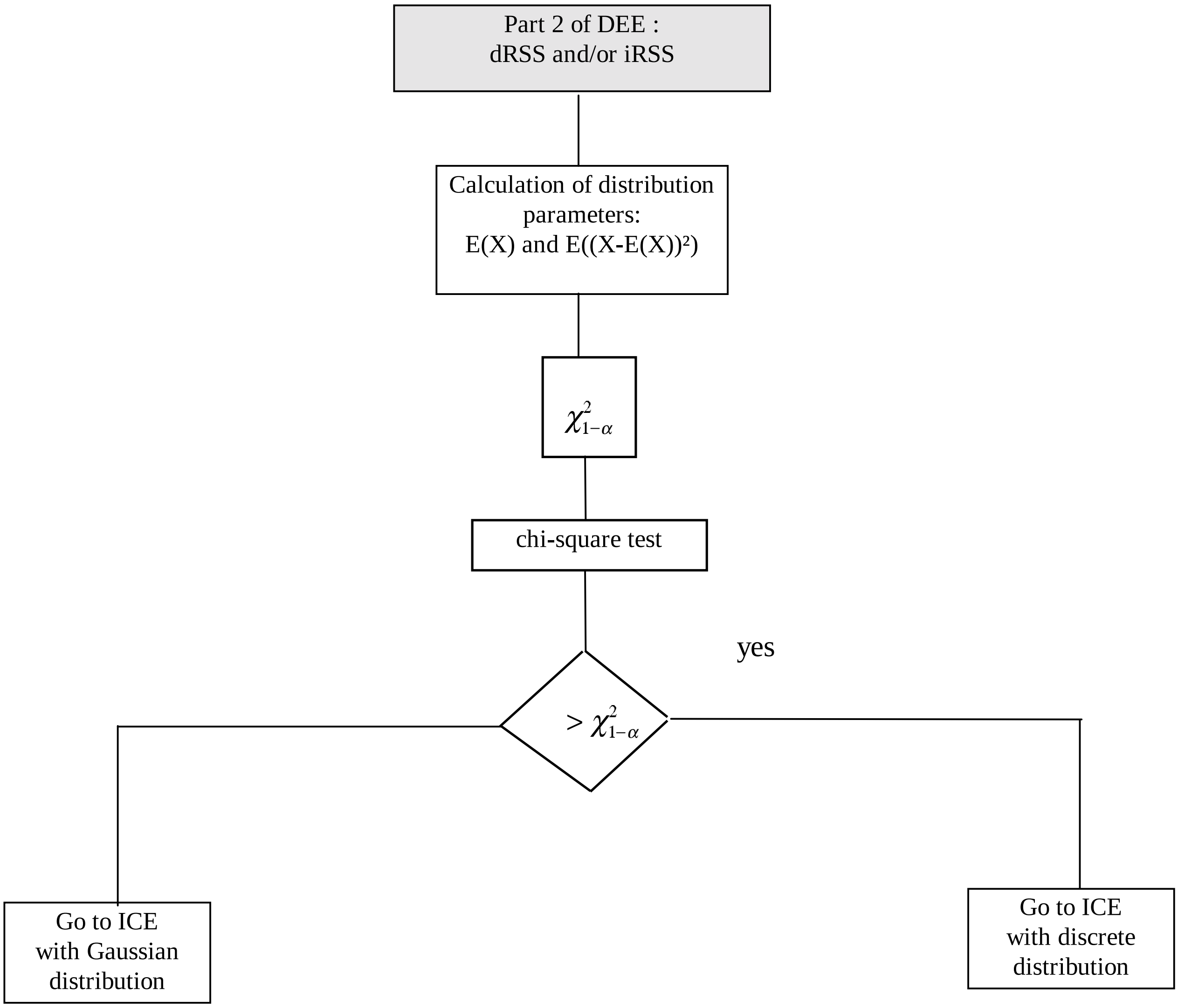


Fig. C.2.


Part 2 of DEE :
dRSS and/or iRSS
Calculation of distribution parameters:
E(X) and E((X-E(X))²)
$\chi^2_{1-\alpha}$
chi-square test
yes
$> \chi^2_{1-\alpha}$
Go to ICE with Gaussian distribution
Go to ICE with discrete distribution

Sub-annex C.a

Chi-Squared Goodness-of-Fit Test

The chi-squared goodness-of-fit test is one the oldest and best known statistical tests.

Lets assume $X_1, X_2, \ldots, X_N$ be a sample set drawn from a population with unknown cumulative distribution function (cdf) $F_x(x)$. Chi-squared test is based on testing the null hypothesis

$H_0 : F_x(x) = F_0(x)$ for all x

against the alternative

$H_1 : F_x(x) \neq F_0(x)$ for some x

Assume that N observations are grouped into K mutually exclusive categories. Lets denote by N_j the observed number of trials in jth category ($j = 1, 2, \ldots, K$). In addition, denote N_j^0 the number of trials expected to fall into jth category according to the known cdf $F_0(x)$.

The actual test employs the following criteria:

$$Y = \sum_{j=1}^{K} \frac{\left(N_j - N_j^0\right)^2}{N_j^0}, \quad \sum_{j=1}^{K} N_j = N$$

which tends to be small when H_0 is true and large when H_0 is false. The Y is also random variable which obeys chi-square distribution for large N.
In practice, for the hypothesis H_0 to prevail we expect

$P(Y > \chi^2_{1-\alpha}) = \alpha$

where α is the significant level, say 0.05 or 0.1; the quantile $\chi^2_{1-\alpha}$ corresponds to probability of $1-\alpha$ is given in the tables for chi-squared distribution.(see Table 1)

The chi-squared goodness-of-fit test is equally applicable to discrete and continuous probability density functions.

Table 1. Quantile $\chi^2_{1-\alpha}$ for chi-squared distribution

$1-\alpha$ / K	0.975	0.95	0.90	0.75
10	3.25	3.94	4.86	6.74
20	9.59	10.85	12.44	15.45
30	16.79	18.49	20.60	24.48
40	24.43	68.51	29.05	33.66
50	32.36	34.76	37.69	42.94
60	40.48	43.19	46.46	52.29
70	48.76	51.74	55.33	61.70
80	57.15	60.39	64.28	71.14
90	65.65	69.13	73.29	80.62
100	74.22	77.93	82.36	90.13

ANNEX D

INTERFERENCE CALCULATION ENGINE

The ICE has two different functions:

- Process different interfering signals in order to calculate the probability for interference. Three type of interfering signals are considered: spurious emission, out-of-band emission, blocking and intermodulation.
- Derive generic limits. The output of the ICE is then a multi-dimensional surface giving the probability of interference versus the radio parameters. The general ICE flow chart is shown in Fig. D.1.

The interfering signal distributions are calculated with respect to reference levels or functions of unwanted (emission mask), blocking (receiver mask) or intermodulation attenuation. The translation law for the cdf from reference $ref_{i\text{-}init}$ to reference ref_i is given by the following formula:

$$P\left(iRSS_i\left(ref_i\right) < X\right) = P\left(iRSS_i\left(ref_{i-init}\right) < X - t\left(ref_i - ref_{i-init}\right)\right) \quad ; \quad t = \begin{cases} 1 & ; \quad i = \text{spur} \\ -1 & ; \quad i = block \\ -3 & ; \quad i = \text{interm}\,od \end{cases} \qquad \text{(D1)}$$

The complete and quick (approximate) flow charts for the ICE are shown in Figs. D.2 and D.3 respectively. For sake of simplicity, the case of t=1 (eq. (D1), spurius case) appears in flowchats D.2 and D.3.

Quick calculation algorithm :

In the ICE quick calculation algorithm we make the following two assumptions:
1) The i_iRSS are independent variables, where the index 'i' corresponds to the i-th type of interfering scenario.
2) One of the i_iRSS is dominant with respect to all the other interfering signals.
The overall probability P_D for not being interfered by the composite interfering signal reads

$$P_D = P\left(dRSS/iRSS_{composite} > C/I \mid dRSS > sens_{vr}\right) \qquad \text{(D2)}$$

Using the second assumption, we can approximate (D2) by the following equation :

$$P_D \approx P\left(\bigcap_{i=1}^{n}\left(\frac{dRSS}{i_iRSS} > \frac{C}{I} \middle| dRSS > sens\right)\right) \qquad \text{(D3)}$$

and since the i_iRSS are independent variables, we can write (D3) as

$$P_D \approx \prod_{i=1}^{n} P\left(\frac{dRSS}{i_iRSS} > \frac{C}{I} \middle| dRSS > sens\right) \equiv \prod_{i=1}^{n} P_i\left(C/I\right) \qquad \text{(D4)}$$

For each interfering scenario corresponds a set of references, ref_i, e.g. spur, a_{vr}, etc. The user can choose the set of references that will be used in the calculation of P_D. We incorporate ref_i in (D4) and get the following approximation :

$$P_D \approx \prod_{i=1}^{n} P_i\left(C/I, ref_i\right) \qquad \text{(D5)}$$

which is used in the quick calculation algorithm. It can be easily shown that 1-P_D gives the probability of being disturbed by at least one of the n interferers.

Complete ICE flow chart :

Three cases are considered:

1) The desired and/or the interfering signals are correlated. In this case the probability P_D is calculated by processing directly the data vectors. For each interfering scenario, the interfering signals of all interferers are summed up to get $iRSS_{composite}$. Then, from the two vectors $dRSS$ and $iRSS_{composite}$ we calculate the probability P_D :

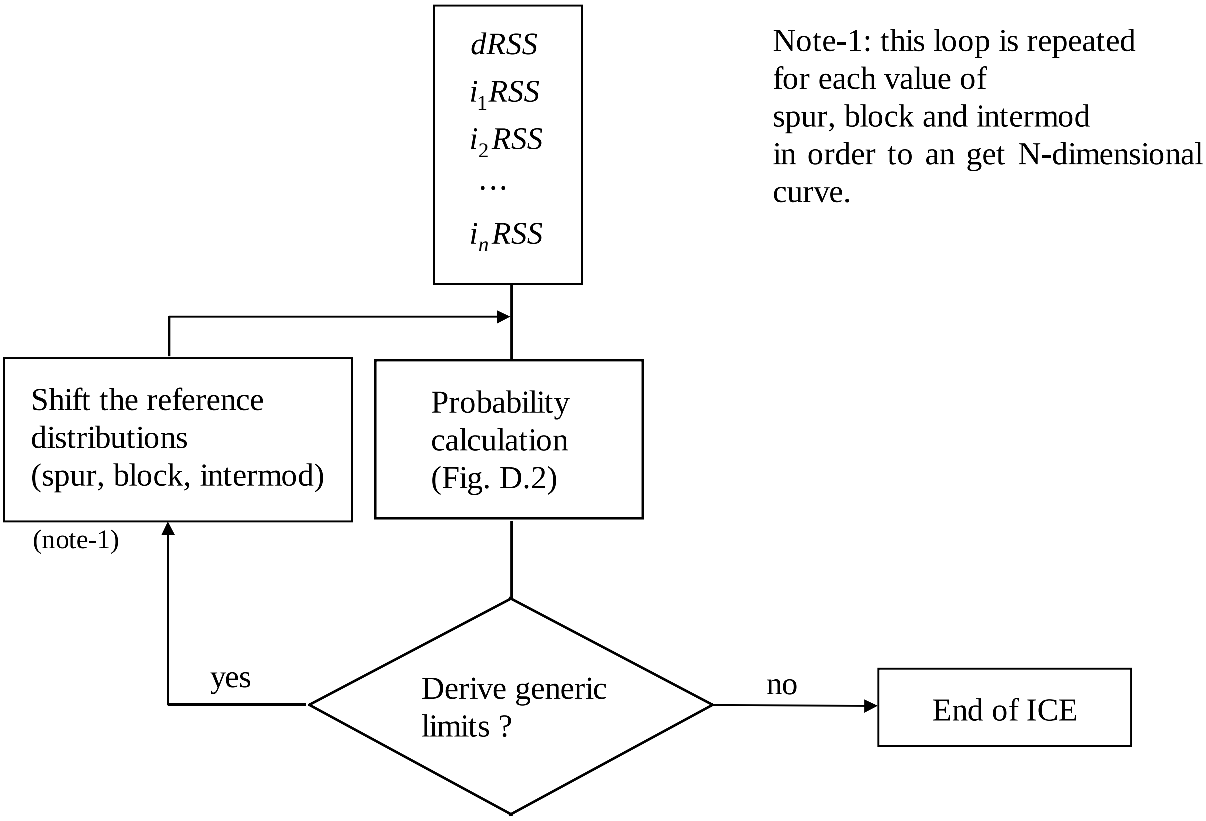
$$P_D = P\left(dRSS/iRSS_{composite} > C/I \mid dRSS > sens\right) \qquad \text{(D6)}$$

by summing up all the terms satisfying $dRSS>sens$. Similarly to the quick calculation case, when we sum up elements form the data vectors to calculate (D5), we should update the data so that it corresponds to a desired set of references.

2) All signals are uncorrelated and their distributions (calculated by the DEE) are given in closed form. First, the cumulative distribution function of the composite interfering signal is calculated by integrating the i_iRSS distribution functions. Note that the ref_i cause linear shifts of the i_iRSS distributions with respect to one another. In the calculation of $i_iRSS_{composite}$ the i_iRSS distributions should be shifted so that they all refer to the same set of references. Finally, (D5) is calculated by using the conditional probability formula which integrates the distributions $dRSS$ and $iRSS_{composite}$.

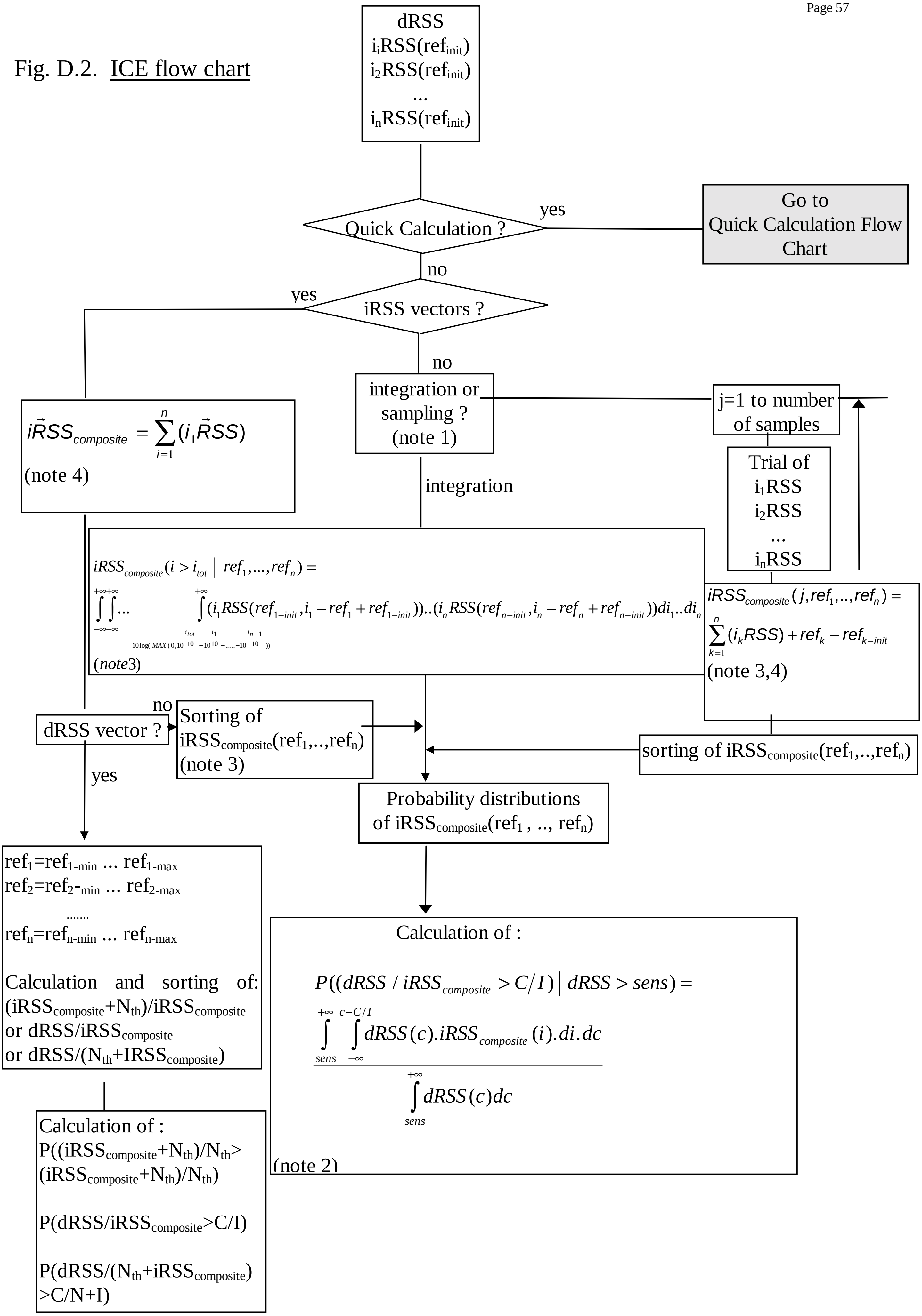
3) The third case is similar to the second one, with the exception that the $iRSS_{composite}$ distribution function is determined by the MC technique.

Fig. D.1. General ICE flow chart



The flow chart in figure D.1 is describing the logical process of ICE, which is well suited in the case of the full integration for the calculation of $iRSS_{composite}$ (see flow chart D.2). However, in the case of input vector data or Monte Carlo sampling process, the calculation of the summation of vectors for determining $iRSS_{composite}$ and the trials of i_iRSS (respectively), which are time and ressource consuming, can be made only once as shown in figure D.2.

Fig. D.2. ICE flow chart



Note 1: computing time is the criteria to choose between sampling or integrating
Note 2: this formula is detailed in the document SE21(96)/20 add 1. (dRSS/I) is the criteria used in this example. Other criteria may be used
Note 3: ref_1,..., ref_n are the values of the relevant parameters (spur, a_v, ...) for which the calculation of the probability of interference is needed.
Note 4 : The meaning of this sum is symbolic since the addition is to be made on the linear values and that i_iRSS are expressed in dB.

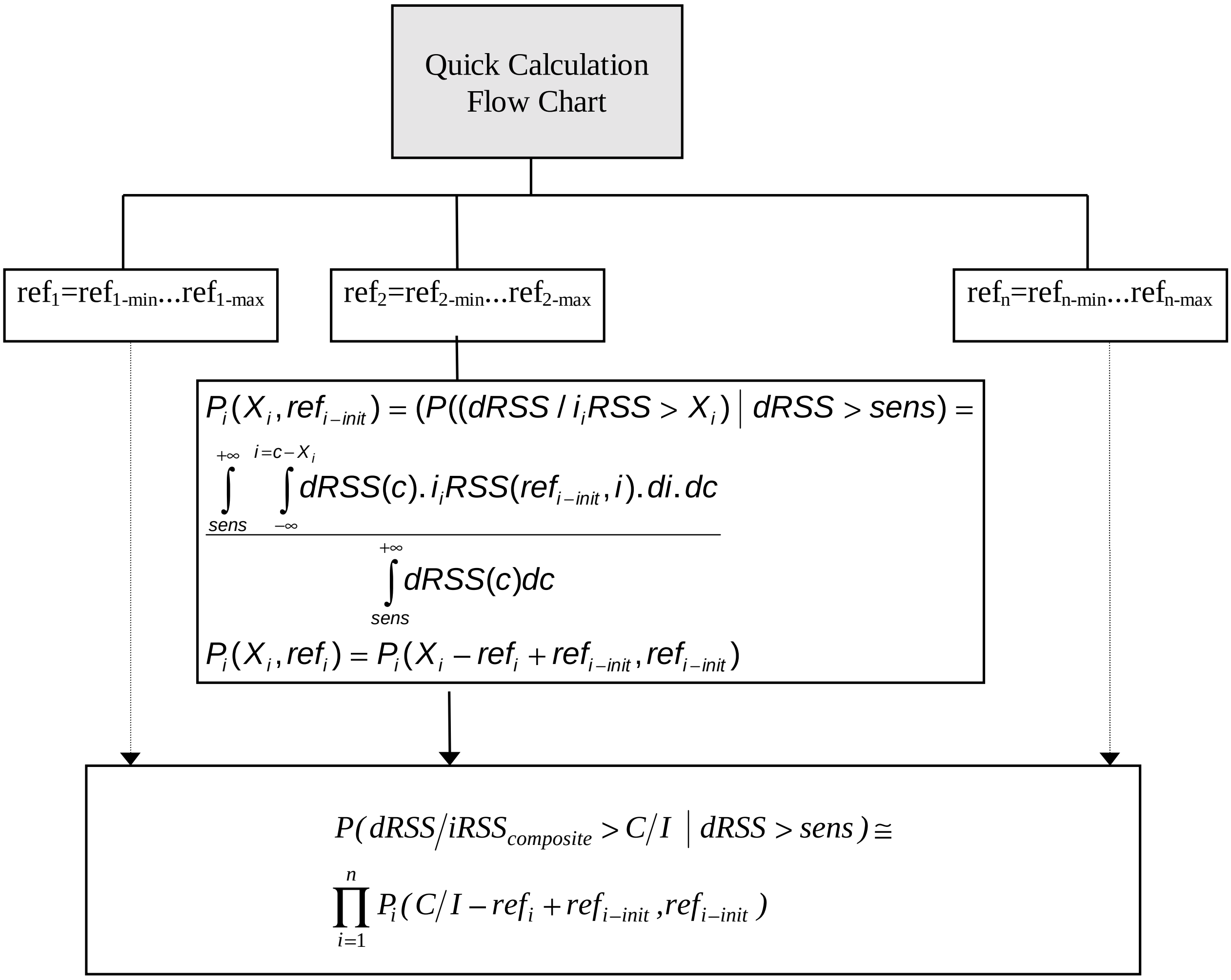


Fig. D.3. ICE quick calculation flow chart.