RECOMMENDATION ITU-R SM.1134-1*, **

Intermodulation interference calculations in the land-mobile service

(1995-2007)

Scope

This Recommendation serves as a basis for the calculation of a maximum of three intermodulation interference that are created at the output of a receiver under influence of intensive unwanted signals at the receiver input due to non-linearity of an amplitude response of the receiver.

Keywords

Intermodulation interference, unwanted signals, non-linearity

The ITU Radiocommunication Assembly,

considering

a) that, in the most typical cases, the major factors which determine interference in the land-mobile service include:

– in-band intermodulation products which are generated by two (or more) high-level interfering signals;

– unwanted emission that can occur in a transmitter when any other signal from another transmitter is also presented at the input of RF stages of the influenced transmitter;

– the wanted and interfering signal levels are random variables;

b) that two (or more) unwanted signals must have specific frequencies so that the intermodulation products fall into the frequency band of a receiver;

c) that the probability of occurrence of intermodulation interference due to more than two high-level unwanted signals is very small;

d) that the intermodulation interference calculation procedure will offer a useful means of promoting efficient spectrum utilization by the land-mobile service,

recommends

1 that the receiver intermodulation model presented in Annex 1 should be used for intermodulation interference calculations in the land-mobile service;

2 that intermodulation interference calculations should follow the following procedure, details of which are presented in Annex 1;

2.1 to determine mean value and dispersion of a random wanted signal power at the receiver input;

2.2 to determine mean value and dispersion of a random intermodulation interference signal power at the receiver input;

2.3 to determine the probability that the intermodulation products generated both in the receiver itself and as a result of the intermodulation in the transmitter will occur during the reception;

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* This Recommendation should be brought to the attention of Radiocommunication Study Group 5.

** Radiocommunication Study Group 1 made editorial amendments to this Recommendation in the years 2018 and 2019 in accordance with Resolution ITU-R 1.

3 that the zones affected by intermodulation interference and relevant necessary geographical separation of interfering transmitters and receivers should be determined on the basis of a given value of the interference probability, as it is described in Annex 1.

Annex 1

Intermodulation models

This Annex describes two intermodulation models; the receiver intermodulation (RXIM) model and the transmitter intermodulation (TXIM) model. It is divided into five sections.

Section 1 outlines the general formula for calculating receiver intermodulation interference. Section 2 describes the RXIM measurement procedure. Section 3 outlines a procedure for evaluating receiving intermodulation interference using the general formula. Section 4 outlines the formula for transmitter intermodulation interference. Section 5 describes how the probabilities of RXIM and TXIM interference are calculated.

1 Receiver intermodulation analysis model

The two-signal, third-order intermodulation interference power is given by the following formula (ex-CCIR Report 522-2, Düsseldorf, 1990):

$$P_{ino} = 2(P_1 - \beta_1) + (P_2 - \beta_2) - K_{2,1} \qquad (1)$$

where:

P_1 and P_2: powers of the interfering signals at frequencies f_1 and f_2, respectively

P_{ino}: power of the third-order intermodulation product at frequency $f_0 (f_0 = 2f_1 - f_2)$

$K_{2,1}$: third-order intermodulation coefficient, may be computed from third-order intermodulation measurements or obtained from equipment specifications

β_1 and β_2: RF frequency selectivity parameters at frequency deviations Δf_1 and Δf_2 from the operating frequency f_0, respectively.

The values of β_1 and β_2 for example can be obtained from the equation to calculate the attenuation of a signal at an off-tune frequency.

$$\beta(\Delta f) = 60 \log \left[1 + \left(\frac{2\,\Delta f}{B_{RF}} \right)^2 \right] \qquad (2)$$

where B_{RF} is the RF bandwidth of the receiver.

It is worth noting that for a particular set of third-order intermodulation measurements for land mobile analogue radio receivers operating in the VHF and lower UHF bands, equation (1) may be manipulated to derive the following formula [McMahon, 1974]:

$$P_{ino} = 2P_1 + P_2 + 10 - 60 \log(\alpha f) \qquad (3)$$

where αf is the mean frequency deviation (MHz) and is equal to:

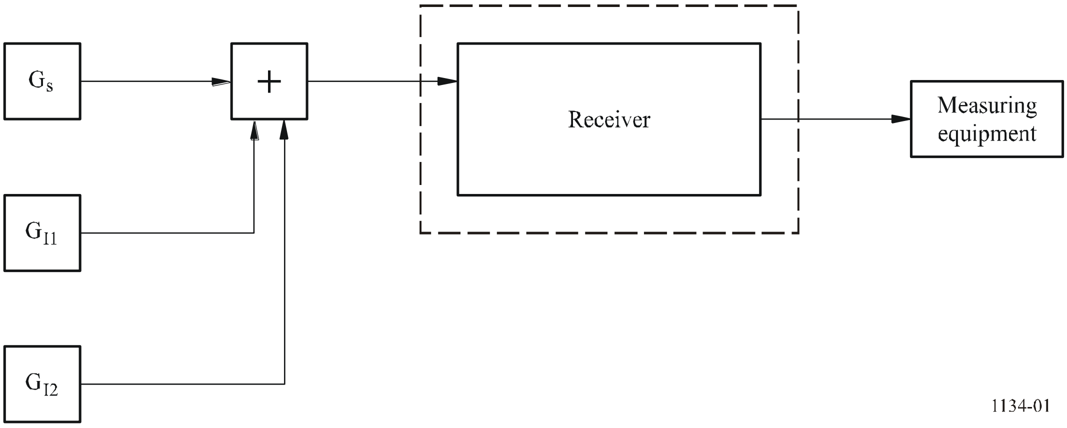
$$\frac{\Delta f_1 + \Delta f_2}{2}$$

2 Receiver intermodulation interference characteristics

In Fig. 1, G_s is the signal generator of the wanted signal (WS). G_{I1} and G_{I2} are the signal generators of the interfering signals (IS) which constitute the RXIM product. These signals are applied to the input of the receiver (RX).

FIGURE 1

Block diagram for receiver intermodulation measurements



When measuring the RX intermodulation characteristic, there are two IS with equal levels from the generators G_{I1} and G_{I2} and the WS with level P_{sr}, from the generator G_s that are carried to the RX input. The frequency detuning of the first IS is chosen equal Δf_0, as for the second IS – it is approximately equal $2\Delta f_0$. The level of both IS at the RX input is increased until $P_I(IM)$ is reached when the reception quality of the WS should not reduce below a specified value. The reception quality is definitely connected with protection ratio A.

Note that:

P_{sr}: sensitivity of radio receiver (dBW)

$P_I(IM)$: the sensitivity to intermodulation, that was measured for the receiver (dBW).

Therefore, according to equation (1):

$$P_{ino} = 3P_I(IM) - 2\beta(\Delta f_0) - \beta(2\Delta f_0) - K_{2,1} \tag{4}$$

This level is related to P_{sr} as follows:

$$P_{sr} - A = P_{ino} \tag{5}$$

$K_{2,1}$ is therefore:

$$K_{2,1} = 3P_I(IM) - 2\beta(\Delta f_0) - \beta(2\Delta f_0) - P_{sr} + A \tag{6}$$

3 Procedure for receiver intermodulation analysis

3.1 General model

Interferences caused by intermodulation products (IMP) in the receiver occur when the following two conditions are fulfilled:

$$F_R - 0.5 \cdot B_{IF} \le f_{IMP} \le F_R + 0.5 \cdot B_{IF} \tag{7}$$

and

$$P_s - P_{ino} < A \tag{8}$$

where:

- f_{IMP}: frequency of the IMP under consideration
- F_R: tuning frequency of the receiver
- B_{IF}: passband value of the IF stage or based band filter bandwidth if there is no IF stage
- P_s: power of a useful signal (dBm)
- P_{ino}: equivalent power of the IMP interference recalculated to the input of the receiver (dBm)
- A: co-channel protection ratio.

P_{ino} is given by equation (1). In view of equation (1), condition (8) may be rewritten as:

$$2P_1 + P_2 - P_s > R_0 \tag{9}$$

where:

$$R_0 = -A + 2\beta_1 + \beta_2 + K_{2,1} \tag{10}$$

3.2 IMP calculation method based on intercept points

3.2.1 In cases of absence of an opportunity of measurement of the receiver $K_{2,1}$ factor, for determination of IMP interference it is expedient to take advantage of such parameters as IP_i – intercept points of i-th order, where i = 2, 3 and 5, and IM_i factors of the same orders for microcircuits which are used in input stages (preselectors and mixers) of modern receivers. Parameters IP_i and IM_i are available from corresponding specifications.

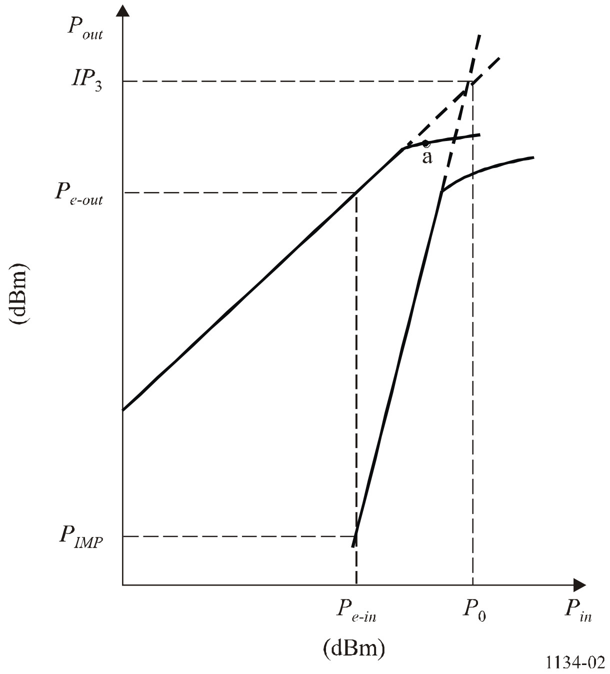
The most widespread is parameter IP_3 (ITU Handbook on Spectrum Monitoring, 2002, § 6.5) – "the third-order intercept point" – a theoretical level, at which the level of 3rd order IMP is equal to individual levels of incoming signals (two equal signals generating IMP such as $2f_1 - f_2$ and $2f_2 - f_1$) recalculated to the output of a non-linear element (see Fig.2).

Parameters IP_i characterize degree of linearity of input stages of the receiver in the sense of their ability to generate IMP of corresponding orders. The higher IP_i levels, the better linearity of the receiver and wider its dynamic range and, therefore, the greater levels of incoming signals at which IMP are produced and better protection of the receiver against IMP interferences.

IM_i factors characterize a susceptibility of the receiver to IMP of corresponding orders. They represent relation of IMP level at the receiver output to a level of incoming signals at its input (two equal signals generating IMP at the output).

FIGURE 2

Third-order intercept point IP_3



Average values and variation limits of parameters of microcircuits used as input stages of receivers (preselectors and mixers), provided by the most known manufacturers, are presented in Table 1. Individual values of these parameters can be obtained from the engineering specifications on relevant equipment. Parameter *G* in Table 1 represents amplification factor of the preselector, and dBc designates decibels relative to the unmodulated carrier power of the emission.

TABLE 1

Parameters of microcircuits of input stages of receivers

G **(dB)**	**IP_3 (dBm)**	**IM_2 (dBc)**	**IM_3 (dBc)**	**IM_5 (dBc)**
12 ± 5	28 ± 5	–24 ± 5	–30 ± 5	–35 ± 5

Calculating formulas for IMP components that can fall into IF passband of the receiver are given in Table 2 which presents:

f_{IMP}: IMP frequencies of 2nd, 3rd and 5th orders generated by two or three incoming signals

$P_{e\text{-}in}$: the power of the equivalent incoming signal at the input of the receiver – two or three incoming signals at the input of the receiver with equal levels $P_{e\text{-}in}$ are generating the same IMP as incoming signals with different levels P_1, P_2, P_3

P_{IMP}: IMP levels of 2nd, 3rd and 5th orders resulted by two or three incoming signals at the input, where P_1, P_2, P_3 – powers of incoming signals at frequencies f_1, f_2, f_3 correspondingly. Values of *PIMP* are expressed in terms of IP_i and IM_i.

TABLE 2

IMP interferences of 2nd, 3rd and 5th orders under 2 or 3 unwanted incoming signals

Frequency, f_{IMP}	$f_g \pm f_h$ ($f_g > f_h$)	$2f_g - f_h$	$f_k + f_l - f_m$	$3f_g - 2f_h$	$2f_k - 2f_l + f_m$
The order and type of products	2 (1; 1)	3 (2; 1)	3 (1; 1; 1)	5 (3; 2)	5 (2; 2; 1)
$P_{e\text{-}in}$ (dBm)	$(P_g + P_h)/2$	$(2P_g + P_h)/3$	$(P_k + P_l + P_m)/3$	$(3P_g + 2P_h)/5$	$(2P_k + 2P_l + P_m)/5$
P_{IMP} (dBm)	$2 (P_{e\text{-}in} + Gi - IP_2$	$3 (P_{e\text{-}in} + G) - 2 \cdot IP_3$	$3 (P_{e\text{-}in} + G) - 2 \cdot IP_3 + 6$	$5 (P_{e\text{-}in} + G) - 4 \cdot IP_5$	$5 (P_{e\text{-}in} + G) - 4 \cdot IP_5 + 9.5$
	$IM_2 + P_{e\text{-}in}$	$IM_3 + P_{e\text{-}in}$	$IM_3 + P_{e\text{-}in} + 6$	$IM_5 + P_{e\text{-}in}$	$IM_5 + P_{e\text{-}in} + 9.5$

In Table 2 for frequencies of IMP f_{IMP} and for IMP levels $P_{e\text{-}in}$ of various subscript indexes are determined as follows.

For two incoming signals: each index g and h accepts one of two values 1 or 2 under the condition:

$$g + h = 3$$

For three incoming signals: each index k, l and m accepts one of three values 1, 2 or 3 under the condition:

$$k + \mathrm{l} + m = 6$$

Calculations of IMP levels $P_{e\text{-}in}$ for various IMP components should be made for the same distributions of indexes as for calculation of frequencies f_{IMP} of these components.

Table 2 also shows the number of components f_{IMP} and possible number of different IMP levels $P_{e\text{-}in}$ of various orders under different levels of incoming signals. From formulas for $P_{e\text{-}in}$ it can be concluded that at different levels of incoming signals different IMP component at the output for the same order also have various levels which lend themselves to calculation by this method.

Relationships between IP_i and IM_i levels can be found by equating P_{IMP} values in Table 2:

$$IP_2 = P_{e\text{-}in} + 2G - IM_2$$

$$IP_3 = P_{e\text{-}in} + 0.5\ (3G - IM_3)$$

$$IP_5 = P_{e\text{-}in} + 0.25\ (5G - IM_5)$$

The equivalent IMP level recalculated to the input of the receiver P_{ino} is equal:

$$P_{ino} = P_{IMP} - G$$

To attenuate unwanted incoming interfering signals, diplexing or passband filters are usually installed at receiver inputs before preselectors. Parameters of filters (under trapezoidal shapes of their characteristics) are: the passband B_{RF1}, the border of the attenuation band B_{RF2} and attenuation of incoming signals $\beta(\Delta f)$ outside the passband (at $\Delta f > 0.5 \cdot B_{RF2}$ the attenuation is considered as to be constant and equal L_F dB).

In that case insertion losses of the filter (dB) are:

$$\beta(\Delta f) = \begin{cases} 0 & \text{at } |\Delta f| \le 0.5 \cdot B_{RF1} \\ a \cdot |\Delta f| + c & \text{at } 0.5 \cdot B_{RF1} \le |\Delta f| \le 0.5 \cdot B_{RF2} \\ L_F & \text{at } 0.5 \cdot B_{RF2} \le |\Delta f| \end{cases}$$

where: $|\Delta f|$ – frequency offset of the incoming signal at the receiver input

$$a = L_F / 0.5\,(B_{RF2} - B_{RF1})$$

$$c = -\,0.5 \cdot a \cdot B_{RF1}$$

The power of the signal at the input of the preselector P_j at frequency f_j (j = 1; 2; 3) equals:

$$P_j = P_{j\text{-}in} - \beta\,(\Delta f)$$

where $P_{j\text{-}in}$: the power of the incoming signal at the input of the receiver.

3.2.2 Procedure of IMP interference calculation contains the following steps

Step 1: Determination of attenuation of incoming signals acting at the input of the receiver by input filters $\beta\,(\Delta f_j)$, j = 1; 2; 3.

Step 2: Calculation of levels of the incoming signals acing at the input of the preselector P_j.

Step 3: Determination of IMP levels at the output of the mixer P_{IMP}.

Step 4: Estimation of the equivalent IMP level recalculated to the input of the receiver P_{ino}.

Step 5: Calculation of the signal – interference ratio at the input of the receiver R.

Step 6: Comparison of the signal – interference ratio R with the protection ratio A for determination of compatibility conditions of the receiver with other radio-electronic systems in the particular electromagnetic environment.

3.2.3 Example of calculations

Let us suppose that it is required to calculate IMP interference of a kind $f_1 + f_2 - f_3$ in the receiver and to estimate its harmful effect.

Entries: IP_3 = 24 dBm; G = 15 dB; $P_{1\text{-}in}$ = –50 dBm; $P_{2\text{-}in}$ = –10 dBm; $P_{3\text{-}in}$ = –15 dBm; P_s = –114 dBm;A = 9 dB; L_F = 30 dB.

Let frequency offsets of the incoming signals at the input of the receiver $|\Delta f_j| = |F_R - f_j|$ are:

$$|\Delta f_1| \le 0.5 \cdot B_{RF1};\ |\Delta f_2| > 0.5 \cdot B_{RF2} \text{ and } |\Delta f_3| > 0.5 \cdot B_{RF2},$$

i.e. one incoming signal lies in the passband of the input filter of the receiver and other two incoming signals – outside of the passband.

In this case:

$$\beta\,(\Delta f_1) = 0;\ \beta\,(\Delta f_2) = \beta\,(\Delta f_3) = 30 \text{ dB}$$

$$P_j = P_{j\text{-}in} - \beta\,(\Delta f_j);\ P_1 = -50 \text{ dBm};\ P_2 = -40 \text{ dBm};\ P_3 = -45 \text{ dBm}$$

Let's calculate $P_{e\text{-}in}$ and P_{IMP} with the help of equations of Table 2:

$$P_{e\text{-}in} = (-50 - 40 - 45)/3 = -45 \text{ dBm}$$

$$P_{IMP} = 3\,(-45 + 15) - 2 \cdot 24 + 6 = -132 \text{ dBm}$$

$$P_{ino} = P_{IMP} - G = -132 - 15 = -147 \text{ dBm}$$

$$R = P_s - P_{ino} = -114 - (-147) = 33 \text{ dBm}$$

$R > A$ and, therefore, in accordance with equation (8) compatibility is provided.

4 Power of transmitter intermodulation products

The power P_i of the intermodulation product occurring in the transmitter and subsequently reaching the receiver input may be written as:

$$P_i = P_2' - \beta_{12} - \beta_{10} - K_{(2),1} - L_{10} \quad (11)$$

where:

- P_2': interfering transmitter power (with frequency f_2) at the output terminals of the affected transmitter (with frequency f_1), in which the intermodulation products occur (dBW)
- β_{12}, β_{10}: attenuation due to the output and antenna circuits of the affected transmitter at frequency f_1 to interfering transmitter at frequency f_2, and to intermodulation product at frequency f_0, respectively (dB)
- $K_{(2),1}$: intermodulation conversion losses in the transmitter (dB) which is different from $K_{2,1}$ in equation (1)
- L_{10}: attenuation of intermodulation product on the path between the transmitter with frequency f_1 and the receiver (dB).

Interference caused by TXIM occurs when:

$$P_s - P_i < A \quad (12)$$

where A is the co-channel protection ratio.

5 Probability of interference

5.1 Probability of RXIM interference

Recommendations ITU-R P.370, ITU-R P.1057 and ITU-R P.1146 point out that, due to fading, the wanted and interfering signal levels are random variables with a log-normal distribution. Hence, the left side of condition (9), expressed in dBW, represents the sum of independent normal random quantities and constitutes a normal random quantity. The mean value $\overline{R}$ and dispersion σ_R^2 of the random quantity $R = 2P_1 + P_2 - P_s$ are equal, respectively, to:

$$\overline{R} = 2P_{1m} + P_{2m} - P_{sm}$$
$$\sigma_R^2 = 4\sigma_1^2 + \sigma_2^2 + \sigma_s^2$$

where:

P_{1m}, P_{2m}, P_{sm} are mean values and $\sigma_1^2, \sigma_2^2, \sigma_s^2$ are dispersions of wanted and interfering signal power levels at the receiver input (determined on the basis of the data contained in Recommendations ITU-R P.370, ITU-R P.1057 and ITU-R P.1146.

5.2 Probability of TXIM interference

Taking account of equation (11), condition (12) assumes the form:

$$P_2' - P_s - L_{10} > T_0 \quad (13)$$

where:

$$T_0 = \beta_{12} + \beta_{10} + K_{(2),1} - A$$

The mean value $\overline{T}$ and dispersion σ_T^2 of the random quantity:

$$T = P_2' - P_s - L_{10}$$

are equal respectively to:

$$\overline{T} = P_{2m}' - P_{sm} - L_{10m}$$
$$\sigma_T^2 = \sigma_2^2 + \sigma_s^2 + \sigma_1^2$$

where:

P_{2m}', P_{sm}, L_{10m}: mean values

$\sigma_2^2, \sigma_s^2, \sigma_1^2$: dispersions of the random quantities P_2', P_s, L_{10}.

5.3 Probability of intermodulation products

The probability α that intermodulation products, generated both in the receiver itself and as a result of intermodulation in the transmitter (conditions (9) and (13), respectively), will occur during reception is equal to:

$$\alpha = \int_x^\infty e^{-t^2/2} \frac{dt}{\sqrt{2\pi}} \tag{14}$$

$x = \left(R_0 - \overline{R}\right)/\sigma_R$: on determination of the probability of intermodulation products occurring in receivers (condition (9));

$x = \left(T_0 - \overline{T}\right)/\sigma_T$: on determination of the probability of interference due to intermodulation products occurring in transmitters (condition (13)).

In determining the zones affected by intermodulation interference on the basis of a given value of probability of interference α, the value of x is first determined from equation (14). Then for a known value of P_{sm} one can determine the permissible values of P_{1m} and P_{2m} (or P_{2m}' and L_{10m}) and the corresponding necessary geographical spacings of interfering transmitters and receiver, on which the zone affected by the interference will depend.