Abstract: The effects of mutual interference to Radio system's reliability become more crucial than the classical noise sources, especially for co-located transceivers. The main reason is the tremendous increase in the number of equipments and users of the Radio spectrum bands and the significant improvements in transceivers technology. This paper analyzes Non Linear Desensitization effects which are the main sources of mutual interference especially under co-sited operation conditions. A summary of desensitization blocking saturation, and reciprocal mixing effects are presented. Computation methods are provided as well as mitigation techniques including novel Digital Signal Processing Methods. Scenarios are analysed and application of semi empirical computation methods result in significant improvements under severe co-site conditions with minimum sensitivity reduction of the system receiver.

1. INTRODUCTION

In nowadays Radio Systems the limitation of intra and inter mutual interference between systems become more important than the previous limit of internal and external natural and man-made noise due to: 1. The tremendous increase in the number of equipments and Radio spectrum users. 2. Significant improvements in Receivers (Rx) front end amplifier and frequency converter stages noise figure and improvements in Transmitters (Tx) synthesizers and filters. The harmful effects of mutual interference to Radio systems reliability and performances are most significant in co-sited situations. Where several radio equipments may operate simultaneously from the same location on the ground, ships, aircrafts or space platforms with significant coupling between their respective antennas [1,2]. The main co-sited disturbance is desensitization to Radio Communication, Radio Detection And Ranging (RADAR), telemetry, and other Radio Systems.

2. DESCRIPTION OF DESSENSITIZATION EFFECTS

Receivers desensitization occurs when a strong adjacent signal of frequency $f_s \pm \Delta f$ causes an apparent decrease in the victim Rx gain at the desired frequency $f_d$, followed by an increase in the overall noise figure and a consequent decrease in the signal to noise S/N ratio of the desired signal denoted by $P_{d\text{Rx}}$. Strong desensitization effects are generated from co-sited interfering Tx or from adjacent frequency remote high power sources and may disturb or even completely block the victim Rx. Desensitization disturbance is broadband in frequency for numerous adjacent channels and may be generated even from a single adjacent channel interfering Tx [2,3].

Thus, the desensitization probability of occurrence is higher than from the Inter Modulation ("IM") or from most of the other mutual interference source. Consequently, potentially victim Rx have to be protected from desensitization. In several cases, Rx are not sufficiently protected from the desensitization effect and severe harmful interference result from interfering Tx. In other cases, overdesign results in a complete immunity of Rx, but the price is an increase in the system complexity, cost and global noise figure, reduction of the sensitivity threshold power level and of the system operation range. Therefore, an optimal approach for desensitization immunity is recommended from the predesign stages of Radio Communication Systems [2,4].

3. INVESTIGATION STEPS FOR ANALYSIS OF DESENSITIZATION EFFECTS

The main investigation steps for co-sited victim Rx immunity from severe desensitization effects are as follows:

a. Definition of realistic worst case scenarios in Radio Communication System:

b. Development of an efficient computation method to quantify the desensitization effects on the victim Rx front-end stages.

c. Production of tables and graphs showing the victim Rx loss of sensitivity as a function of frequency intervals $\Delta f$ from interfering Tx, with the front end characteristics as parameters:

d. Provision list of Rx front-end circuits parameters and of local frequency allocation restrictions required to approach immunity from desensitization effects [5,6].

e. Analysis of mitigation techniques useful for reducing radio systems desensitization without reducing significantly the Rx and system operation range.

To illustrate the desensitization analysis techniques the following scenarios have been selected:

(I) - Tactical VHF/FM/FSK mobile radio communication system operating in the 30 to 88 MHz frequency range. The output power of the FM transmitter is assumed to be 50W using vertically polarized $\lambda/2$ dipole antennas. The main desensitization effects is from the saturation of the Rx preamplifier which will be analyzed and computed [7].

(II) - A HF mobile radio communication system operating in the 2 to 30 MHz frequency range. The output peak power is assumed to be 100W and the main desensitization effect is reciprocal mixing which will be analyzed [8].

4. ANALYSIS AND COMPUTATION OF DESENSITIZATION FROM PREAMPLIFIER SATURATION

The Rx Signal to Noise S/N without and with desensitization $(S/N)'$ are equal to:

$$S/N = P_d \cdot P_{ref} \cdot (S/N)_{ref}$$

(1)

$$(S/N)' = (S/N) \cdot L_{des}$$

(2)

where $L_{des} = \left[ \frac{P_{des} \cdot P_{sat}}{R} \right]$ (3)

Since the RF preamplifier in the VHF band will first be blocked, the loss of sensitivity $L_{des}$ can be calculated from the empirical equations developed in [3] where the desensitization rate $R$ is.
The desired power level \( P_d \) depends on the actual Rx operating field conditions for the ambient noise and interference environments. Two sensitivity threshold power levels of \( P_d(1) = -103 \text{ dBm} \) and \( P_d(11) = -93 \text{ dBm} \) at the worst case frequency range \( f_0 = 35 \text{ MHz} \) are used, which is equivalent to a 10-dB SINAD at the Rx output.

\[
P_{ref} = 10 \log KT + 10 \log B + F_{rec} + 6
\]

where \( K \) is the Boltzmann constant, \( T \) the ambient temperature of 300°K, \( B \) the noise equivalent bandwidth, and \( F_{rec} \) the Rx equivalent noise figure for \( KT = 4.15 \times 10^{-21} \text{ J} \) and \( f_0 = 14 \text{ KHz} \). \( F_{rec} = 8 \text{ dB} \) and \( P_{ref} = -119 \text{ dBm} \). Using the worst case threshold power levels \( P_d \) for \( (S/N)_1 \) and \( (S/N)_II \) we obtain respectively: \(-103 + 119 + 10 = 26 \text{ dB and 36 dB} \).

Using (4.5) \( R_1 = 0.84 \) and \( R_1 = 0.94 \). Thus from (3) the RF Amplifier stage sensitivity as a function of the coupling \( AT \) between antennas is given by the semi-empirical expression:

\[
A_f = 10 \log \left[ 1 + 275 \alpha^2 + 28.10^6 \alpha \right] \text{ dB}
\]

where \( \alpha = \left( f_s / f_0 \right) - \left( f_s / f_0 \right) \) (8)

and \( f_s \) is the disturbing Tx frequency equal to \( f_0 \pm \Delta f \).

The frequency attenuations contributed by Butterworth derived filters BPF1 and BPF2 shown in Figure 1 are given by the semi-empirical expression [7],

\[
\Delta f = 10 \log \left[ 1 + 275 \alpha^2 + 28.10^6 \alpha \right] \text{ dB}
\]

where \( \alpha = \left( f_s / f_0 \right) - \left( f_s / f_0 \right) \)

The desensitization parameters and computed results graphs are presented in Table 1 and in Figure 2 as a function of \( \Delta f \). By increasing \( \Delta f \) to 1000 KHz, for instance, and using the parameters of Figure 1, we obtain that: \( A_f = 7.0 \text{ dB}, P_{vi} = 24.0 \text{ dBm} \). The output power level of the saturated amplifier \( P_{sat} \) is 14 to 16 dBm.

\( P_{sat} = 2.0 \text{ to } 4.0 \text{ dBm} \), and \( P_{sat} = 4.0 \text{ to } 2.0 \text{ dBm} \). The mixer and buffer stages will become unblocked as their input power level will fall below the \( P_{sat} \) level. Thus only, the RF amplifier stage influences the desensitization effects for large \( \Delta f \). For \( f_0 = 35 \text{ MHz}, \Delta f = f_0 \pm \Delta f, P_{vi} = 50 \text{ w} \) and \( d \) is 1.0 m. [6]

When the victim Rx operates for maximum sensitivity conditions the RF amplifier will remain blocked up to an increase of \( \Delta f \) to about 

\[
\text{where } \Delta f = 2000 \text{ KHz. Hence, } \Delta f = 2000 \text{ KHz. However, the } \Delta f \text{ has to exceed 6000 KHz in order that the desensitization effects should be completely neglected [3]. Desensitization effects for remote transceivers can be represented by curves of frequency differences } \Delta f = |f_s - f_0| \text{ as a function of the distance } d_{TX} \text{ between the antennas as shown in the scenario of Figure 1 where } d_{TX} = 1 \text{ m. [6]}

The loss of Rx sensitivity as a function of the coupling \( AT \) between the interfering Tx and victim Rx antennas can be calculated from equation 1 to 8. For practical purposes \( AT \) can be translated into a minimum interfering distance \( d_{min} \) between Tx and Rx using a modified free space line of sight (LOS) equation.

**Table 1**

<table>
<thead>
<tr>
<th>( f_0 )</th>
<th>( \Delta f )</th>
<th>( AT )</th>
<th>( (S/N)_1 )</th>
<th>( (S/N)_II )</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00</td>
<td>0.5</td>
<td>0.7</td>
<td>12.5</td>
<td>16.0</td>
</tr>
<tr>
<td>7.50</td>
<td>1.0</td>
<td>0.5</td>
<td>10.0</td>
<td>16.0</td>
</tr>
<tr>
<td>10.0</td>
<td>1.5</td>
<td>0.3</td>
<td>8.5</td>
<td>16.0</td>
</tr>
<tr>
<td>12.5</td>
<td>2.0</td>
<td>0.1</td>
<td>7.0</td>
<td>16.0</td>
</tr>
<tr>
<td>15.0</td>
<td>2.5</td>
<td>0.0</td>
<td>5.5</td>
<td>16.0</td>
</tr>
</tbody>
</table>

*The desensitization effect can be neglected*
Replacing front end stages by preamplifier and/or frequency converters characterized with higher $P_{1, DB}$ gain compression power levels. Push-Pull MOSFET preamplifier has been implemented with typical characteristics: $G_{0} = 10$ dB, $P_{1, DB} = 36$ dBm and 10 W DC power supply requirement. Double Balanced Mixer passive or active Paramixer, for instance, with typical characteristics: $F = 3.5$ dB, $G_{p} = 10$ dB. $P_{ids} = 315$ dBm and 7 W DC power supply requirement [5].

This enhancement of dynamic range enables proper operation under strong interfering power excitations, even for very small $\Delta f$. The price however, is high cost, high power consumption and L.O. drive, bulky dimensions and heavy weight due to high power dissipation requirements [2].

Introducing negative feedback in the front end preamplifier circuit. The price is a small reduction in amplifier gain and in Rx sensitivity but the decrease of desensitization effects is not significant.

Introducing dual mode front-end operation most radio systems operate with a low Transmit/Receive time ratio [5]. Therefore most of the time the collocated Rx operates with maximum sensitivity. However, when the total interfering power level at the Rx input exceeds the desensitization threshold limit a fast electronic switch connects a selective high insertion loss BPF and/or higher upper dynamic range circuits to immunize the system from severe blocking. When the interfering power level decreases below the threshold power level, the Rx is again switched to the sensitive mode [2]. The method can be implemented, for instance, by using two sensitivity threshold power levels of -103 dBm and -93 dBm as presented in chapter 4.

This method is efficient but requires significant modifications and additional cost of the Rx. It is also important to design the input switching diodes circuits for reduced Intermodulation products and low loss of sensitivity from high interference power levels excitation.

Using an Electronic Interference Cancellation Subsystems (EICS) [2]. A sample signal from the potentially interfering Tx is introduced via a coupler or an auxiliary antenna to the Rx. The sampled interfering signal amplitude, time delay an phase are adaptively controlled by special circuitry and compared with the sampled signal from the victim Rx input. The EICS output controlled signal is reintroduced to the Rx diplexer input to cancel the interfering Tx signal [9]. For a well designed EICS an interference power level cancellation of more than 50 dB may be achieved and the protected victim Rx can operate properly even on adjacent channels to the collocated interfering Tx. This very efficient method also requires modifications of the collocated Rx circuits and interferring Tx output connection lines. The special EICS using advanced signal processing techniques, which block diagram is presented in Figure 3, is relatively complex and expensive but very efficient [2, 9].

The new parameters obtained after applying the improvements method are introduced in the computation program to calculate the internal global Rx noise figure $F_{g,n}$, the $P_{1, DB}$ sensitivity and the desensitization parameters. The final Rx new Diplexer filters with $A_{T_{1}} \geq 10$ lg $(1+530 \alpha_{1}^{1} + 1.5.10^{6} \alpha_{1}^{1})$. $L_{1} \geq 5.5$ dB and RF amplifier with $P_{1, DB} \geq 3$ dBm are chosen following an optimization process. An improvement of the required $\Delta F_{T_{1}}$ to 4.3% with full sensitivity and to 3% with reduced sensitivity in the $(S/N)_{II}$ mode were achieved as shown in Table 1 and in the graphs of Figure 2. Applying EICS will significantly reduce the risk of desensitization even for collocated frequency differences of a few hundreds of KHz only.

6. ANALYSIS AND MITIGATION METHODS FOR DESENSITIZATION FROM RX RECIPROCAL MIXING

In most performant HF Rx the antenna is connected via a multiplexer unit to a frequency -up converter without using an HF preamplifier stage due to the reduced ambient sensitivity [7]. Therefore the main victim to interfering desensitization is the Rx frequency converter stage.

The novel generation of Rx, even for VHF ranges, will use DSP techniques to reduce optimally and automatically the effects of noise and interference. These digital Rx require an input Digital to Analog converter as close as possible to the antenna. However the Nyquist sampling criteria impose limitations in the input frequency band, which requires a frequency down converter preceding the amplifier stages [2]. An important mechanism related to frequency converter desensitization process is the reciprocal mixing. As depicted in Figure 4, an interfering signal $P_{des}$ reaching the input of a frequency converter stage generates mixing products with the spurious sideband noise of the LO signal $P_{LO}$. applied to the same frequency converter stage due to slight non linear effects. Part of the mixing products fall in the stage output Intermediate Frequency (IF) band even when the $P_{des}$ frequency falls outside the IF band and would not produce any interference in case of an ideal LO without noise (which of course does not exist). Thus, interfering signal increases the mixer output distortion and loss of sensitivity for the desired signal output $P_{out}$ because of reciprocal mixing desensitization. It has been shown experimentally that with strong interfering signals, the output distortion may become stronger than the desired output signal and the Rx operation is thus completely disturbed especially for low $\Delta f$ between the interfering and the desired frequencies. The frequency converter desensitization threshold input power level also depends on the LO power level drive $P_{LO}$ as shown in Figure 5 [3].

A typical HF system synoptic diagram is presented in Figure 5. The desensitization performance requirement is that, the signal output shall not be compressed by more than 3 dB for interfering signals separated more than 50 KHz with a desired signal of -107 dBm at the Rx input [2, 3].

For a worst case cosited distance of 2m semi-empirical equations are developed [10]. Partial results are presented in tables 2 and 3 the parameters shown in figure 6.
Table 2

<table>
<thead>
<tr>
<th>( f_0 ) (MHz)</th>
<th>( P_{TR} ) (dBm)</th>
<th>( L_1 ) (dB)</th>
<th>( P_1 ) (dBm)</th>
<th>( F_{eq} ) (dB)</th>
<th>( L_s' ) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 5 (3.95)</td>
<td>30</td>
<td>6</td>
<td>24</td>
<td>42.1</td>
<td>3</td>
</tr>
<tr>
<td>5 to 12 (9.30)</td>
<td>34</td>
<td>5</td>
<td>29</td>
<td>38.2</td>
<td>10.8</td>
</tr>
<tr>
<td>12 to 20 (15)</td>
<td>30</td>
<td>4</td>
<td>26</td>
<td>30.9</td>
<td>14.8</td>
</tr>
<tr>
<td>20 to 30 (26.10)</td>
<td>25</td>
<td>3</td>
<td>22</td>
<td>21.7</td>
<td>18.3</td>
</tr>
</tbody>
</table>

TR, \( L_1 \), and \( P_1 \) functions are indicated in figure 6. \( F_{eq} \) is the Rx global noise figure and \( L_s' \) is the worst case desensitization losses for \( \Delta f \geq 700 \text{KHz} \). Table 2 indicate that only for the lower 2 to 5MHz range the desensitization losses are limited. However at this frequency range the global noise figure is the highest which reduce significantly the Rx sensitivity.

Table 3

<table>
<thead>
<tr>
<th>( \Delta f ) (KHz)</th>
<th>( L_{sen} ) (dB)</th>
<th>( \Delta f/\Delta f_0 ) (%)</th>
<th>( (\text{SINAD})' ) dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>28.5</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>190</td>
<td>22.2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>285</td>
<td>18.6</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>475</td>
<td>14.2</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>700</td>
<td>10.8</td>
<td>7.4</td>
<td>0</td>
</tr>
<tr>
<td>2500</td>
<td>7.8</td>
<td>26.3</td>
<td>4.0</td>
</tr>
<tr>
<td>3140</td>
<td>6.0</td>
<td>33.0</td>
<td>7.0</td>
</tr>
<tr>
<td>3550</td>
<td>3.0</td>
<td>37.4</td>
<td>10.8</td>
</tr>
<tr>
<td>4500</td>
<td>7.8</td>
<td>47.4</td>
<td>14.8</td>
</tr>
<tr>
<td>4800</td>
<td>6.0</td>
<td>51.1</td>
<td>18.3</td>
</tr>
<tr>
<td>5080</td>
<td>3.0</td>
<td>53.5</td>
<td>22.2</td>
</tr>
</tbody>
</table>

Using a 4 sections sub-octave filter we conclude that for \( \Delta f < 700 \text{KHz} \) the victim Rx is completely desensitized [10].

For \( \Delta f = 700 \text{KHz} \), \( L_s' = 10.8 - A_{AD} \) which show that a frequency attenuation of at least \( A_{AD} = 7.8 \text{dB} \) is required to achieve \( L_s \leq 3 \text{dB} \) with a SINAD \( \geq 7 \text{dB} \). The Rx frequency response characteristic for desensitization is not symmetrical. In order to achieve a \( (\text{SINAD})' \geq 7 \text{dB} \) are required \( \Delta f \geq 3550 \text{KHz} \) \( (37.4\%) \) and for the lower frequency \(-\) range \( \Delta f \leq 5080 \text{KHz} \) \( (51.1\%) \) as shown in the graph of figure 6.

Thus, the sub-octave 4 section filter cannot protect the collocated Rx from desensitization generated by the co-shared intrasystem Tx for small separation distances between the antennas and special mitigation methods are required for reducing desensitization effects. Most of the mitigation techniques for the VHF Rx systems presented in Chapter 5 can also be useful for the HF system.

1. The Rx selectivity to interfering signals can be improved by increasing the number of the sub-octave input filter frequency ranges. From 4 to 6 sections or more [6] but significantly increases the filter complexity without properly reducing the loss of sensitivity [2].

2. The vulnerable first frequency converter can be replaced by a higher dynamic range stage. For instance, a double balanced mixer passive or active paramixer stage with typical characteristics \( P = 7 \text{dB} \), \( P_{d} = 32 \text{dBm} \), \( P_{IP_1} = 45 \text{dBm} \), \( P_{IP_2} = 20 \text{dBm} \) which require a 7W DC power supply [7]. The high increase in the \( P_{IP_1} \) and \( P_{IP_2} \) power level will significantly reduce the loss of sensitivity and desensitization effects of the first frequency converter stage, even for small \( \Delta f \). The price is an increase in cost and in power supply energy consumption and dissipation [2].

3. Introducing dual mode operation is less efficient than for the VHF systems, and requires modifications and additional cost of the Rx [5, 8].

4. An EICS is efficient and can also be applied for several interfering Tx sources but will significantly increase the cost of the Rx system

5. The Rx system first LO output spectral purity can be improved and the phase noise reduced as function of \( \Delta f \). Only slight improvements in the first frequency converter reciprocal mixing desensitization effects are possible due to the good performances \( (-160 \text{dBm/Hz} \) at \( \Delta f = 700 \text{KHz} \) of the actual tested Rx LO stage [8].

In a following paper the mitigation technique parameters are introduced in the computation program to simulate the real improvements in the victim HF Rx concerning co-shared desensitization effects [10].

5. CONCLUSIONS

The main conclusions from the analysis and computation results are as follows:

1. Both the investigated VHF and HF Rx systems are vulnerable to desensitization from a co-shared intrasystem Tx operating respectively at a distance of 1m and 2m between the Tx and Rx antennas.

2. It is obvious that worst case co-shared situations have not been considered during the development steps of the presented radio systems. Therefore radio systems, especially mobile including...
Cosited transceivers require a desensitization analysis from the first steps of their design and mitigation techniques may be applied to achieve high reliability.

3. The VHF cosited system Rx is significantly desensitized and blocked for relative frequency intervals $\Delta f/f_0$ decreasing from 9% to -1.5%, at a tested frequency of 35 MHz using mitigation techniques as shown in Table 1 and Figure 2.

4. The results for the investigated HF Rx using 4 sections front end sub-octave filter show that good quality communication with SINAD's exceeding 7 dB is possible only for relative frequency intervals above 37.4% ($\Delta f \geq 3550$ KHz) for the high interfering frequencies, and under 53.5% for the low interfering frequencies, as shown in Table 3 and figure 6 at a Rx tuned frequency of 9.5 MHz, for instance.

5. Mitigation techniques are mandatory in case of HF cosited operations. The 4 sections sub-octave filter shown in figure 6 has to be replaced by a 6 or 8 sections which decrease desensitization effects for large frequency intervals. However, the improvement is not sufficient as shown in Figure 6 and additional mitigation techniques presented in Chapters 5 and 6 have to be applied.

REFERENCES


![Fig 1. Typical VHF Receiver Stages Synoptic Diagram required Parameters for Desensitzation Effects Computation](image1)

![Fig 2: Electronic Interferences Cancellation System (EICS) Block diagram to mitigate Cosite Desensitization Interference](image2)
Fig 2. VHF System Rx SINAD with realistic worst case desensitization as function of the frequency difference Δf between the Interfering and the desired frequencies. The results are presented for the tested and optimized Rx at two sensitivity power threshold levels.

Fig 3. Block diagram and parameters of the typical HF receiver stages necessary for desensitization effects computation.

Fig 4. Desensitization from reciprocal mixing, where $P_{rx}$ is the desired signal at the Rx IF stage output and $P_{rx}'$ is the interfering signal spectrum at the RF IF stage output.

Fig 5. Block diagram and parameters of the typical HF receiver.

Fig 6. The HF system Rx computerized Ls' and (SINAD) as function of relative frequency intervals, for the worst case desensitization scenario.