

Intermodulation Interference in the GSM/UMTS Bands

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Abstract

This paper deals with the additional and not usually considered Intermodulation (IMD) interference in GSM/UMTS Bands.

First a simple theoretical background about IMD in radio systems will be presented, followed by a practical application of that theory to a real commercial power amplifier.

Finally some practical advices will be given in order to minimize this type of interference.

I. INTRODUCTION

With the recent growing in mobile communication the spectrum available starts to be more limited.

The interferences between frequencies are a very demanding problem for radio frequency engineers, and in this scenario the

intermodulation interference is one of its components usually ignored. The intermodulation in mobile nonlinear systems can generate two different types of interference: the one that will be called in-band, that is generated inside the GSM900 (Global system for Mobile Communications), GSM1800 or UMTS (Universal Mobile Telecommunications System) band and is derived from inside frequencies, and the out-of band interference that is generated mixing terms from the GSM900, GSM1800 or UMTS band, Fig.1.

Recently this type of problem has a greater impact in new radio systems, mainly, because of the high S/I requirements of the emergent UMTS technology. The IMD in this case can degrade the quality and more important the capacity of this systems [1-2].

This paper consists in three different sections, one where the theoretical background will be given, one where a specific real example will be presented and finally a section about practical tips to improve and minimize the effect of the IMD interference.

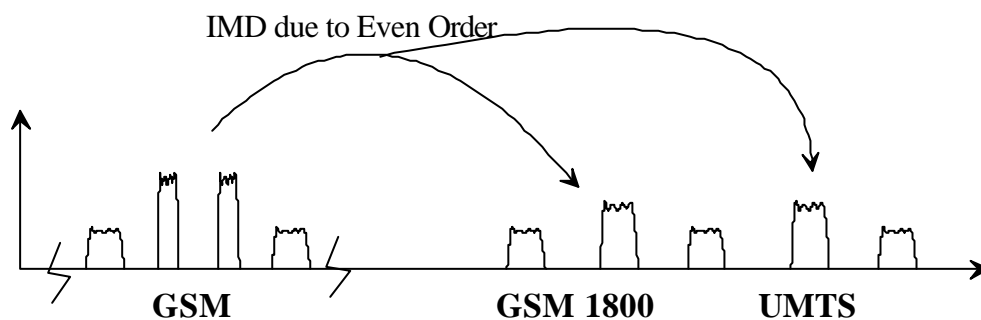


Fig. 1 - IMD in the mobile communications systems.

II. THEORETICAL BACKGROUND

Contrary to any linear system the output of a nonlinear system has output frequencies not only at the same frequency as the input, but at other mixing output components[3]. For instance, consider a third degree nonlinear system where the output can be represented by a 3rd degree polynomial:

$$y[v(t)]=a_1v(t)+a_2v(t)^2+a_3v(t)^3 \quad (1)$$

and the input of this system is a two-tone signal:

$$\begin{aligned} x(t) &= X_1 \cos(\omega_1 t + \phi_1) + X_2 \cos(\omega_2 t + \phi_2) = \\ &= X_1 \frac{e^{j(\omega_1 t + \phi_1)} + e^{-j(\omega_1 t + \phi_1)}}{2} + X_2 \frac{e^{j(\omega_2 t + \phi_2)} + e^{-j(\omega_2 t + \phi_2)}}{2} \quad (2) \end{aligned}$$

$$\begin{aligned} y(t) &= \frac{k_1}{2} \left(X_1 \left(e^{j(\omega_1 t + \phi_1)} + e^{-j(\omega_1 t + \phi_1)} \right) + X_2 \left(e^{j(\omega_2 t + \phi_2)} + e^{-j(\omega_2 t + \phi_2)} \right) \right) + \\ &+ \frac{k_2}{4} \left\{ X_1^2 \left(e^{2j(\omega_1 t + \phi_1)} + e^{-2j(\omega_1 t + \phi_1)} + 2 \right) + X_2^2 \left(e^{2j(\omega_2 t + \phi_2)} + e^{-2j(\omega_2 t + \phi_2)} + 2 \right) + \right. \\ &+ \left. X_1 X_2 \left(e^{j(\omega_1 t + \omega_2 t + \phi_1 + \phi_2)} + e^{-j(\omega_1 t + \omega_2 t + \phi_1 + \phi_2)} + e^{j(\omega_1 t - \omega_2 t + \phi_1 - \phi_2)} + e^{-j(\omega_1 t - \omega_2 t + \phi_1 - \phi_2)} \right) \right\} + \\ &+ \frac{k_3}{8} \left\{ X_1^3 \left(e^{3j(\omega_1 t + \phi_1)} + e^{-3j(\omega_1 t + \phi_1)} + 3e^{j(\omega_1 t + \phi_1)} + 3e^{-j(\omega_1 t + \phi_1)} \right) + X_2^3 \left(e^{3j(\omega_2 t + \phi_2)} + e^{-3j(\omega_2 t + \phi_2)} + 3e^{j(\omega_2 t + \phi_2)} + 3e^{-j(\omega_2 t + \phi_2)} \right) + \right. \\ &+ \left. X_1^2 X_2 \left(6e^{j(\omega_2 t + \phi_2)} + 6e^{-j(\omega_2 t + \phi_2)} + 3e^{j(2\omega_1 t + \omega_2 t + 2\phi_1 + \phi_2)} + 3e^{-j(2\omega_1 t + \omega_2 t + 2\phi_1 + \phi_2)} + 3e^{j(2\omega_1 t - \omega_2 t + 2\phi_1 - \phi_2)} + 3e^{-j(2\omega_1 t - \omega_2 t + 2\phi_1 - \phi_2)} \right) + \right. \\ &+ \left. X_1 X_2^2 \left(6e^{j(\omega_1 t + \phi_1)} + 6e^{-j(\omega_1 t + \phi_1)} + 3e^{j(2\omega_2 t + \omega_1 t + 2\phi_2 + \phi_1)} + 3e^{-j(2\omega_2 t + \omega_1 t + 2\phi_2 + \phi_1)} + 3e^{j(2\omega_2 t - \omega_1 t + 2\phi_2 - \phi_1)} + 3e^{-j(2\omega_2 t - \omega_1 t + 2\phi_2 - \phi_1)} \right) \right\} \quad (3) \end{aligned}$$

Table 1 – Mixing Intermodulation Products

Mixing Product	Frequency	Band
$\omega_1 - \omega_2 + \omega_2$	898.4MHz	GMS 900
$\omega_2 - \omega_1 + \omega_1$	905.8MHz	GMS 900
$2\omega_1 - \omega_2$	891MHz	GMS 900
$2\omega_2 - \omega_1$	913.2MHz	GMS 900
$2\omega_1$	1796.8MHz	
$\omega_2 + \omega_1$	1804.2MHz	TFTS
$2\omega_2$	1811.6MHz	GMS 1800

the output will be similar to expression (3).

As can be seen by the simple expansion presented on (3) the output will have different spectral components at: $\omega_1 + \omega_1 - \omega_1$, $\omega_2 + \omega_2 - \omega_2$, $\omega_1 + \omega_2 - \omega_2$ and $\omega_2 + \omega_1 - \omega_1$ that are coincident with the signal itself, $2\omega_2 - \omega_1$, $2\omega_1 - \omega_2$ that can be considered in-band distortion, $\omega_2 - \omega_1$, that appears at the base-band, $2\omega_1$, $\omega_1 + \omega_2$, $2\omega_2$ at the second harmonic and $3\omega_1$, $2\omega_1 + \omega_2$, $2\omega_2 + \omega_1$, $3\omega_2$ at the third harmonics. In the GSM900/GSM1800/UMTS case the nonlinear distortion can be a problem in three of this different cases: at the in-band signal, at the 2nd harmonic and at the signal that is coincident with the linear output part.

For instance consider the case of a nonlinear system with two GSM 900 carriers at its input; $\omega_1=898.4\text{MHz}$ and $\omega_2=905.8\text{MHz}$ the possible interference output will appear at the mixing frequencies presented on Table 1.

Using the Portuguese commercial spectral division [4] the two principal carriers belong to one operator while the 3rd mixing, 891MHz, belong to the lower operator and the 913.2MHz to the upper operator, Fig. 2, and the 2nd harmonic will fall exactly on the GSM1800 band or TFTS band and could degrade this part of the spectrum. If the nonlinear device is derived with a strong input power than other carriers could be jammed and interferences can occur derived from these distortion components, which will cause interference among mobile operators, Fig.1.

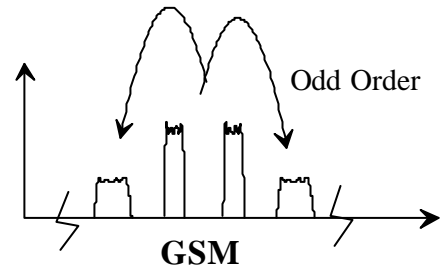


Fig. 2 - In-band IMD.

Similar calculations can be done if a two-tone carrier is considered in the GSM 1800 band, there not only the GSM 1800 can be interfered, but there are mixing terms that can fall in the UMTS band. Consider for example two GSM 1800 frequencies at $\omega_1=1879.8$ MHz, channel 885, and $\omega_2=1805.2$ MHz, channel 512, this two different frequencies can generate a mixing third order product that will fall right into the middle of the UMTS band, and so it will degrade the complete system.

The previous results predict the correct position of the output distortion frequencies. Its computed power is related to the presented power series expression (1). The commercial available power amplifiers datasheets, normally do not present this type of power series to characterize the nonlinearity behaviour. The figure of merit used to relate the linear output power to the intermodulation power is the well known 3^d order Intercept Point, IP3, for the in-band intermodulation.

IP3 is defined as the output power at which the fundamental power intersects the 3^d order intermodulation power, Fig. 3, this point is obviously an hypothetic point, since the power amplifier has already saturated at this output power, nevertheless this figure of merit able the calculation of small signal intermodulation power.

Considering two equal power tones at the input of the power series presented in expression (1), IP3 can be related to the power series as [5]:

$$IP_3 = P_{outo}(\omega_1) = \frac{k_1^2 X^2}{2} = \frac{1}{2} \sqrt{\frac{k_1^6 16}{k_3^2 9}} = \frac{k_1^3 2}{k_3 3} \quad (4)$$

and the two-tone Intermodulation Ratio is defined as IMR₂:

$$IMR_{2dBc} = 2(IP3_{dBm} - P_{OTdBm}) + 6dBc \quad (5)$$

where P_{OTdBm} is the total output power in dBm, $P_{OTdBm} = P_{\omega_1} + P_{\omega_2}$.

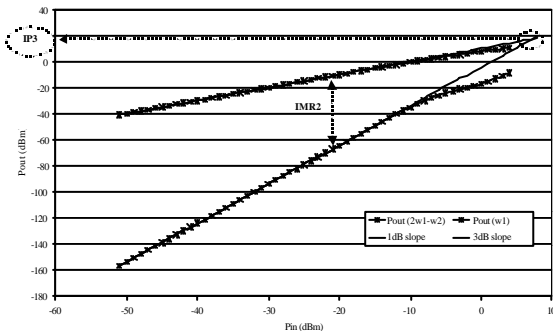


Fig. 3 - IP3 Definition.

III. GSM IMD INTERFERENCE CASE STUDY

Consider a practical example of a GSM booster amplifier. This type of device generate amplification both on the upper and down link; for this case study only the down link will be approached, its block diagram is presented on Fig.4.

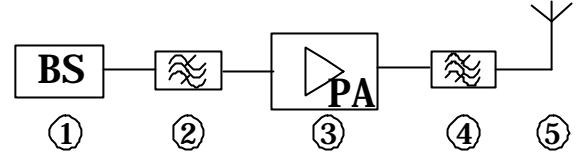


Fig. 4 - Booster line up.

From Fig.4 it is possible to identify: 1 - Base Station, 2,4 - Band Pass Filter, 3 - Power Amplifier (PA) and 5 - Antenna. The booster was considered to be a commercial available from Celwave [6], the main characteristics of this PA are: $G=51dB$, $IP_3=47dBm$, input $P_{1dB}=-8dBm$.

Using the results previously presented on expression (5), and relating them to the input power per tone, the intermodulation power at the IMD frequencies will be:

$$P_{IMD_2} = 3G_{dB} + 3P_{indBm} - 2IP_{3dBm} \quad (6)$$

Now consider that the base station is providing a two GSM, 898.4MHz and 905.8MHz, carriers each one with -11dBm; the power at each distortion component will be:

$$P_{2\omega_1 - \omega_2} = P_{891MHz} = 26dBm, P_{2\omega_1 - \omega_2} = P_{913.2MHz} = 26dBm.$$

Considering a mobile user 1Km away from the base station, the interfered received power centred in the IMD frequencies will be $P_{IMD} = 26 - L_{prop}$, L_{prop} is the attenuation due to the propagation, and considering the best case, only line of sight free space propagation will be accounted for. So for a

$1Km \rightarrow \left(\frac{\lambda}{4\pi d}\right)^2 = -91.5dB$ loss of free space propagation, the received interference will be $P_{IMD} = 26 - 91.5 = -65.5dBm$.

If another carrier signal appears at 913.2MHz then its power should be bigger then $-65.5dBm$ in order not to be masked by the IMD generated by this booster. When the third interfered carrier is from the same commercial operator, this fact is not a problem, because the mobile phone will chose one of the strongest carriers available, unless this two carriers are already fully used. But when it is from another operator, this new component can interfere and jam the other communication channel.

2nd order distortion will appear on the 1800 GSM or UMTS band, but unfortunately the technical characteristics given by the PA supplier are not enough to 2nd order distortion calculations.

The same effect previously presented can occur in many others devices, for example the input low noise amplifier of a mobile phone, or a multicarrier base station.

A. Extrapolation for the GSM1800/UMTS bands

If similar calculations were done for a power amplifier tuned for the GSM 1800 or the UMTS band, similar problems would appear in those services, as was explained in the theoretical study presented.

In the case study only the in-band IMD was considered, using a simple two tone approximation, but if a real signal is to be accounted for, then the resulting spectrum should not be approximated by a two tone sinusoidal input. In that case a more complex input signal should be considered. In the literature this type of signal is usually modelled by a narrow band white Gaussian noise spectra [8]. In that case the measured figure of merit should be a multi-tone figure of merit, and not a two-tone figure of merit.

The multi-tone figure of merit that should be considered is the Adjacent Channel Power Ratio (ACPR) for the in-band distortion and the Noise Power Ratio (NPR) or the newly developed Co-channel Power Ratio (CCPR) for the co-channel distortion [7-8].

These figures of merit can be related to the two-tone IP_3 by using simple relation formulas developed in [7].

So not only the power amplifiers should be more linear, but the operators should pay more attention when installing UMTS multi-carrier boosters.

IV. Minimize IMD Interference

In this section some advices in order to minimize the effects of the IMD interference will be presented. The procedures presented will be used by the telecommunications operators, and so, well known procedures, like for instance linearizers will not be addressed since that is a manufacturer concern.

The first simple way to minimize the intermodulation interference of a power amplifier block is to make some back off in order to operate him in a lower input power, which will minimize the IMD, since for the n^{th} order distortion it will decrease n dB by each dB of input backoff. This is a very simple procedure, but will increase the price of the system, since a power amplifier will be used far from its normal point of operation, thus a stronger amplifier will be used for delivering the same output power.

A more effective way to minimize, not the IMD, but its effects in the overall communication system, is the new frequency hopping systems that are been implemented, both in the GSM and in the UMTS systems. Since in the frequency hopping the carrier frequencies are continuously changing the mixed IMD frequencies will be changing too, and so the same effect that is obtained with other type of interference, like for example multi-path, can be minimized the same way.

An obvious tip is to correctly fulfil all the manufacturer specifications, since a bad connector, or some usually linear

device drove into material saturation can generate intermodulation interference or even worst can be damaged and generate all kind of interference.

V. CONCLUSIONS

In this paper an explanation of the not well-known effects of IMD into GSM/UMTS mobile systems were addressed.

First with a simple theoretically background, some problems were presented, and then a GSM case study of a commercial power amplifier presented. With this example it was obvious that the normal operation of a power amplifier can be disastrously to the correct mobile system operation.

These results were then extrapolated for more complex operation and some advices for IMD minimization was discussed.

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