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MODELLING OF INTERFERENCE CAUSED BY UPLINK SIGNAL FOR LOW EARTH ORBITING SATELLITE GROUND STATIONS

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ABSTRACT
Microsatellites in Low Earth Orbits (LEO) have been in use for the past two decades. Low Earth Orbit satellites are used for public communication and also for scientific purposes. Thus, it may be expected that such missions will be further developed in the near future especially in fields where similar experiments by purely Earth-based means are impracticable. Ground stations have to be established in order to communicate with such satellites, and the quality of communication depends on the performance of the satellite ground station, in addition to that of the satellite. Usually these scientific satellites communicate with ground stations at S-band. The performance of the ground station could be disturbed by intermodulation interference because of permanent presence of uplink signal. Intermodulation products caused by GSM signals and uplink satellite signal are potential to disturb, especially in urban areas [1], [2]. Thus, within these papers the interference of intermodulation products caused by uplink signal and any other radiofrequency signal present in the front end of the ground station's receiving system is analyzed and then modelled. Based on the modelling concept, the intermodulation interference calculator is introduced as a main application point of these papers.

KEY WORDS
LEO, satellite, interference

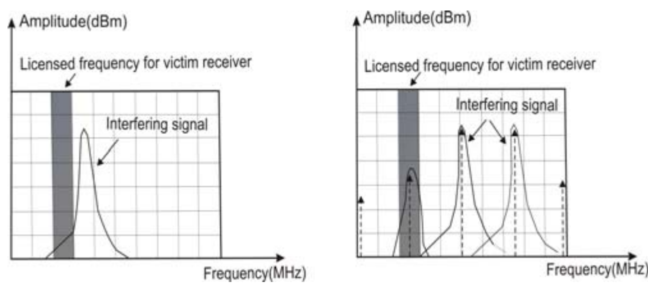
1. Introduction

In principle the typical satellite communication system comprises a *ground segment* and a *space segment*. The basic resources available for communication satellites are *radio frequency spectrum* (RF) and *orbits*. The ground segment consists of all the ground stations. The function of a ground station is to receive information from, or transmit information to, the satellite in the most cost effective and reliable way. The functionality of the ground station can be disturbed because of interference, since interference may be considered as a form of noise. Effects of interference must be assessed in terms of what is tolerable disturbing level to the end user receiver. Interference effect to the end user receiver will depend on the amount of frequency overlap between the interfering spectrum and the wanted channel passband.

From the technical and practical point of view, the following classification of interference should be considered [3].

- *Co - channel interference*
- *Out - of - band interference*

These two scenarios in Fig. 1 are presented.



(a) (b)

Fig. 1. Co-channel interference (a), and out - of - band interference (b)

The receiver hit by interference is called *victim* receiver. The *co-channel interference* occurs when the victim receiver is disturbed by the system or equipment operating at the same frequency as the victim receiver. This is caused by unexpected legal or illegal (unlicensed) signals. Applying strictly the ITU recommendations on emitted power and frequency planning it is possible the co-channel interference to be controlled and minimized [3]. More problematic is *out-of-band interference*. This interference occurs when the victim receiver is hit by signals which are generated by equipment which does not operate in the same frequency as the victim receiver. The phenomenon of generating other signals from one ore more signals is called *intermodulation*.

These new generated signals can unexpectedly fall within a victim receiver licensed passband (Fig. 1b). In case the generated intermodulated signal is too strong, it will not only interfere but it could completely block the desired receiving signal. Through modelling this process, the problem can be analyzed and avoided in advance.

2. Intermodulation Interference

The major source of interference in a satellite communication system is the intermodulation noise generated by nonlinear transfer characteristics of devices. Toward the uplink, the intermodulation noise is mainly generated because of high power amplifier (HPA) nonlinearity. Related to downlink performance, especially in urban areas (presence of GSM, UMTS, WiMax networks) intermodulation should be considered because of low noise amplifier (LNA) nonlinearity. Disturbance introduced due to nonlinearity is known as *intermodulation interference.*

The nonlinear transfer characteristic may be expressed as a Taylor series which relates input and output voltages [4]:

$$e_0 = ae_i + be_i^2 + ce_i^3 + \ldots \quad (1)$$

Here, a, b, c, and so on are coefficients depending on the transfer characteristic, e_0 is the output voltage, and e_i is the input voltage, which consists of the sum of individual carriers. Intermodulation interference components can be classified as:

▪ *Harmonic Products*
▪ *Intermodulation Products*

Harmonic products are single tone distortion products caused by device nonlinearity. When a non-linear device is stimulated by a signal at frequency f_1, spurious output signals can be generated at the harmonic frequencies 2 f_1, 3 f_1... N f_1. The order of the harmonic products is given by the frequency multiplier; for example the second harmonic is second order product. Harmonics are usually measured in dBc, which means dB below the carrier (fundamental) output signal.

Intermodulation products are multi-tone distortion products that result when two or more signals at frequencies f_1, f_2,... f_n are present at the input of a nonlinear device. The spurious products which are generated due to the non-linearity of a device are related to the original input signals frequencies. Analysis and measurements in practice are most frequently done with two input frequencies. The frequencies of the two-tone intermodulation products are:

$$Mf_1 \pm Nf_2 \quad \text{where } M,N = 0,1,2,3,\ldots$$

The order of the distortion product is given by the sum *M+N*. The second order intermodulation products of two signals at f_1 and f_2 would occur at $f_1 + f_2$, $f_2 - f_1$, $2f_1$ and $2f_2$. The third order intermodulation products (component ce_i^3 of Eqn. 1) of the two signals at f_1 and f_2 would be $3f_1$, $3f_2$, $2f_1 + f_2$, $2f_1 - f_2$, $f_1 + 2f_2$ and $f_1 - 2f_2$. These are presented in Fig. 2. Mathematically intermodulation product calculation could result in "negative" frequency, but it is the absolute value of these calculations that is of concern. Broadband systems may be affected by all non-linear distortion products. Narrowband circuits are only susceptible to those in the passband. Bandpass filtering can be an effective way to eliminate most of the undesired products without affecting in band performance (see Fig. 2).

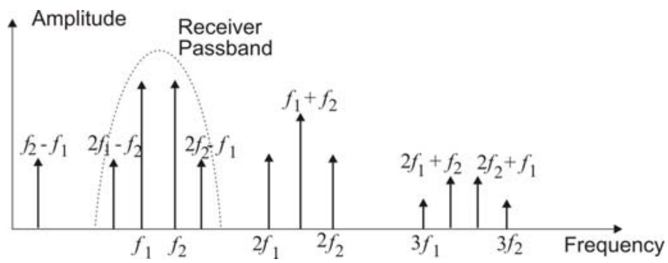


Fig. 2. Second and third order intermodulation products

Third order of intermodulation products are usually too close to the fundamental signals to be filtered out, so the third order (and to a lesser extent fifth order) products contribute the major proportion of the intermodulation noise power. The closer the fundamental signals are to each other, the closer third intermodulation products will be to them. Filtering becomes very hard if the intermodulation products fall inside the passband. These unwanted intermodulation products can occur in receivers and may coincide with the operating frequency of the receiver in which case the wanted signal can be masked. The level of these products is a function of the *power received*. Moreover, the amplitude of the intermodulation product decreases with the order of the product. Further, out-of-band intermodulation products transmitted from the ground stations or satellites result in interference to other systems, also. To minimize such harmful emissions, radio regulations restrict such out-of-band transmissions from ground stations to very low levels [3], [4].

To eliminate the impact of intermodulation products there is no single technical method, but on site experimental investigations are needed. Such approach for LEO ground stations is further clarified.

3. Intermodulation Interference by Uplink Signal

At the ground stations located in urban areas with high density of mobile radio systems it is not easy to eliminate intermodulation interference signals since these are unpredictable. As, above mentioned in case of intermodulation each specific case specifically should be studied.

Satellite ground station in urban area is designed so that, at the receiver input, the level of the signal received from the satellite via the main beam of the ground station antenna exceeds the in-band noise by an adequate margin. But, the unwanted out-of-band inputs, as intermodulation products, generated by the ground station transmit signal and any other radio frequency signal in front of low noise amplifier (for example: signals from nearby mobile system base stations as presented in Fig. 3), even though they are received via sidelobes in the ground station's antenna pattern, they could be higher and mask the wanted signal.

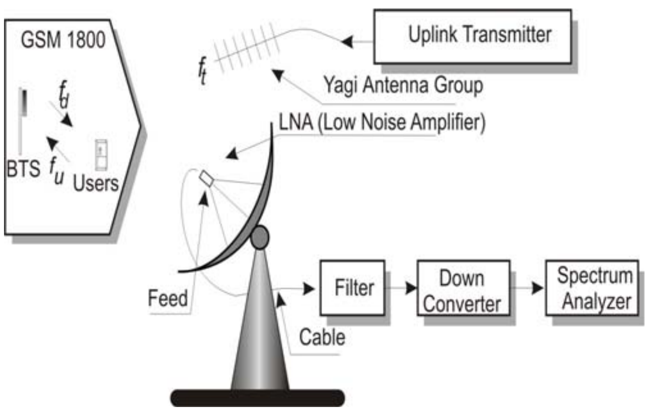


Fig. 3. Intermodulation scenario at satellite ground station

In Fig. 3 is presented the experiment set up which enables to check the intermodulation disturbance at the receiving satellite ground station. In Fig. 3, in front of satellite receiving ground station the GSM 1800 signals are presented. The similar procedure could be used in case of other radio signal presence, also.

The presence of intermodulation products, at ground station, near the downlink frequency f_r caused by GSM 1800 and uplink signal f_t are expected because of eventual non-linearity of the low noise amplifier used in the front end at the downlink of the ground station. By the non-linearity of the low noise amplifier, the intermodulation products will be generated from the uplink signal at frequency f_t on one hand and GSM signals at frequencies f_{GSM} (f_u, f_d) on the other [5].

3.1 Interference modelling

Generally, if spurious signals generated as intermodullation products behind low noise amplifier fall within a passband of a receiver and the signal level is of sufficient amplitude, it can degrade the performance of the receiver. So, the receiver's operation will be disturbed if two above conditions are fulfilled. Based on this concept it is built the intermodullation interference modelling which enables the interference calculation caused by any radio source of frequency f_x and satellite uplink signal of frequency f_t. Only third order of intermodullation products is considered. Among third order of intermodullation products are considered only components of frequencies $2f_x - f_t$ and $2f_t - f_x$. Fig. 2 tells us that these products could fall within a receiver's passband. Other intremodullation products of frequencies, $3f_x$ $3f_t$, $2f_x + f_t$ and $2f_t + f_x$ usually fall too far from the passband and practically are eliminated by filtering. Thus these products are not treated in modelling concept.

The amplitudes of intermodullation products of frequencies $2f_x - f_t$ and $2f_t - f_x$ are respectively $3A_x^2 A_t$ and $3A_t^2 A_x$, (these yields out from trigonometry) where A_x is amplitude of any radio signal of frequency f_x in front of low noise amplifier which is potential to cause intermodulation with uplink satellite signal of frequency f_t and amplitude A_t. Thus, third order of intermodullation products is characterized by:

$$f_{i1} = 2f_x - f_t, N_{i1} = 3A_x^2 A_t \quad (2)$$

$$f_{i2} = 2f_t - f_x, N_{i2} = 3A_t^2 A_x \quad (3)$$

where f_{in} is intermodualtion interference frequency of amplitude N_{in} for $n = 1,2$ behind the low noise amplifier. Since, the analyses are related mainly to the frequency domain, in order to simplify the case it is supposed that there is no amplification on overall system chain.

Usually, the amplitude A_x is too low in front of low noise amplifier since it is limited by ITU rules about radiated power and consequently it is expected that the amplitude $N_{i1} = 3A_x^2 A_t$ will not disturb the receiver. The most dangerous component is $N_{i2} = 3A_t^2 A_x$ since the amplitude A_t is of high level because this is amplitude of uplink signal which has to overcome too high attenuation toward the satellite. The reference checking point is downconverter's IF output or receiver's IF input. So, the intermodulation interference is checked around intermediate frequency f_{IF}. The mirroring into intermediate frequency is achieved by downlink local oscillator frequency f_{LO}. All frequencies are mirrored by

f_{LO}, including intermodulation products and desired receiving signal of frequency f_r. Thus, it is:

$$f_{IF} = f_{LO} - f_r \quad (4)$$

For a receiver with bandwidth $B = 2\Delta f$, the receiving passband at IF input is from $f_{IF} - \Delta f$ up to $f_{IF} + \Delta f$ where f_{IF} is intermediate frequency which usually is 140MHz or 70MHz. Thus, the receiver could be disturbed if the intermodullation product mirrored at IF, falls within frequency band at IF input, mathematically expressed as:

$$f_{IF} - \Delta f \leq f_{in} - f_{LO} \leq f_{IF} + \Delta f \quad (5)$$

By substituting f_{IF} form Eqn. 4 to Eqn.5 yields out,

$$(f_{LO} - f_r) - \Delta f \leq f_{in} - f_{LO} \leq (f_{LO} - f_r) + \Delta f \quad (6)$$

Then further, if we substitute f_{in} from Eqn. 2 and Eqn. 3 at Eqn. 6 will have:

$$(f_{LO} - f_r) - \Delta f \leq (2f_x - f_t) - f_{LO} \leq (f_{LO} - f_r) + \Delta f \quad (7)$$

$$(f_{LO} - f_r) - \Delta f \leq (2f_t - f_x) - f_{LO} \leq (f_{LO} - f_r) + \Delta f \quad (8)$$

Thus, if frequency f_x of external radio source fulfills the Eqn. 7 or Eqn. 8 the desired signal at the receiver could be masked by intermodullation interference. Then the level of respective signal should be compared with the level of desired signal at IF input. For comparison of these levels it is sufficient the relationship in between the relative values. Usually this is checked by measurement with spectrum analyzer at IF check point. The criteria for amplitudes comparison between the desired and interference signal depends on the Earth's station size and dedication. The criteria, between downlink carrier level and interference signal level ranges from 20 dB to 30dB [6].
This is mathematically expressed by Eqn. 9, as:

$$S_{(IF)}(\text{dB}) - N_{in(IF)}(\text{dB}) \geq (20 \div 30)\text{dB} \quad (9)$$

here $S_{(IF)}$ is desired signal power and $N_{in(IF)}$ intermodullation interference signal power at IF input. These two power levels can be calculated or measured in order to conclude about the receiver's disturbance. The above concept is presented through flowchart in Fig. 4. Input parameters in Fig. 4 are: f_x is frequency of any radio source in front of low noise amplifier of the satellite receiving system, f_t uplink transmit frequency, f_r ownlink receiving frequency and B is downlink receiver's bandwidth.

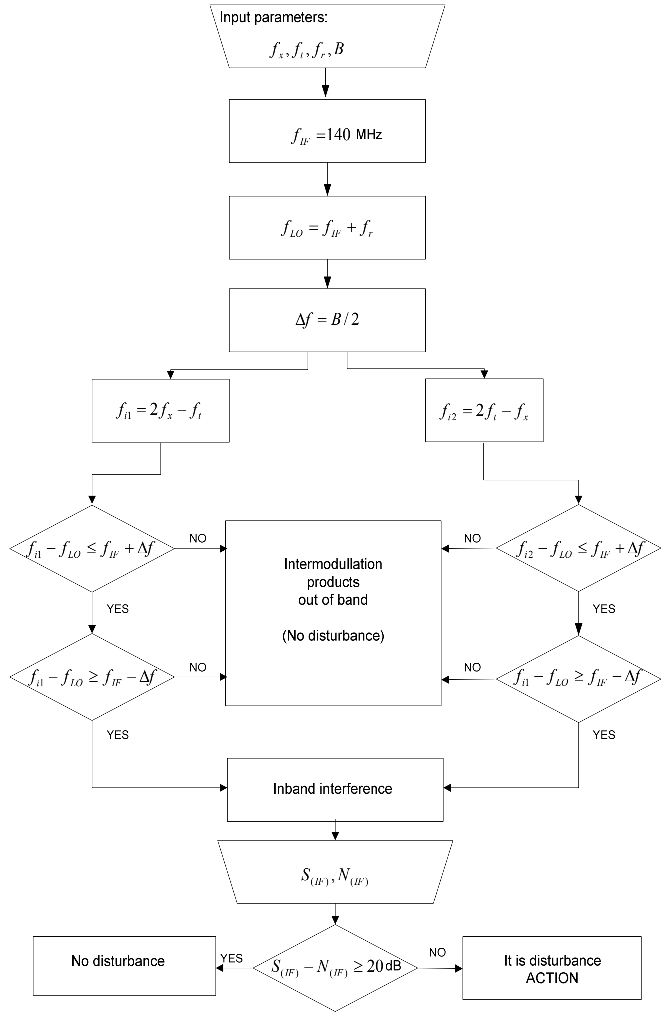


Fig. 4. Intermodulation interference modelling flowchart

Considering above flowchart it is structured intermodulation interference calculator presented in Fig. 5.

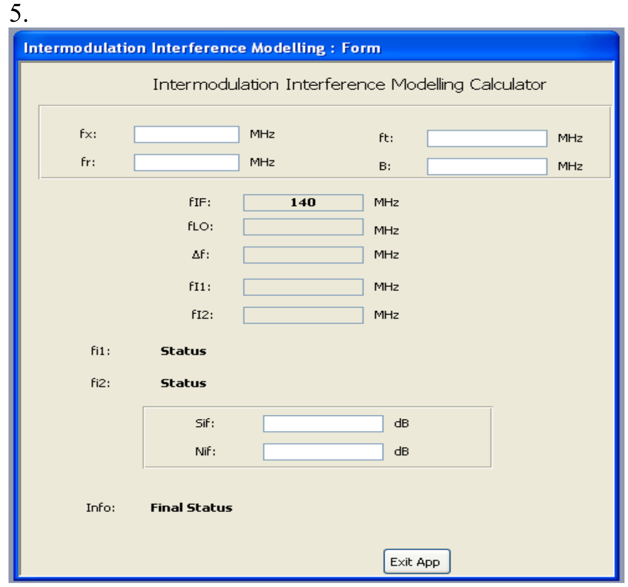


Fig. 5. Intermodulation interference calculator

Usually, only one of the treated components falls within a passband and cause the disturbance. So, if intermodulation components are out off band, then under **Status** (see Fig. 5) for f_{in}, $n = 1,2$ will show up this text: "Intermodulation products out of band (no distrurbance)", and no further analyses are needed. In case when one of components falls within a band, then under **Status** for f_{in}, $n = 1,2$ will show up this text: "In band interference" and further analyses related to the amplitude level are needed. If amplitude of interference is under limited level at **Final Status** will show up text as, "No disturbance", and if the amplitude of interference level is above planned limit shows up the text:" It is disturbance (Action)".

For a particular case, where uplink transmits with frequency $f_t = 2055$ MHz, the intermodulation products $2f_t - f_d$ generated by uplink frequency and few GSM 1800 downlink frequencies f_d (communication from BTS toward the mobile customer) in Table 1 are presented [3].

Table 1. Third order of intermodulation products

f_t	f_d	$2f_t - f_d$
2055MHz	1805.2MHz	2304.8 MHz
2055MHz	1807.0MHz	2293.0MHz
2055MHz	1807.4MHz	2292.6 MHz
2055MHz	1820.0MHz	2290.0 MHz
2055MHz	1829.2MHz	2280.8 MHz
2055MHz	1876.4MHz	2233.6 MHz

Further, for $B = 100$ KHz, $f_{IF} = 140$ MHz and $f_r = 2232$ MHz, $f_{LO} = 2372$ MHz, the receiving bandwidth, at IF output of the downconverter or as input of the receiver, the bandwidth is:

$$139.95\text{MHz} < f < 140.05\text{MHz} \qquad (10)$$

From Table 1 the intermodulation products (third column) are mirrored in IF band by local oscillator of frequency 2372MHz. The mirrored intermodulation products are: 67.2MHz, 79MHz, 79.4MHz, 82 MHz, 91.2MHz and 138.4MHz.

No one of these intermodulation products is within a frequency range under Eqn. 10, so there is no intermodulation interference. For the above case the intermodulation interference disturbs receiving system if in front of low noise amplifier is present signal of frequency $f_x = 1598$ MHz or $f_x = 2283.5$ MHz. This is confirmed applying intemodulation interference calculator.

4. Conclusion

A methodology for analyzing the impact of intermodulation interference on reception performance has been described. These analyses are of high importance on the final decision of the ground station design. The introduced "intermodulation interference calculator" based on modeling concept could be applied on uplink signal frequency selection in order to avoid the interference. This methodology is applicable for MEO (Medium Earth Orbiting) systems, also.

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