9
Interference Aspects

9.1 General Interference Aspects

Generally, interference sources are statistically independent. Interference may be considered as a form of noise. Thus, the interference at each source may be added directly to give the total interference at the end user receiver. The effects of interference must be assessed in terms of: (i) the amount of frequency overlap between the interfering spectrum and the wanted channel passband of the end user receiver and (ii) the tolerable disturbing (interference) signal power level to the end user receiver. There are various sources of interference in a satellite communication system. These may be broadly classified as ***intra-system*** and ***inter-system***.

Intra-interference can occur when the filters used for isolating adjacent channels do not have sufficient roll-off characteristic. This interference is called adjacent channel interference (ACI). Such interference can be minimized by using adequate guard bands between adjacent channels and well-designated filters. A ***guard band*** (GB) is the difference between the upper edge of the band and the last frequency within a band. However, the use of wide guard bands leads to inefficient use of the channel bandwidth and higher operating cost per carrier. Therefore, a technical and economic compromise should be made. Whatever the compromise is chosen, part of the power of a carrier adjacent to a given carrier will be captured by the receiver tuned to the frequency of the carrier considered. Quality is maintained if the captured power is under permitted limits. A link margin of (0.5–1) dB is adequate to compensate for intra-system interference (Richharia 1999).

Intra-system interference can be caused by coupling of orthogonally polarized signals in dual polarized system, also. A horizontally polarized signal can interfere with vertically polarized signal and vice versa. Rain and ice can cause interference at ground stations because of depolarization. This can be minimized by using well-designed ground station receivers and antennas (typical values of cross-polar discrimination in well-designed antennas are of the order of 25–30 dB) (Richharia 1999), or especially by applying circular polarization.

Inter-system interference may occur between a satellite system and terrestrial system whenever the same frequencies are shared. Certain frequency bands above 1 GHz are shared between the fixed satellite and fixed terrestrial services. Both services are necessary to satisfy the telecommunication needs of the world, so these services have coexisted for over four decades and probably will continue to coexist in the future. With so many telecommunications services using radio transmissions, interference between services can arise in a number of ways. Figure 9.1 shows the possible interference scenarios between satellite and terrestrial services:

- Satellite transmitter interferes into terrestrial station receiver (1)
- Terrestrial station transmitter interferes into satellite receiver (2)

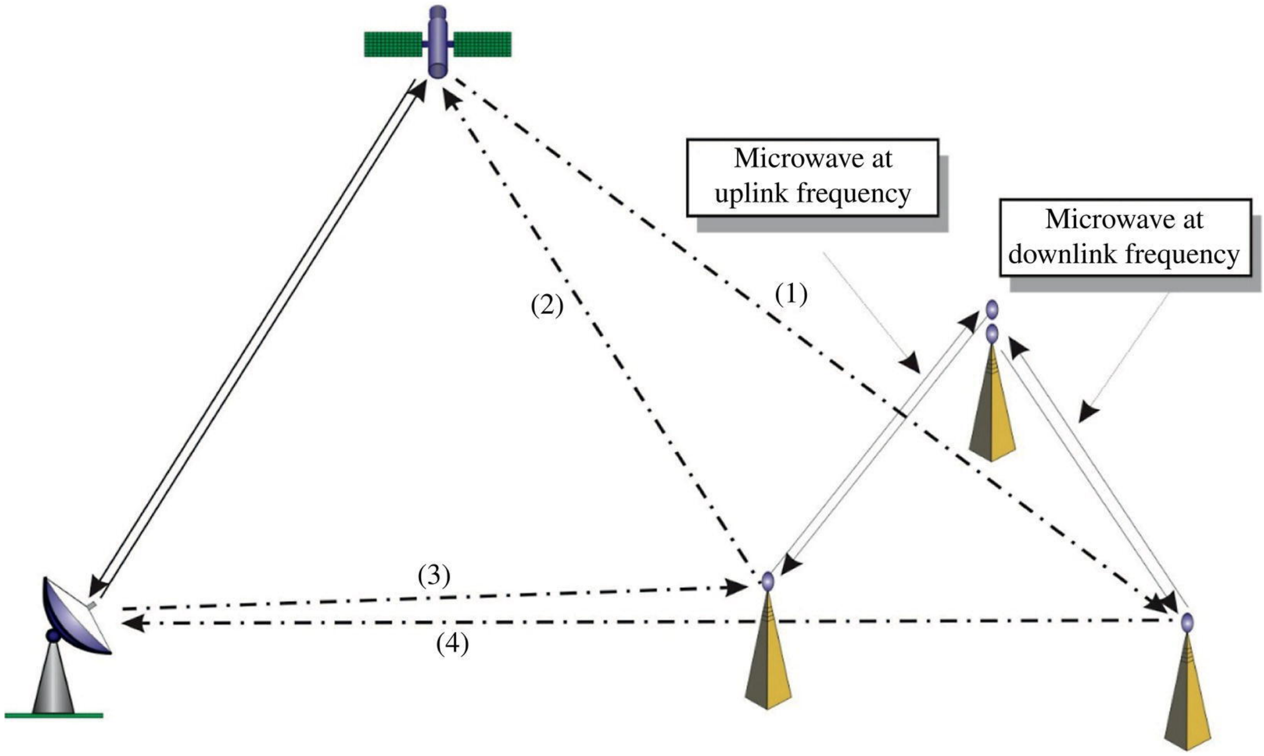


Figure 9.1 Interference scenarios.

- Satellite ground station transmitter interferes into terrestrial station receiver (3)
- Terrestrial station transmitter interferes into satellite ground station receiver (4)

The satellite ground stations typically operate at high elevation angles, while terrestrial stations operate at low elevation angles. This simplifies situation allowing spatial discrimination in both direction (3) and (4) in Figure 9.1. But, for low Earth orbit (LEO) satellites there is a communication under low elevations angles, also, so the interference effects have to be considered. (The term ***ground station*** is specifically associated with satellite circuits and ***terrestrial station*** is specifically associated with microwave line of sight circuits.)

Permitted frequency sharing imposes limits on transmission levels for terrestrial transmitters, ground satellite stations, and satellite transmitters in certain bands and services, aiming to minimize intersystem interference. These limitations should be coordinated to reduce interference. Procedures have been developed to permit the coexistence of networks sharing the same frequency by mutual agreement. The procedures and coordination are under International Telecommunication Union (ITU) responsibility. Based on these ITU radio regulations limits, we can apply the following means by which can be reduced the interference for scenarios described in Figure 9.1:

- Limitations on satellite power-flux density (PFD) produced at the surface of the Earth (1).
- Limitations on the terrestrial station EIRP and power delivered to the antenna (2).
- Limitations on the satellite ground station power radiated toward the horizon (3).
- Limitations on distances between satellite ground stations and terrestrial stations (3), (4).
- Antenna performance standards (3).

The values for interfering signals due to frequency reuse cross-polarization, multiple beam interferers, and interference power received from other systems (intra-system and inter-system), must be obtained by carefully constructing the link equation for each case (Difonzo 2000).

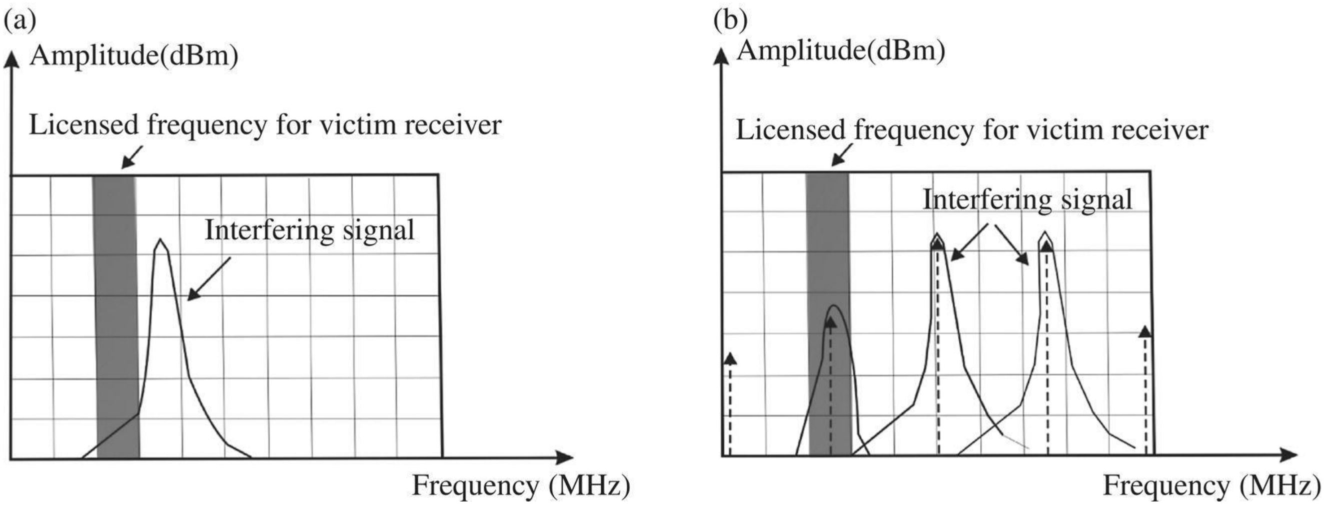


Figure 9.2 Co-channel interference (a), and out-of-band interference (b).

From the technical and practical point of view, two classifications of interference should be considered (Gordon and Morgan 1993). These two scenarios are presented in Figure 9.2:

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

The ***co-channel interference*** occurs when the user's receiver is disturbed by the system or equipment operating at the same frequency as the user's receiver (Figure 9.2a). More problematic is ***out-of-band interference***. This interference occurs when the intended receiver is hit by signals that are generated by equipment that does not operate in the same frequency as that receiver. The phenomenon whereby one or more new signals are generated is called ***intermodulation***. These new generated signals (***intermodulation products***) can unexpectedly fall within a victim receiver's licensed passband (Figure 9.2b), interfering with signal reception. 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. If the signal is too strong, it will completely block the desired receiving signal (Bulloch 1987; Mendenhall 2001; National Telecommunications and Information Systems 2006).

9.2 Intermodulation Products

The influence source of noise 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 the high-power amplifier (HPA) nonlinearity. Related to downlink performance, especially in urban areas (presence of wireless networks, fixed or mobile) intermodulation should be considered because of the 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:

$$e_0 = ae_i + be_i^2 + ce_i^3 + \ldots \qquad (9.1)$$

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.

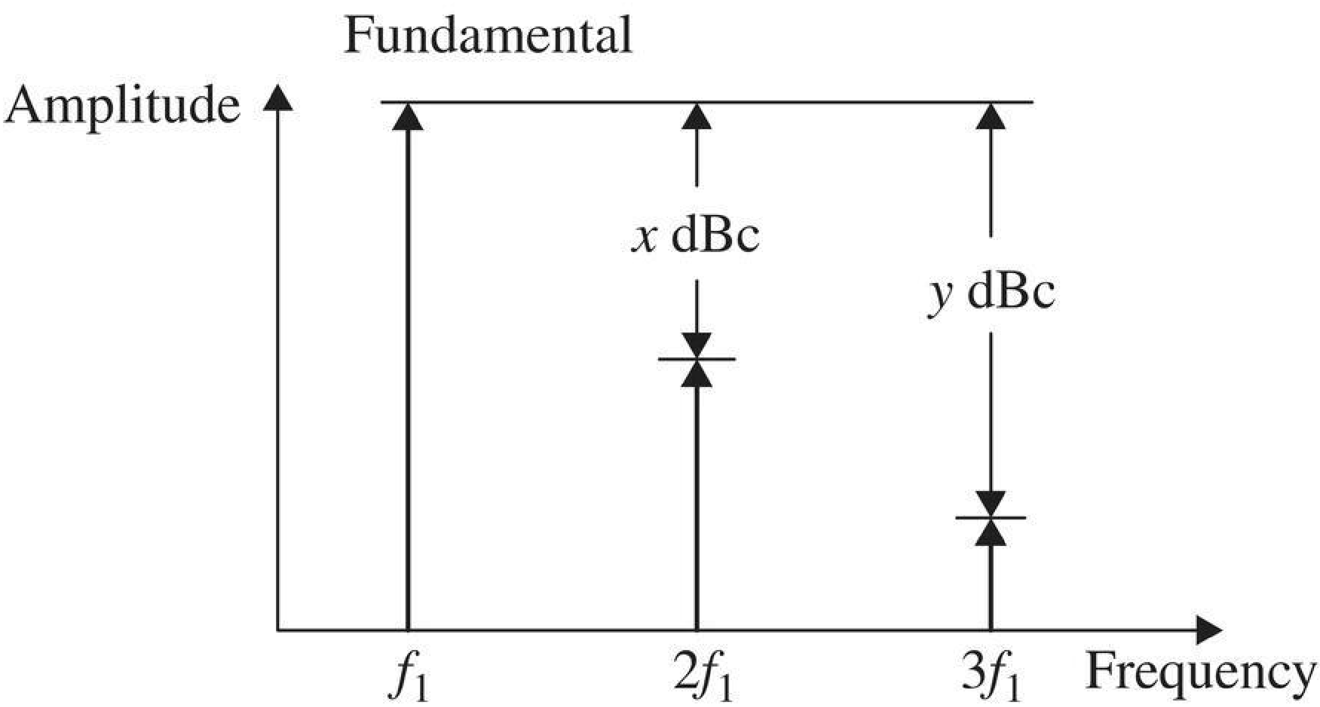


Figure 9.3 Harmonic products.

Intermodulation interference components can be classified as:

- Harmonic products
- Intermodulation products

Harmonic products are single-tone distortion products caused by device nonlinearity. When a nonlinear device is stimulated by a signal at frequency f_1, spurious output signals can be generated at the harmonic frequencies $2f_1$, $3f_1$,... Nf_1. The order of the harmonic products is given by the frequency multiplier; for example, the second harmonic is a second-order product. These harmonics are presented in Figure 9.3. Harmonics are usually measured in dBc (indexed by c), 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 $f_1, f_2, \ldots f_n$ are present at the input of a nonlinear device. The spurious products, which are generated due to the nonlinearity of a device, are related to the original input signals frequencies. Analysis and measurements in practice are most frequently done with two input frequencies (sometimes termed ***tones***).

The frequencies of the two-tone intermodulation products are:

$$Mf_1 \pm Nf_2 \text{ where } M,N = ,1,2,3\ldots \tag{9.2}$$

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 Eq. 9.1) of two signals f_1 and f_2 would be $3f_1$, $3f_2$, $2f_1 + f_2$, $2f_1 - f_2$, $f_1 + 2f_2$ and $f_1 - 2f_2$ (Maral and Bousquet 2002; Dodel 1999). These are presented in Figure 9.4. 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 nonlinear 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 Figure 9.4).

Third-order 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*** and the ***linearity of the receiver/preamplifier***. 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. To minimize such harmful emissions, radio regulations restrict such out-of-band transmissions from ground stations to very low levels. There is no single technical method to eliminate the impact of intermodulation products; on-site experimental investigations are needed (Mendenhall 2001). Such approach and experimental results for LEO ground stations will be further clarified later.

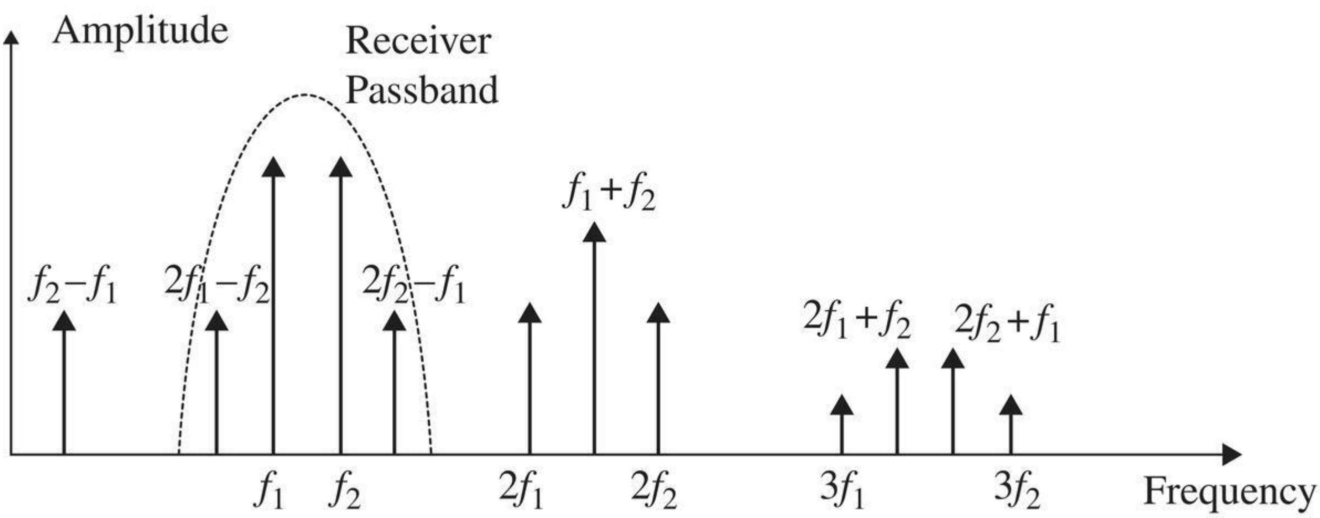


Figure 9.4 Second- and third-order intermodulation products.

The regulations for various satellite communication and recommendations that affect the planning and design of satellite communication system pertain to:

- Frequency allocations for various satellite communication services

- Constrains on the maximum permissible RF power spectral density from the ground station (CCIR Rec 524)
- Antenna pattern of ground stations (CCIR Rec 465 and 580)
- Constraints on the maximum permissible transmission levels from satellites (CCIR Rec 358)
- Permissible interference from other networks (CCIR Rec 466, Rec 483 and Rec 523)

9.3 Intermodulation by Uplink Signal at LEO Satellite Ground Stations

At the ground station located in an urban area with the high penetration of mobile radio systems, it is not easy to eliminate intermodulation interference signals since these are unpredictable. There is no single technical method to eliminate them, so again, on-site investigations and experimental measurements are needed.

Ground stations in urban areas should be 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 uplink signal and signals from nearby mobile system base stations, even though they are received via sidelobes in the ground station's antenna pattern, they could be higher and can mask the wanted signal (Maral and Bousquet, 2002; Sklar 2001; Mendenhall 2001).

Idea: The intention is to mathematically and by executed experiment confirm whether the intermodulation products will disturb the receiver at the Vienna satellite ground station dedicated for communication with MOST satellite.

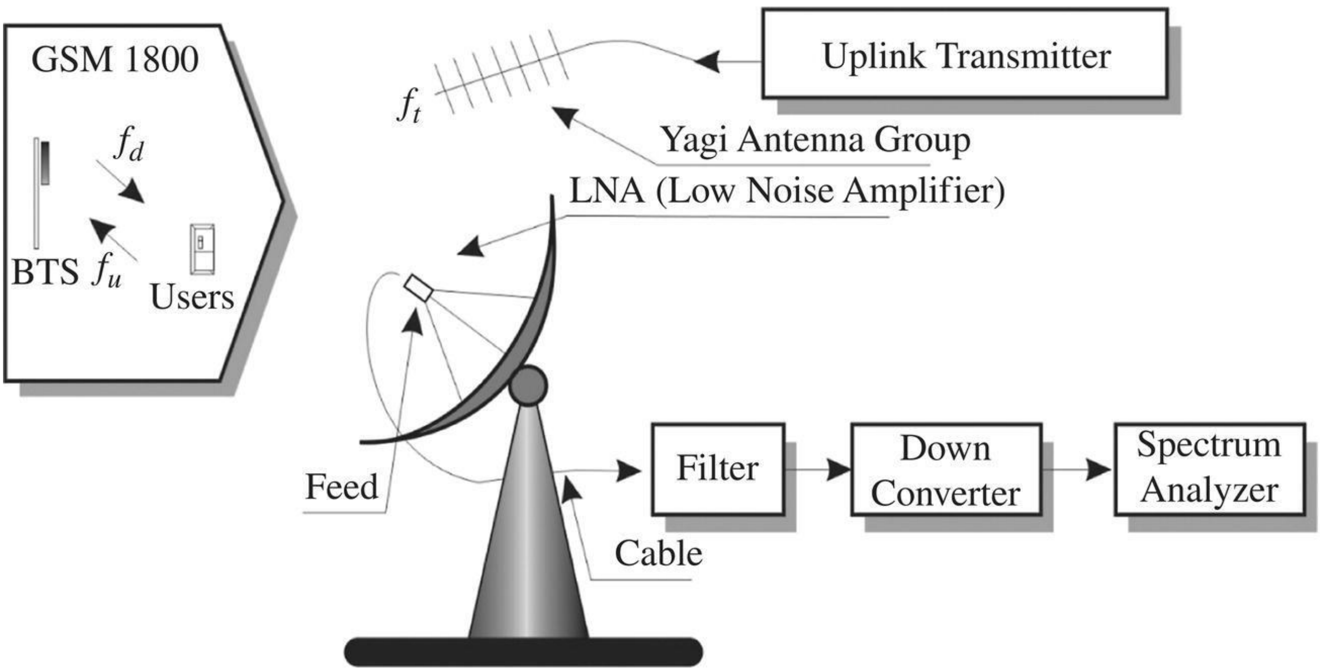


Figure 9.5 Intermodulation scenario at satellite ground station.

Method: Math analysis and experimental execution is applied. Figure 9.5 presents the experiment setup that enables us to generally check the intermodulation disturbance at the any receiving satellite ground station (Cakaj et al. 2005).

In Figure 9.5 in front of satellite receiving ground station the GSM 1800 signals are presented. The similar procedure could be used in case of other MW signal presence, also. As in case of intermodulation, each specific case specifically should be studied. Thus, here we analyze further the intermodulation disturbance at Vienna satellite ground station within MOST scientific space observation project.

The presence of intermodulation products, at ground station, near the downlink frequency (f_r = 2232 MHz) caused by GSM 1800 and uplink signal (f_t = 2055 MHz) is expected because of eventual nonlinearity of the LNA used in the front end at the downlink of the ground station. By the nonlinearity of the LNA, the intermodulation products will be generated from the uplink signal at frequency f_t on one hand and GSM signals at frequencies f_{GSM} on the other. Only third-order intermodulation products will be considered.

In order to make correct analysis, www.rtr.at provides the GSM frequency plan related to GSM 1800 providers in Austria. These data are presented in Table 9.1 (Cakaj et al. 2005), showing the first channel, a few in the middle, and the last one.

Table 9.1 Frequencies of GSM 1800 providers operating in Austria.

Channel	f_u	f_d	Provider
512	1710.2 MHz	1805.2 MHz	TMA
521	1712.0 MHz	1807.0 MHz	TMA
523	1712.4 MHz	1807.4 MHz	Mobilkom
586	1725.0 MHz	1820.0 MHz	Telering
632	1734.2 MHz	1829.2 MHz	One
868	1781.4 MHz	1876.4 MHz	One

In Table 9.1 f_u is the GSM uplink signal frequency and f_d is the GSM downlink signal frequency of the GSM 1800 network (see Figure 9.5). Based on ITU-R F.382-6, 1.7GHz–2.1GHz frequency band for mobile systems is 1710 MHz–1785 MHz for the uplink and 1805 MHz–1880 MHz for the downlink. Recall that the difference between the upper edge of the band and the last frequency within a band is called ***guard band*** (GB). So, in this case the guard bands are:

$$GB_u = 1785\,\text{MHz} - 1781.4\,\text{MHz} = 3.6\,\text{MHz} \tag{9.3}$$

$$GB_d = 1880\,\text{MHz} - 1876.4\,\text{MHz} = 3.6\,\text{MHz}$$

Signals present at the front end of the preamplifier of the receiving system at the ground station are presented in Figure 9.6. Intermodulation products generated by signals at frequencies f_t and f_u fall too far on the frequency domain from the receiver's downlink frequency f_r; therefore, they will not be considered here. Third-order intermodulation products generated by frequencies f_t and f_d are $2f_t \pm f_d$ and $2f_d \pm f_t$.

Only, products $2f_t - f_d$ are worth further analysis, because only they fall in the frequency domain near the receiver's frequency f_r.These intermodulation products appear at the preamplifier's (LNA) output (respectively at the filters input) in frequency domain (RF) (see Figure 9.7) (Cakaj et al. 2005; Cakaj and Malaric 2007).

The respective frequencies of these signals correlated to Table 9.1 are presented in Table 9.2.

These signals will be filtered before going into the downconverter (see Figure 9.5). The situation behind the filter and in front of the downconverter is presented in Figure 9.8.

From Figure 9.8 it is clear that the filter has substantially attenuated a considerable number of interference contributions from intermodulation products. The local oscillator frequency of the downconverter at the satellite ground station is f_{LO} = 2372 MHz. Then, if all signals presented in Figure 9.8 in RF domain mirror into IF domain with frequency f_{LO}, the spectrum in Figure 9.9 follows (Cakaj et al. 2005; Cakaj and Malaric 2007).

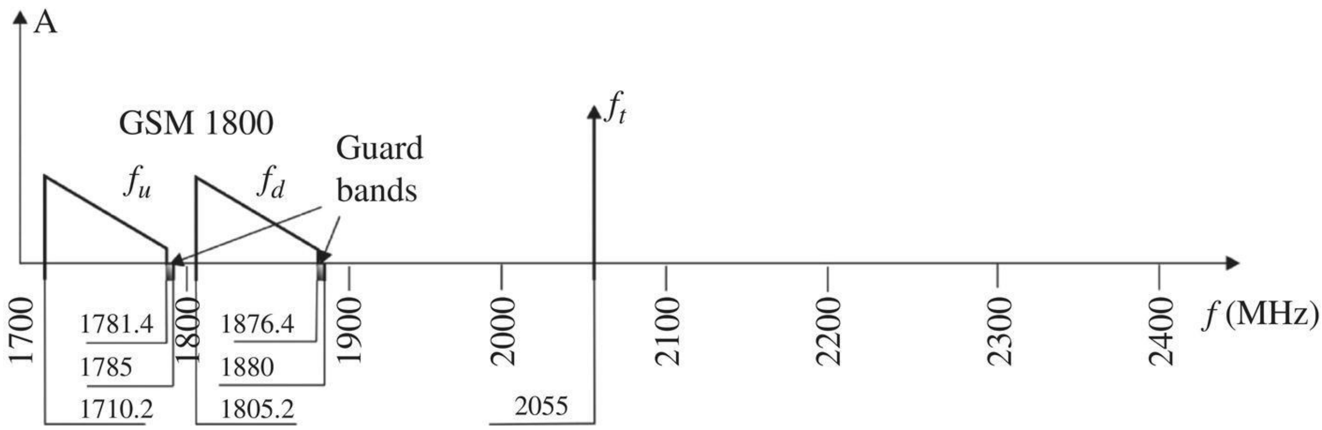
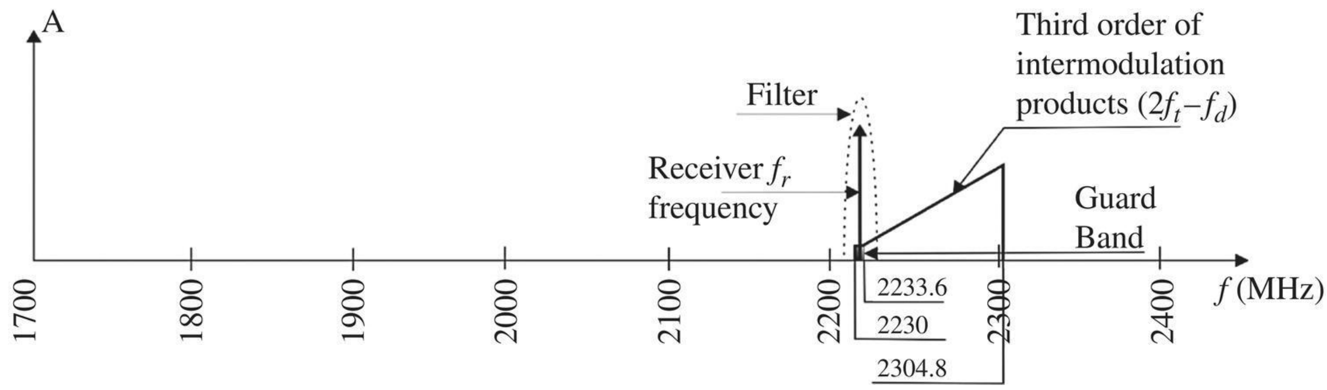


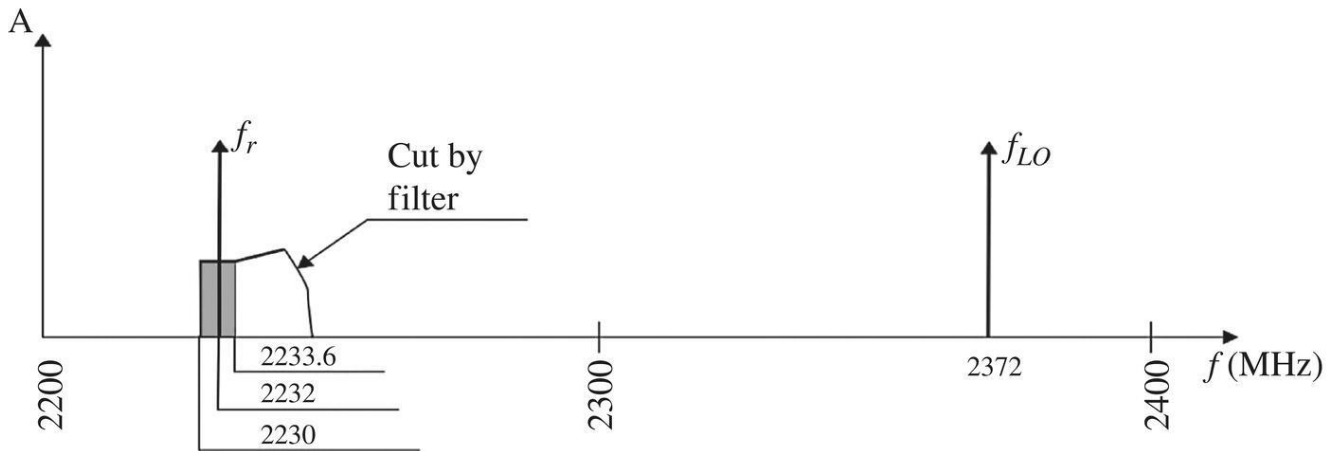
Figure 9.6 Signals present at frontend of preamplifier (LNA) of the downlink.



[Figure 9.7](#) Third order of intermodulation products.

[Table 9.2](#) Third order intermodulation products.

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



[Figure 9.8](#) Signals in front of downconverter.

From [Figure 9.9](#) it is obvious the presence of intermodulation products behind the downconverter and in front of the demodulator.

Results: In Figure 9.9, in the center is our desired signal which is coming from the satellite at IF input with frequency of 140 MHz. The receiving bandwidth from Table 3.1 is 76.8KHz. So, looking at IF output of the downconverter, or as input of the receiver, the bandwidth is

$$139.9616MHz < f < 140.0384MHz \tag{9.4}$$

The intermodulation interference will affect the desired signal if respective intermodulation frequencies fall within this range. From Table 9.2 the intermodulation products (third column) are mirrored in IF band by local oscillator of frequency 2372 MHz. The mirrored intermodulation products are: 67.2, 79, 79.4, 82, 91.2, and 138.4 MHz. No one of these intermodulation products is within a frequency range under Eq. (9.4), so there is no intermodulation interference. In this case, an advantage is that satellite downlink frequencies lie in a band that is in fact the mirrored guard band.

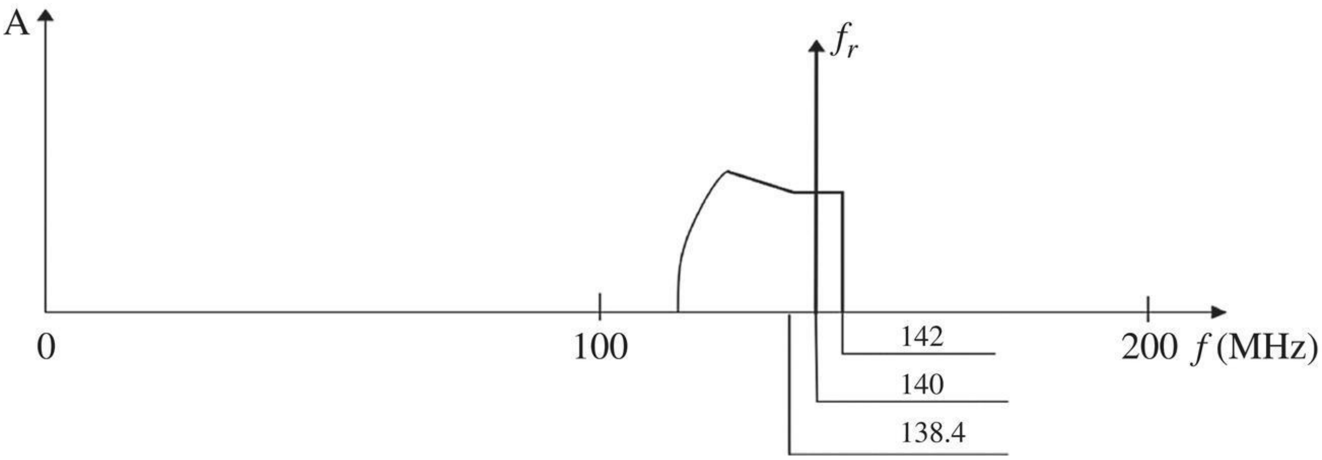


Figure 9.9 Downconverter output.

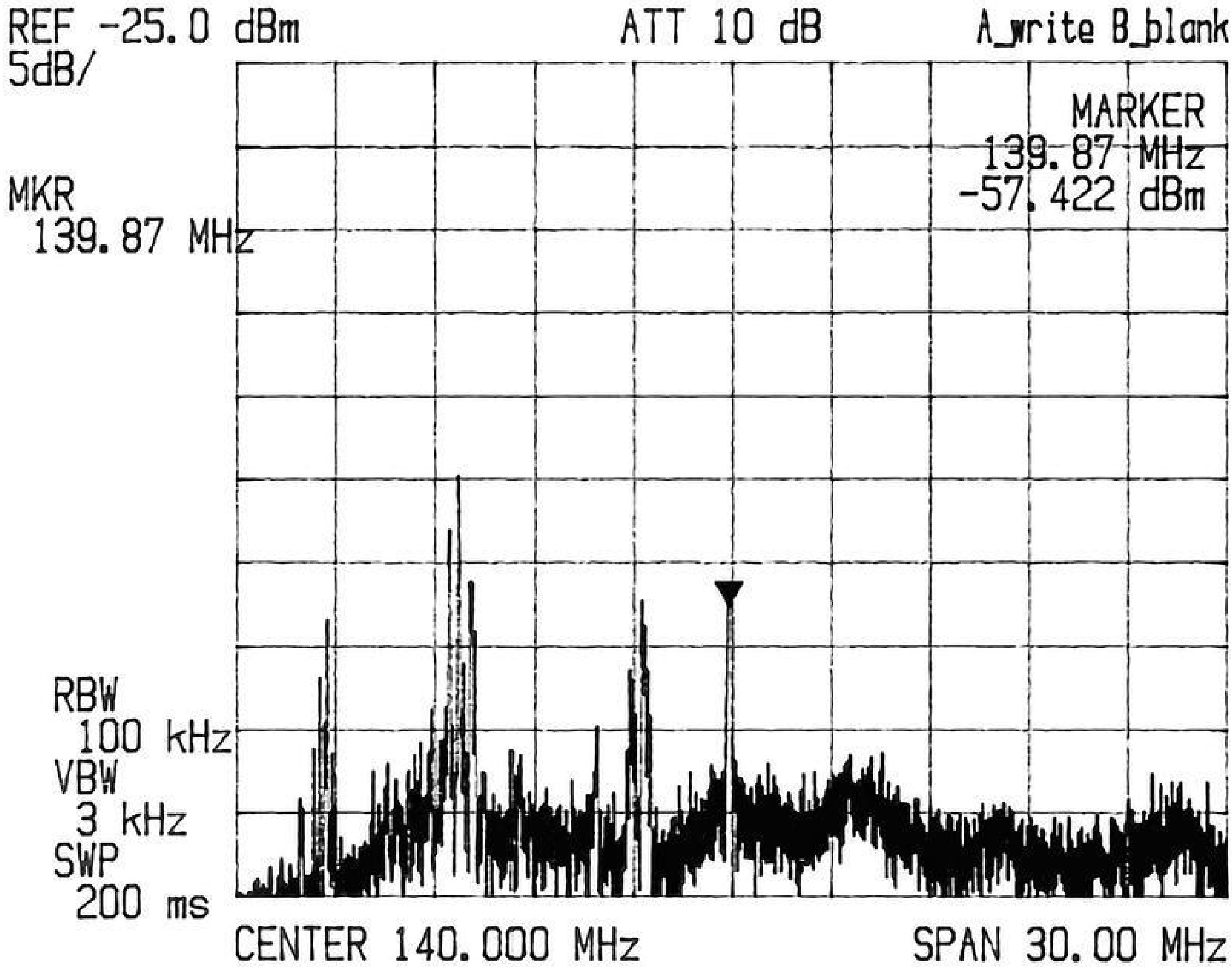


Figure 9.10 Presence of intermodulation products.

Intermodulation products are recorded by experiment, and the appropriate set up is presented in Figure 9.5. The IF record by spectrum analyzer confirming a mathematical calculation is presented in Figure 9.10. (Cakaj et al. 2005; Cakaj and Malaric 2007).

In the center of Figure 9.10 is the desired signal coming from the satellite. On the left side there are intermodulation products that do not mask the desired receiving signal. The span in Figure 9.10 is 30 MHz. The receiving bandwidth from Table 3.1 is 76.8 KHz, so although intermodulation products are present, they are too far from the receiving bandwidth to significantly degrade the signal. The advantage of this case is that the satellite downlink frequencies lie in a band that is in fact the mirrored guard band of GSM 1800 MHz in IF domain (Figure 9.8 and Figure 9.9).

The envelope around signal f_r at Figure 9.9 stemmed from mathematical analysis and the envelope of the experimentally recorded signal around f_r are almost identical, in this case confirming each other. This makes possible to have LNAs directly connected to the feed without filter, and therefore the ***maximum downlink margin***.

Conclusion: The final conclusion is that the presence of the 50 W uplink signal and the GSM 1800 signals do not produce intermodulation products that disturb the performance of the downlink receiving system at the (LEO) satellite ground station. This makes it possible to have LNAs directly connected to the feed without filter, and therefore the maximal downlink margin. But, in case of the intermodulation disturbance, the filter should be implemented in the front end, more exactly in between the feeder and LNA.

9.4 Modeling of Interference Caused by Uplink Signal for LEO Satellite Ground Stations

Idea: Interference can negatively affect the functionality of the satellite ground station. The major source of interference in a satellite communication system is intermodulation noise generated by nonlinear transfer characteristics of devices. Toward the uplink, the intermodulation noise is mainly generated because of HPA nonlinearity. Related to the downlink performance, especially in urban areas (presence of mobile and fixed wireless networks) intermodulation should be considered because of LNA nonlinearity. Disturbance introduced due to nonlinearity is known as intermodulation interference. If spurious signals generated as intermodulation products behind LNA fall within a passband of a receiver and the signal level is of sufficient amplitude, it can degrade the receiver's performance.

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. These new generated signals can unexpectedly fall within a victim receiver licensed passband. In case the generated intermodulation signal is too strong, it will not only interfere but could completely block the desired receiving signal. Filtering becomes very hard if the intermodulation products fall inside the passband. So, the receiver's operation will be disturbed if two conditions are fulfilled: (i) interference signal fall within a passband; and (ii) has too high power.

Based on this concept and the example described under Section 9.3, the idea is to build the intermodulation interference modeling flowchart that enables the interference calculation caused by any other radio source of frequency f_x and the satellite uplink signal of frequency f_t. From the appropriate model will be built the interference calculator to determine and predict such disturbances of the receiver, based on the radio signals environmental presence.

Method: Based on interference concepts and the previously mathematical interpretation, considering radiofrequency signal (f_x) present in the front end of the satellite ground station's receiving system, which is potential for generating intermodulation interference, it is analyzed and then modeled the intermodulation interference, and further is introduced the intermodulation interference calculator.

Only third-order intermodulation products are considered. Among third-order intermodulation products are considered only components of frequencies $2f_x - f_t$ and $2f_t - f_x$. Analyses under Section 9.2 confirmed that these products could fall within a receiver's passband. Other intermodulation 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 the modeling approach (Cakaj et al. 2008; Cakaj 2010).

The amplitudes of intermodulation products of frequencies $2f_x - f_t$ and $2f_t - f_x$ are respectively $3A_x^2A_t$ and $3A_t^2A_x$ (these yields out from trigonometry) where A_x is amplitude of any radio signal of frequency f_x

in front of LNA, which has the potential to cause intermodulation with uplink satellite signal of frequency f_t and amplitude A_t. Thus, third-order intermodulation products are characterized by:

$$f_{i1} = 2f_x - f_t, N_{i1} = 3A_x^2 A_t \quad (9.5)$$

$$f_{i2} = 2f_t - f_x, N_{i2} = 3A_t^2 A_x \quad (9.6)$$

where f_{in} is intermodulation interference frequency of amplitude N_{in} for n = 1, 2 behind the LNA. Since, the analyses are related mainly to the frequency domain, in order to simplify the situation, it is assumed that there is no amplification on overall system chain.

Usually, the amplitude A_x is low in front of LNA 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 high because this is the amplitude of uplink signal that must 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 local oscillator frequency of f_{LO}. All frequencies are mirrored by f_{LO}, including intermodulation products and desired receiving signal of frequency f_r. Thus, it is:

$$f_{IF} = f_{LO} - f_r \quad (9.7)$$

For 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 the intermediate frequency, which is usually 140 MHz or 70 MHz. Thus, the receiver could be disturbed if the intermodulation product mirrored at IF falls within frequency band at IF input, mathematically expressed as:

$$f_{IF} - \Delta f \le f_{in} - f_{LO} \le f_{IF} + \Delta f \quad (9.8)$$

By substituting f_{IF} from Eq. (9.7) to Eq. (9.8) yields

$$(f_{LO} - f_r) - \Delta f \le f_{in} - f_{LO} \le (f_{LO} - f_r) + \Delta f \quad (9.9)$$

Then, further, if we substitute f_{in} from Eq. (9.5) and Eq. (9.6) at Eq. (9.9) will have:

$$(f_{LO} - f_r) - \Delta f \le (2f_x - f_t) - f_{LO} \le (f_{LO} - f_r) + \Delta f \quad (9.10)$$

$$(f_{LO} - f_r) - \Delta f \le (2f_t - f_x) - f_{LO} \le (f_{LO} - f_r) + \Delta f \quad (9.11)$$

Thus, if intermodulation frequency fulfills the Eq. (9.10) or Eq. (9.11) the desired signal at the receiver could be masked by intermodulation interference.

The next step is considering power (amplitude) issue. Thus, the level of interfering signal should be compared with the level of desired signal at IF input. For comparison of these levels, it is sufficient to consider the relationship between the two relative levels (one of them is the reference level). Usually this is measured with a spectrum analyzer at IF checkpoint. 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 range from 20 to 30 dB (http://www.satsig.net/interfer.html). This is mathematically expressed by Eq. (9.12):

$$S_{(IF)}(dB) - N_{in(IF)}(dB) \ge (20 \div 30)dB \quad (9.12)$$

where $S_{(IF)}$ is desired signal power and $N_{in(IF)}$ intermodulation 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 the flowchart in Figure 9.11. Input parameters in Figure 9.11 are: f_x is frequency of radio source in front of LNA of the satellite receiving system, f_t uplink transmit frequency, f_r downlink receiving frequency, and B is downlink receiver's bandwidth. Considering the appropriate flowchart, it is structured the following intermodulation interference calculator presented in Figure 9.12 (Cakaj et al. 2008; Cakaj 2010).

Usually, only one of the treated components falls within a passband and causes the disturbance. So, if intermodulation components are out of band, then under status for f_{in}, n = 1, 2 will show up this text: "Intermodulation products out of band (no disturbance)," and no further analyses are needed.

In case when one of components falls inside the 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)."

Results: This study is further confirmed under a particular case, where uplink transmits with frequency f_t = 2055 MHz, and in the surrounding environment are present GSM 1800 signals designated as f_d.The third-order generated intermodulation products frequencies are ($2f_t - f_d$), as given in Table 9.2, Section 9.2 (Cakaj et al. 2005). Further, for B = 100KHz, 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, is:

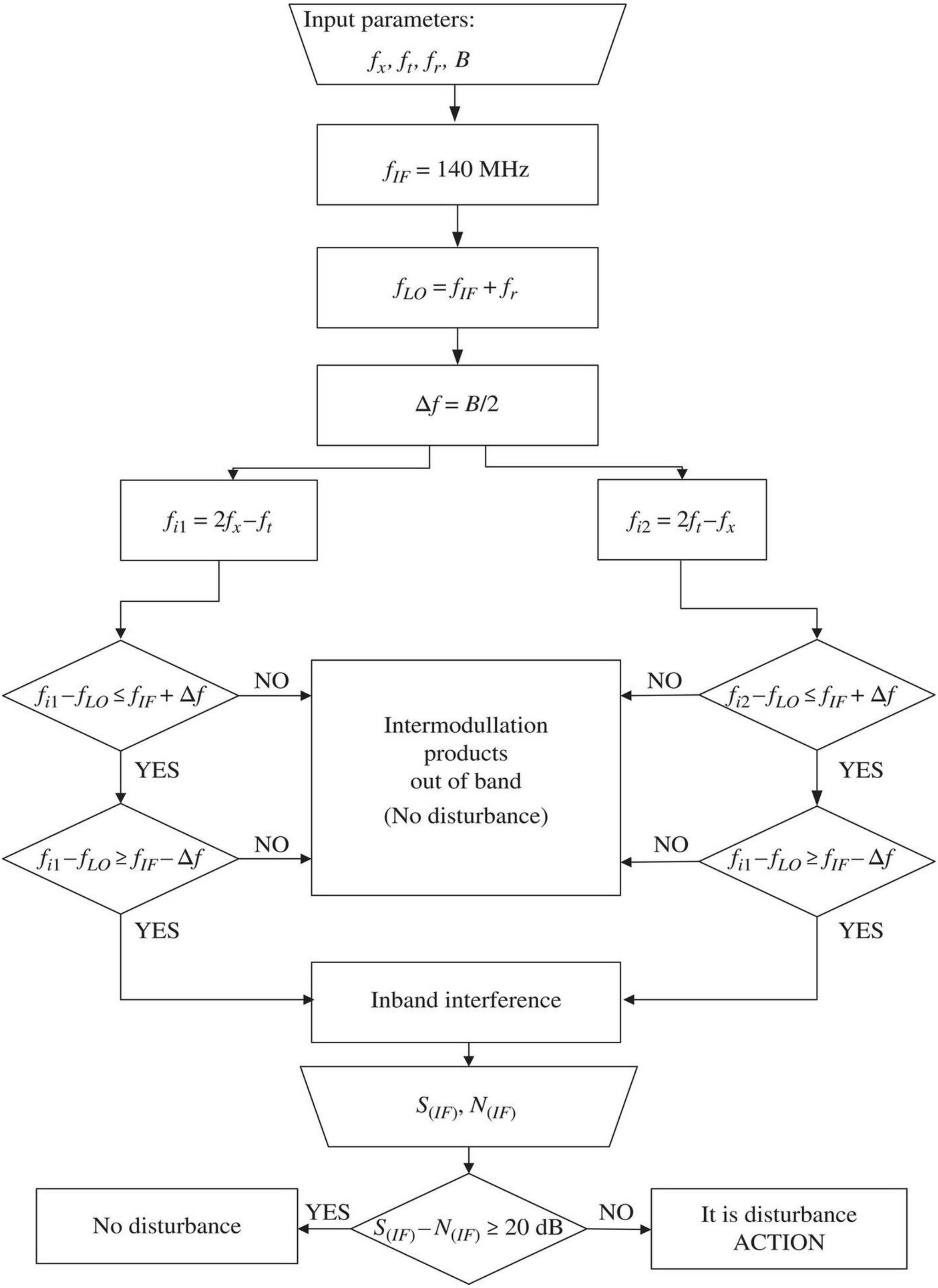


Figure 9.11 Intermodulation interference modeling flowchart.

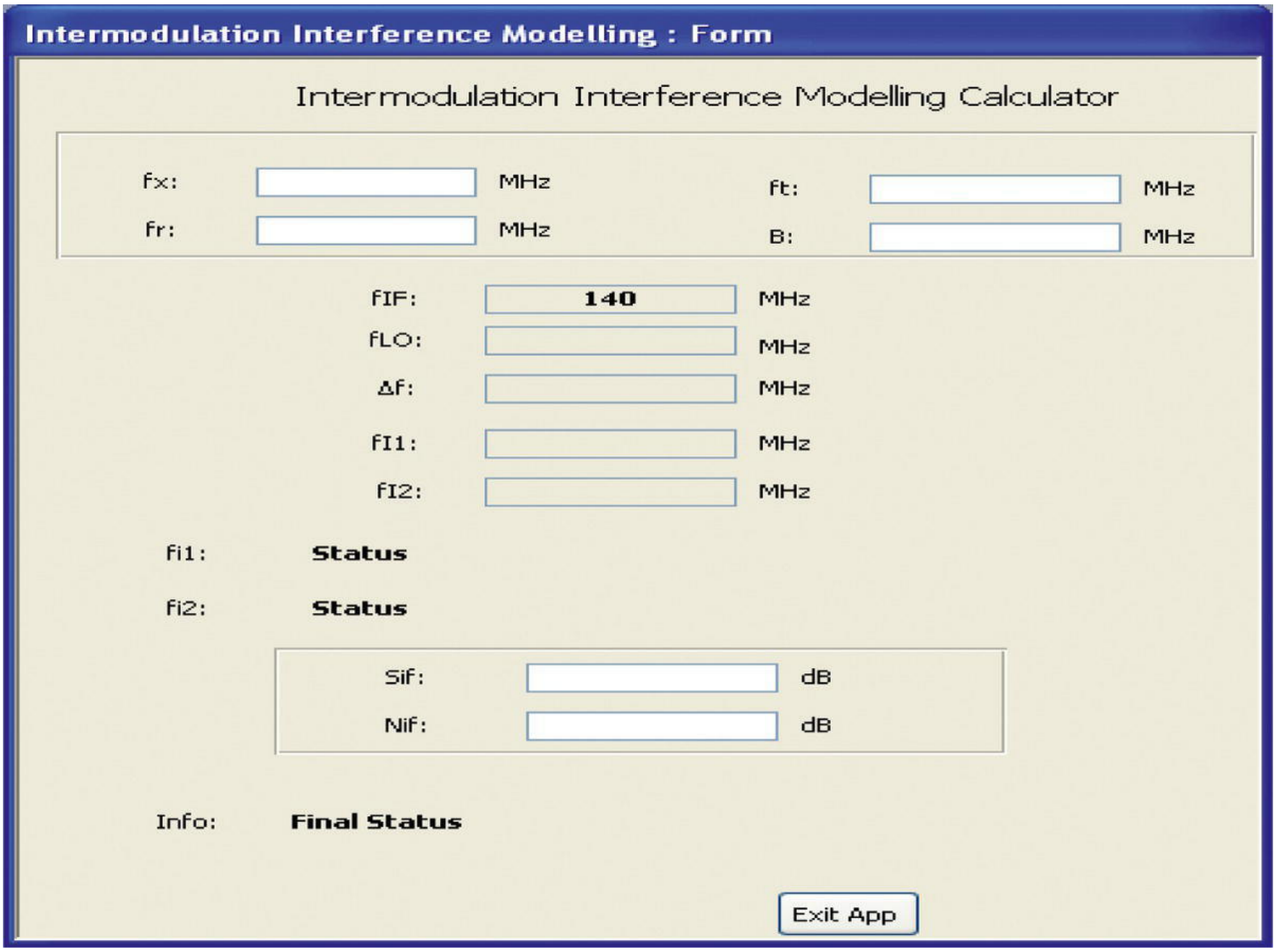


Figure 9.12 Intermodulation interference calculator.

$$139.95MHz < f < 140.05MHz \tag{9.13}$$

f_{IF}, f_r, f_{LO} are, respectively, intermediate, receiving, and local oscillator frequencies. From Table 9.2 the intermodulation products (third column) are mirrored in IF band by local oscillator of frequency 2372 MHz. The mirrored intermodulation products are: 67.2, 79, 79.4, 82, 91.2, and 138.4 MHz. No one of them falls within mirrored IF bandwidth, thus the conclusion is that there is no downlink disturbance by intermodulation products. Finally, for the case presented under Section 9.3, at Figure 9.5 the intermodulation interference disturbs receiving system if in front of LNA is present a signal of frequency f_x = 1598 MHz or f_x = 2283.5 MHz. This is confirmed by applying intermodulation interference modeling.

Conclusion: The introduced modeling concept could be applied on uplink signal frequency selection in order to avoid the interference. These analyses are of high importance on the final decision of the ground station design. This methodology is applicable for medium Earth orbit (MEO) MEO systems, also. The math analysis and experimental results, under 9.3, are completely in accordance with results stemmed from the modeling approach.

9.5 Downlink Adjacent Interference for LEO Satellites

The downlink adjacent interference is expected when two satellites operate in close proximity to each other and share the same frequency, affecting the desired signal-to-noise ratio of the downlink. Further, this problem is considered and analyzed under very practical operational circumstances for SARSAT (Search and Rescue Satellite Aided Tracking) system (constellation). The SARSAT system is operated and managed by NOAA (National Oceanic and Atmospheric Administration).

The SARSAT system is designed to provide distress alert and location data to assist on search and rescue operations. SARSAT locates distress beacons (406 MHz) activated at distress locations. The system calculates a location of the distress event using Doppler processing techniques. Processed data are continuously retransmitted through the SARSAT downlink to local user terminals (LUT) when satellites are in view. The downlink communication, from SARSAT satellites to LUTs, will be further treated from the interference point of view.

Receive-only ground stations, specifically designed to track the search and rescue satellites as they pass across the sky are called LUTs. The communication link is established when the satellite flies within a LUT's visibility. This “fly-over” is called a ***satellite pass***. The distress beacon signal is received on the satellite uplink from the distress location and then it is transmitted to LUTs by downlink. Normally, the beacon location is random and LUT locations are fixed and known. The LUTs are fully automated and completely unmanned at all times [Losik 1995; Landis and Mulldolland 1993]. Communication from satellite operates in two modes (Repeater mode and store and forward mode, Figures 8.4, 8.5, Chapter 8) transmitting in LHCP (left-hand circular polarization) to any LUT in its view (COSPAS –SARSAT System Monitoring and Reporting 2008).

The LEOLUT (means LUT dedicated for LEOs), usually includes a satellite receive antenna, a digital processing system, and the software for control, monitoring and processing functions. When a satellite receives a beacon signal from a distress location, the Search and Rescue Processor (SARP) on board the LEO satellite performs Doppler processing and generates an entry into the 2.4 kb/s processed data stream (***pds***) that is continuously "dumped" to any LEOLUT in view of the satellite's downlink footprint. (COSPAS –SARSAT System Monitoring and Reporting 2008).

LEOLUT software accepts the satellite's downlink data stream, then decodes and extracts beacon data messages. From each satellite pass taken by the LEOLUT, software selects data from each detected beacon and validates time, frequency (Doppler shifted frequency), and message content. Data from each pass, and for each beacon identification number, is then passed to the solution processing software. The solution processing software determines an optimum location based on a Doppler frequency curve, built based on frequency shift. An example of recorded Doppler curve at LUT is given in Figure 9.13.

This is an excellent Doppler curve providing 15 Doppler events, noted from 1 to 15. Time is given on the x-axis and Doppler frequency shift on the y-axis. Using the orbital parameters of the satellite, the beacon frequency, and the known Doppler shift, the distance of the beacon relative to the projection of the satellite orbit ground-track on the Earth can be determined as is depicted in Figure 8.10 (Vataralo et al. 1995; Cakaj et al. 2010a).

Communication reliability during a satellite pass may be degraded when satellites sharing the same downlink frequency are adjacent to each other. The downlinks of all SARSAT LEO satellites use the same 1544.5

MHz frequency (COSPAS – SARSAT 406 MHz Frequency Management Plan, 2008). In cases where the satellites are within the main lobe of the local user terminal antenna, transmissions from adjacent satellites act as interference to one another, consequently degrading the desired signal at the appropriate LUT (Vataralo et al. 1995; Cakaj and Malaric 2007). This can result in missed distress beacon bursts or no stored solutions received at the LUT, consequently no data is provided about a distress location. This should be avoided as much as possible!

Analysis on interference prediction, interference periods, and mitigating procedure are further discussed. Interference mitigation of significant duration, with attached measurement results, is also presented. For further analytical purposes, to avoid repetition, we use the data from Table 8.1 and Table 8.2, which present the space and ground segment of the SARSAT system.

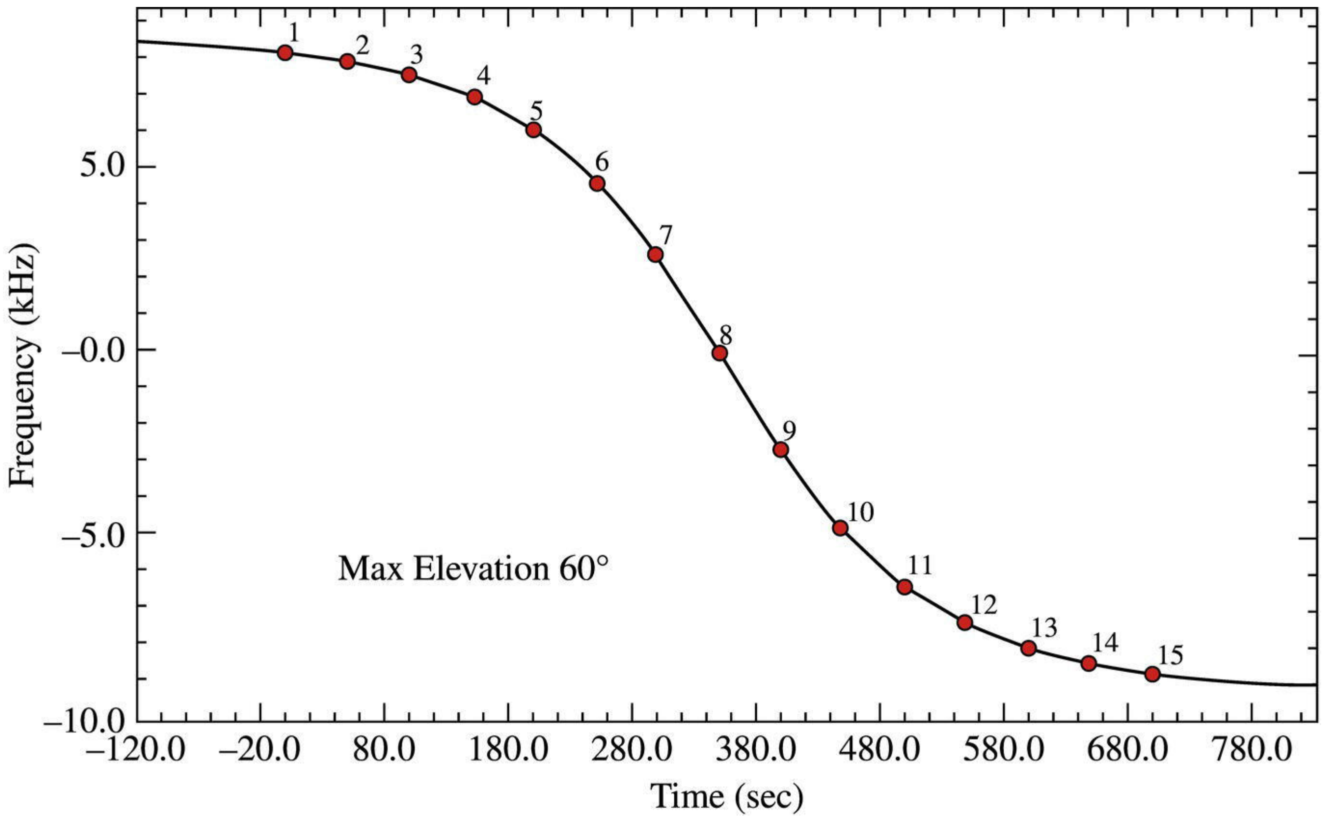


Figure 9.13 Doppler curve.

9.6 Adjacent Satellites Interference (Identification/Avoiding)

Satellites are considered as adjacent if they are too close to each other determined by their space orbital parameters, or too close in radar map or as the ground tracks, which for further analysis is applied. The adjacent satellite interference manifests when two adjacent satellites share the same downlink frequency, and are seen too close to each other from the ground station. If the transmitted EIRP (equivalent isotropic radiated power) from each satellite is similar, for two satellites close to each other, the two signals will act as interference to each other, severely degrading the received desired signal (Kanellopoulos et al. 2007; Cakaj et al. 2010a). The above is illustrated in Figure 9.14 where the receiving ground stations noted as AK, CA, and HI (as a part of SARSAT ground segment) are looking at two satellites S9 and S11(a part of SARSAT space segment).

The downlink of all SARSAT LEO satellites uses the same 1544.5 MHz frequency, and in principle the same transmitted EIRP from each satellite. Thus, if two satellites are too close to each other, their signals will interfere with each other, severely degrading the received signal (COSPAS – SARSAT 406 MHz Frequency Management Plan, 2008). The received carrier frequency provides a useful measure of the interference level. The carrier frequency of the transmitter is 1544.5 MHz, but the relative velocity between the satellite and LUT causes a Doppler shift in the received frequency, and a plot over time shows the characteristic Doppler curve of a LEO satellite. As the orbital positions of the two satellites converge, so do their relative velocities to the LUT and Doppler curves (COSPAS –SARSAT System Monitoring and Reporting 2008).

Slight differences in relative velocity between the two interfering satellites cause two distinct curves of carrier frequency. When the difference in relative velocity and angular separation is minimal, the Doppler curves of the carrier frequency become almost identical. Figure

9.15 shows the real-time received carrier frequency for Florida-1 and Florida-2 LUTs. Florida-1 is tracking S9 and Florida-2 is tracking S11 (Cakaj et al. 2010a).

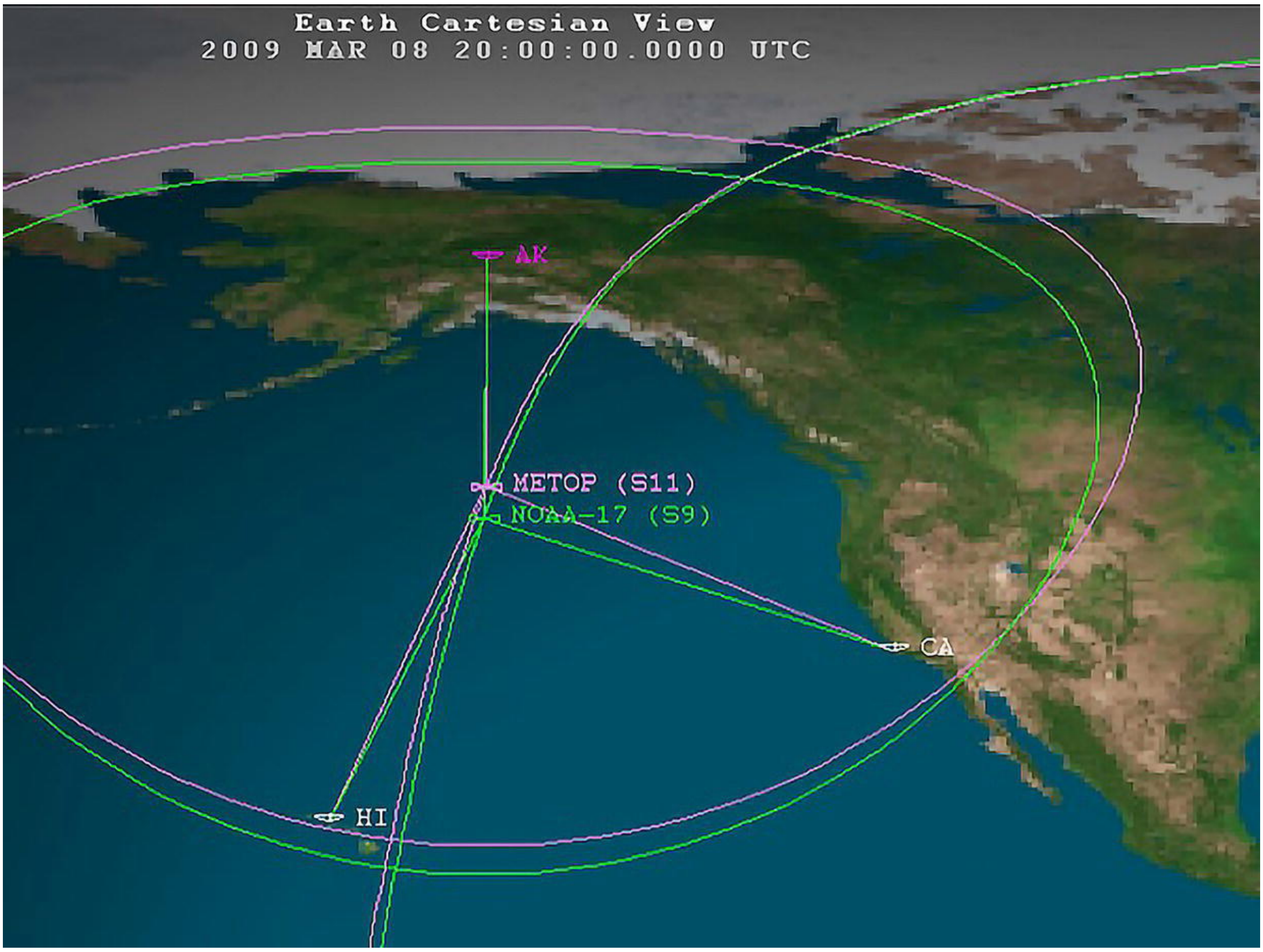


Figure 9.14 Adjacent satellites seen from the ground station.

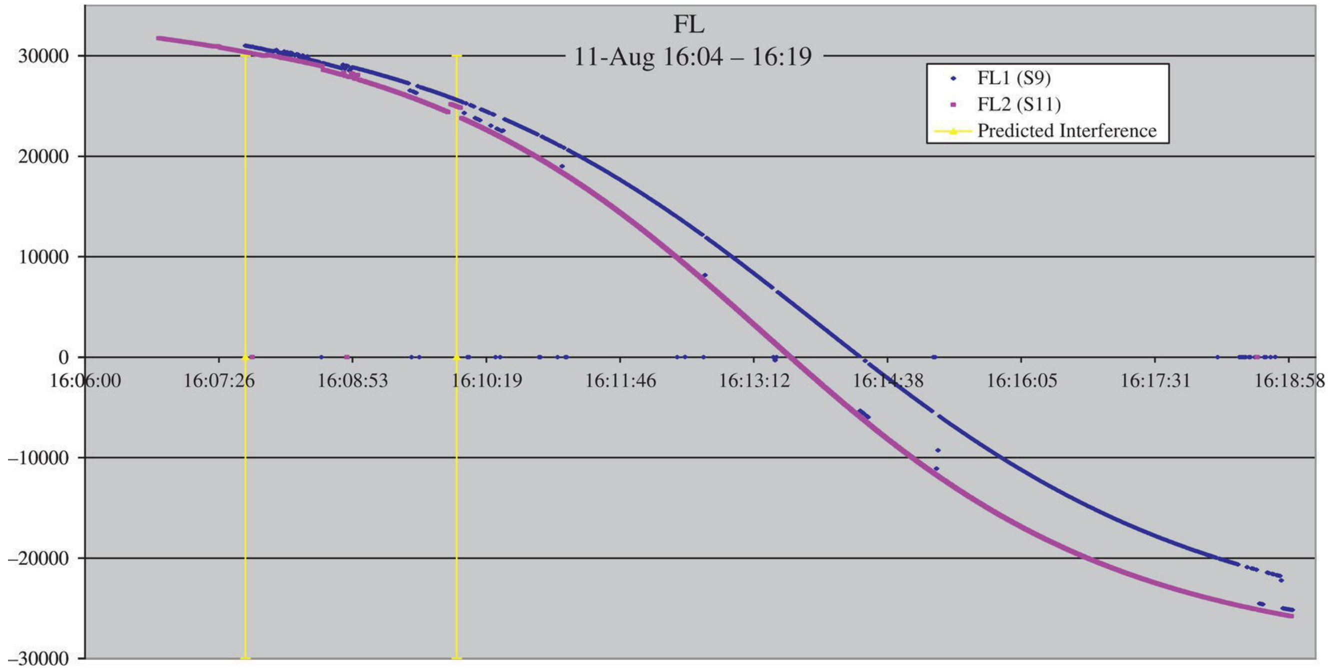


Figure 9.15 Interference interval.

When the receiver locks on the interfering signal, jumping (interruptions on curve) of the received carrier frequency is seen. These interruptions in carrier lock result in loss of downlink capability and can visually show when interference has occurred. Figure 9.15 shows that for most of the pass, each LUT is successfully locked on its desired signal. Two vertical lines, in Figure 9.15 show the time interval of interference. This can result in missed bursts (missed Doppler event), or no signal received at all.

Table 9.3 Passes affected by interference.

Date	DOY	AOS	LOS	LUT	SAT	Orbit	Reason
03.08.09	067	16 : 31	16 : 43	LSE	S9	34 844	No ***pds*** solution
03.08.09	067	16 : 35	16 : 47	CA2	S9	34 844	No ***pds*** solution
03.08.09	067	18 : 08	18 : 18	AK2	S9	34 845	No ***pds*** solution
03.08.09	067	19 : 56	20 : 04	CA1	S9	34 846	No ***pds*** solution

04.16.09	106	19 : 49	19 : 58	CA2	S9	35 401	No ***pds*** solution
04.16.09	106	21 : 34	21 : 44	HI2	S9	35 402	No ***pds*** solution
04.17.09	107	0 : 58	1 : 11	GU2	S11	12 932	No ***pds*** solution

For SARSAT system, the downlink interference between S11 and S9 (Figure 9.15) was documented by France in March and April 2009, when S9 and S11 were close to each other. The March 8, 2009, occurrence of interference between these two satellites caused four passes, over a period of three orbits, which produced no ***pds*** solutions. The April 16, 2009, occurrence of interference caused three passes with no ***pds*** solutions over a period of three orbits, presented in Table 9.3 (DOY means day of the year). But, the number of no ***pds*** solutions alone cannot accurately gauge the amount of interference in the downlink. It is a significant variability in the number ***pds*** bursts received by the satellite during each orbit depending on the path.

Considering orbital parameters (Table 8.1), three pairs of operational SARSAT satellites are susceptible to this interference condition: S10/S12, S9/S11, and S7/S8 identified and presented in Table 9.4 with their respective orbital periods and differences between them, and recorder by NOAA orbital software are given in Figure 9.16.

The small difference in orbital periods of the S10/S12 pair is particularly concerning. The ***Orbit repeat cycle*** indicates the number of orbits that satellite should pass through to achieve the same position relative to the adjacent satellite and to the fixed ground station. Mathematically, ***Orbit repeat cycle*** is the ratio of orbit period and orbital difference. Further, for this cycle to be expressed in days, it should be divided by the mean motion from Table 8.1 (for example for S12 is 14.1095). The SARSAT documented that the launch of S12 (NOAA-19) into an orbital plane similar to

S10 (NOAA-18), and with nearly identical orbital periods, created long ***periods of adjacent interference***. The first period of extended interference occurred September 15–20, 2009 (Cakaj et al. 2010a).

Table 9.4 SARSAT adjacent satellites.

Satellite	Orbit period	Difference	Orbit repeat cycle	Repeat cycle (days)
SARSAT12	01 : 42 : 03.53	00 : 00 : 01.30	4710	334
SARSAT10	01 : 42 : 02.23			
SARSAT11	01 : 41 : 18.10	00 : 00 : 10.92	556	39
SARSAT 9	01 : 41 : 07.18			
SARSAT 8	01 : 41 : 56.75	00 : 00 : 52.55	116	8
SARSAT 7	01 : 41 : 04.20			

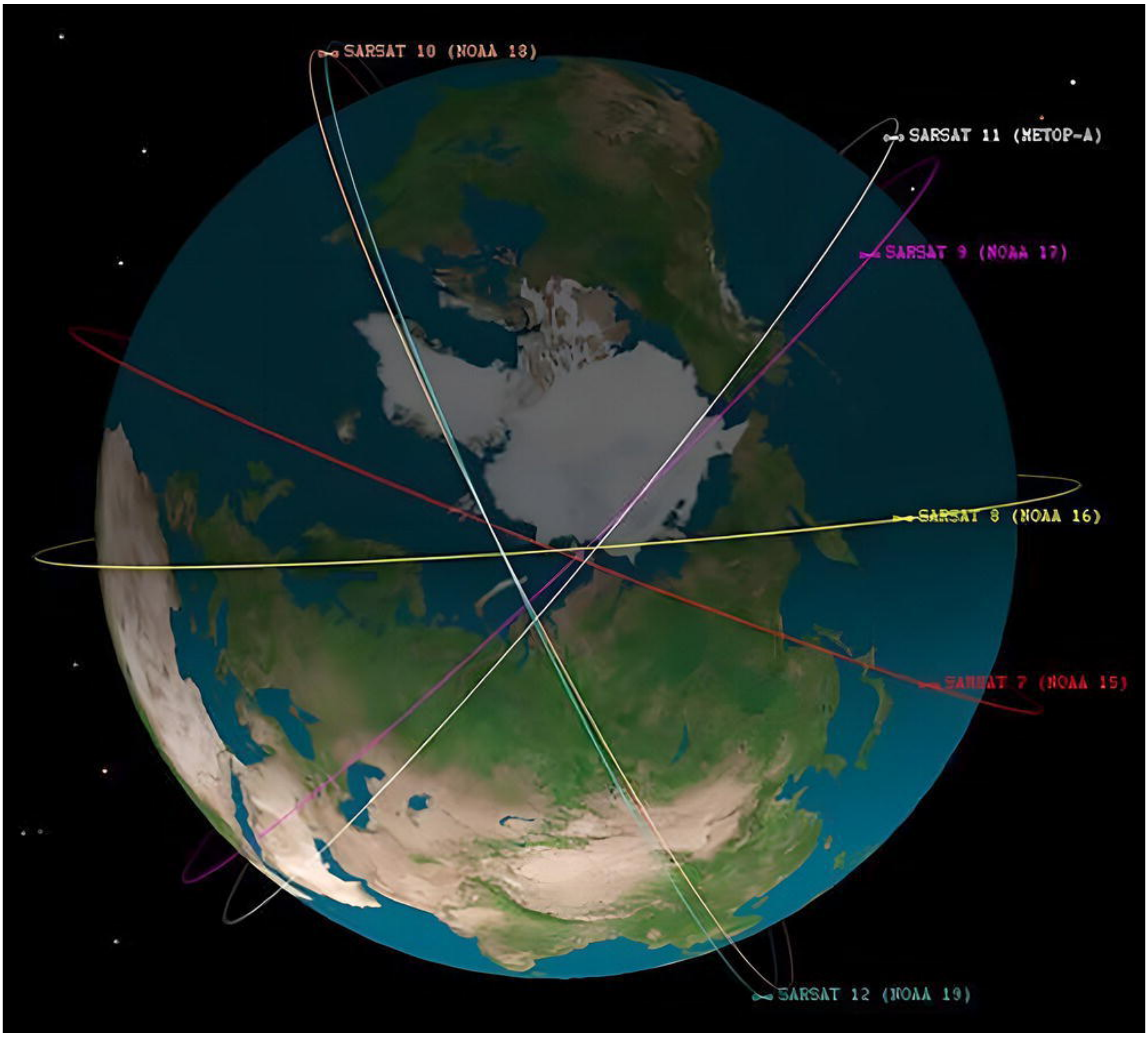


Figure 9.16 SARSAT adjacent satellites.

9.6.1 Adjacent Interference Identification and Duration Interval

To determine the duration of the interference periods, one must find the minimal angular separation between satellites as seen from the ground station, when interference occurs. This is highly dependent on the gain pattern and pointing accuracy of the LUT antenna. For a typical LEOLUT antenna gain pattern, the −3 dB (half power) beamwidth is found to be ±4.25°. This beamwidth represents the necessary angular separation to prevent undesired signals from being highly amplified. As the angular separation increases, the gain of the interfering source decreases. Since the distance between the two satellites is relatively constant during a singular pass, it can be seen that the apparent angular separation is greatest when the satellites are at their maximum elevation (closest approach) (Cakaj et al. 2010a). Thus, minimum angular separation occurs when the satellites are at minimum elevation. Thus, the cases with low elevation are of interest from the interference aspect.

Idea: Under the case that the satellites based on their orbital parameters are adjacent, and the interference is expected, the main question is to conclude how long it will take? Further elaborated!

Method: Mathematical and simulation approach are applied and confirming each other. Let us consider a LUT with antenna aperture of ±4.25°. This antenna is tracking a satellite, which is moving ahead relative to another satellite which is seen at minimum elevation above the horizon (5°), as shown in Figure 9.17.

These adjacent satellites, seen at low elevation and with a very low separation angle, have great potential to interfere with each other. The slant range is calculated for elevations of 9.25° and 5° (5° is designed horizon with 4.25° separation) from the ground station. Spatially the separation angle is the spherical angle from 0° to 4.25°. The 0° point is on the desired satellite, and 4.25° point is the −3 dB interference point; consequently, it is the largest possible distance for interference from another satellite. The general formula for the slant range (***d***) under elevation $\boldsymbol{\varepsilon}_0$ is (Cakaj and Malaric 2007):

$$d = R_E\left[\sqrt{\left(\frac{H + R_E}{R_E}\right)^2 - \cos^2\varepsilon_0} - \sin\varepsilon_0\right] \tag{9.14}$$

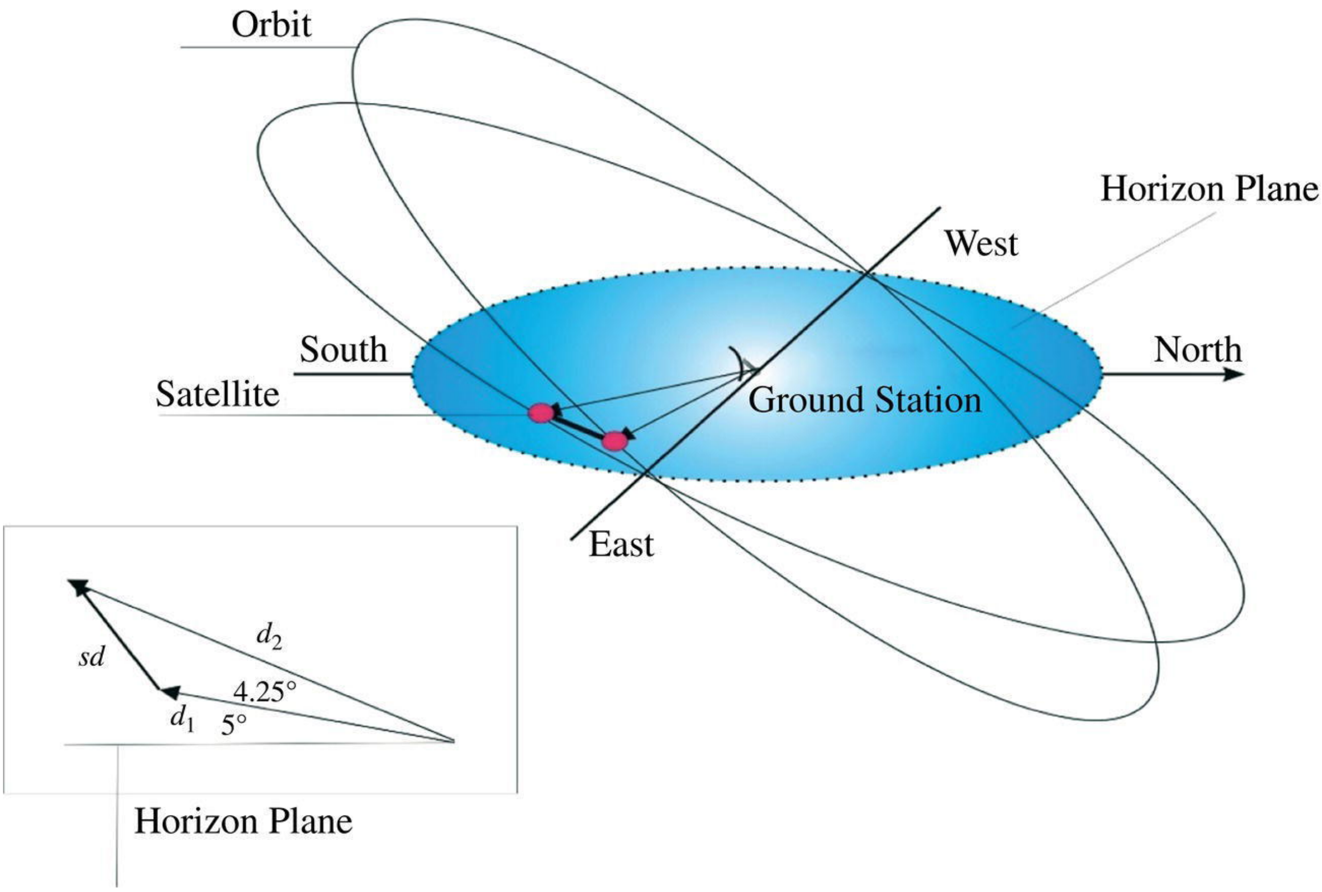


Figure 9.17 Adjacent satellites angular separation.

where, R_E = 6378km is Earth radius and H is orbital altitude. The separation distance (**sd**) can then be determined using a small angle approximation and applying cosines theorem, as:

$$sd = \sqrt{d_1^2 + d_2^2 - 2d_1 d_2 \cos 4.25^\circ} \tag{9.15}$$

Where d_2 is the slant range of pointed satellite from the ground station and d_1 is the slant range of the adjacent satellite potential to interfere.

Altitude H for each satellite is taken from Table 8.1. The slant ranges and separation distances calculated based on Eq. (9.14) and Eq. (9.15) are presented in Table 9.5. For more exact calculations, these separation distances should be multiplied by cosines of separation angle (projection of separation distance in its own orbit), which for too-low angles can be considered as 1. This separation distance when interference may occur, and the difference in orbital periods can then be used to find the duration of possible interference. Considering that these satellites are always moving with a particular velocity ***v***, the question is how long they can be together within a separation angle of 4.25° or lower!

Table 9.5 SARSAT adjacent satellites.

Satellite	Slant range (at 9.25°) (km)	Slant range (at 5°) (km)	Separation distance (km)
SARSAT12	2544.5		416.4
SARSAT10		2903.8	
SARSAT11	2470.3		399.1
SARSAT 9		2812.9	
SARSAT 8	2534.4		341.4
SARSAT 7		2806.5	

Table 9.6 SARSAT adjacent satellites.

Satellite	Velocity (km/s)	Duration (s)	Interference repeat cycle (#Orbits)	Repeat cycle (#days)
SARSAT12	7.423	56.3	43.3	3.10
SARSAT10	7.423			
SARSAT11	7.446	53.9	4.9	0.35
SARSAT 9	7.441			
SARSAT 8	7.447	46.1	0.9	0.06

Results: Finally, the math results for separation distances between adjacent satellites and interference repeat cycle are given in Tables 9.5 and 9.6.

In Table 9.6, the ***Duration*** represents expected time interval of possible adjacent interference. (This is needed time for satellite S12(S10) moving at velocity of 7.423km/s to pass the critical separation distance of

416.4km). The frequency of these events and their duration relative to the fixed ground stations depend on the difference of orbital period times (Table 9.4). The ratio of interference time duration to time difference in orbital periods represents ***Interference repeat cycle per orbit***. For duration of 56.3s divided by orbital time difference of 1.3s from Table 9.4 the repeat cycle is 43.3. This cycle is expressed in days when divided by mean motion (Table 8.1, it is 14.1095). Thus, for repeat cycle of 43.3 divided by 14.1095 stems the value of approx. 3.10 days. Considering separation distance, predictions for the interference repeat cycle of satellite pairs are listed in Table 9.6. Math results from Table 9.6 are in full accordance with outputs from orbital software given in Table 9.4.

Conclusion: In general, the difference in orbital periods between the two satellites will dictate the duration and repeatability of interference intervals. From Table 9.6 it is obvious that the S10/S12 pair experiences the highest interference repeat cycle – consequently, the longest possible interference disturbance, because of too-close orbital periods. This means that the satellite pair S10/S12 is of particular concern from the interference aspect. The S7/S8 pair is the least experiences with interference (obvious from Figure 9.16).

9.7 Modulation Index Application for Downlink Interference Identification

On support of interference identification, LEOLUT's software uses two more parameters: modulation index (mean) and modulation index (root mean square – RMS). Modulation index indicates the quantity by which the modulated variable varies around its unmodulated level (Cakaj 2012). Considering downlink phase modulation, modulation index (mean) relates to the variations in the phase of the carrier signal, expressed as:

$$m_i = \Delta\theta(t) \tag{9.16}$$

$\Delta\boldsymbol{\theta}(\boldsymbol{t})$ is the phase deviation.

The other measure is modulation index (root mean square). In mathematics, the root mean square (RMS) is a statistical measure of the magnitude of varying quantity. It is especially useful for sinusoids wave forms. In case of set of n values m_{i1}, m_{i2}, ...m_{in},the RMS is given by (Mean-Root-Square, 2012; Yafeng et al. 2004):

$$m_{RMS} = \sqrt{\frac{m_{i1}^2 + m_{i2}^2 + \ldots + m_{in}^2}{n}} \tag{9.17}$$

The corresponding formula for a continuous function $m(t)$ defined over the time interval $T_1 < t < T_2$, the RMS is:

$$m_{RMS} = \sqrt{\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} |m(t)|^2 dt} \tag{9.18}$$

For illustration and interpretation, two different Doppler curves are given, with no interference and the next one with interference presence, presented in Figures 9.18 and 9.19, respectively.

The received carrier frequency is shown on the left axis, and modulation index mean and RMS (route mean square) on the right axis. Modulation index indicates the quantity by how much the modulated variable varies around its unmodulated level. Considering downlink phase modulation, this index relates to the variations in the phase of the carrier signal.

In Figure 9.18, there is no interference, so the lines expressing modulation index and root mean square index are almost flat, confirming noninterference presence. Figure 9.19, is the case with medium maximal elevation of 36°. Figure 9.19 shows the interference during AOS (acquisition of satellite- left circled part). Further, as the satellite moves toward higher elevation there is no interference (medium part of figure) and then again there is interference near LOS (loss of satellite- right circled part). Frequency jumps in the downlink carrier can be seen in the lower-right corner of Figure 9.19, manifested by a high mean modulation index at the same time. In Figure 9.19, it is very expressive modulation index and frequency jump during the loss of satellite. In Figure 9.19 modulation index is circled and mean root square index is squared, confirming exactly the principles discussed.

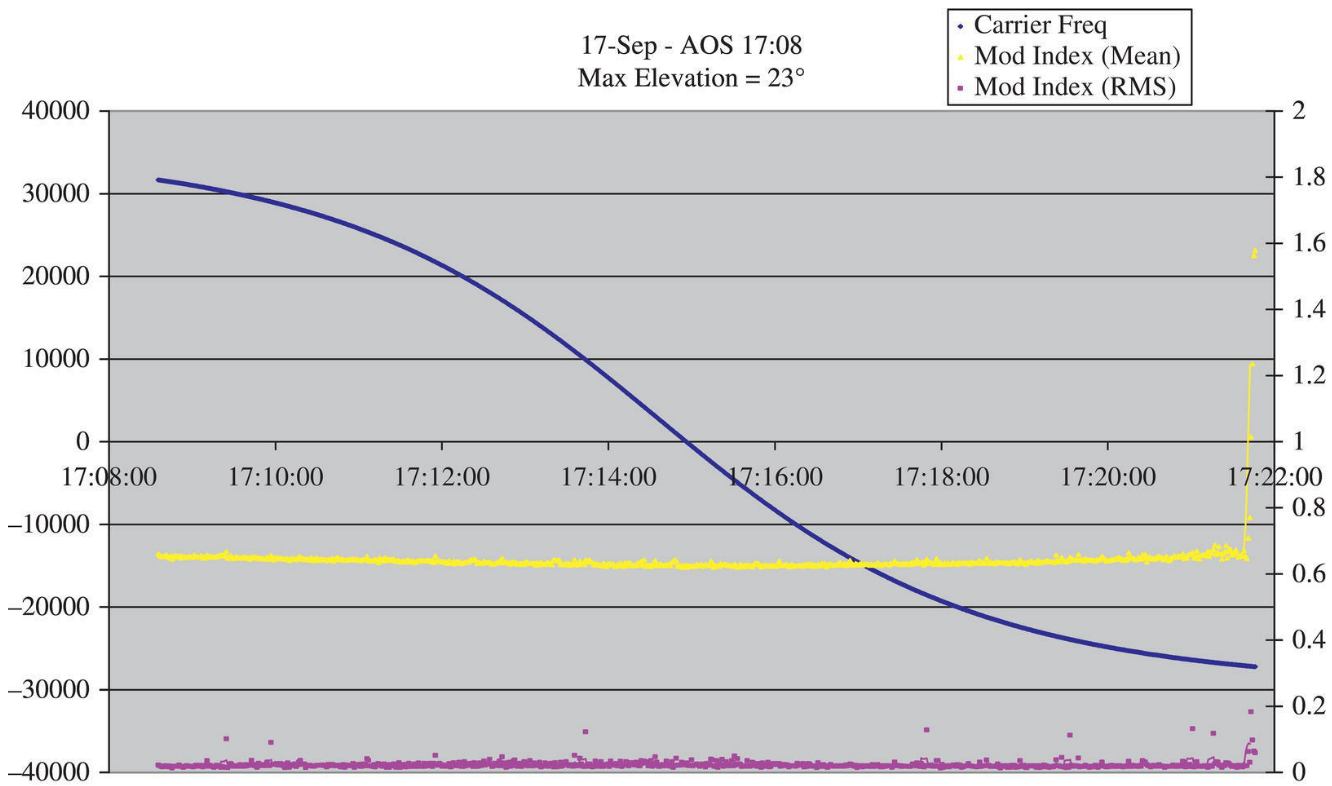


Figure 9.18 No interference Doppler curve for Max. El. 23 °.

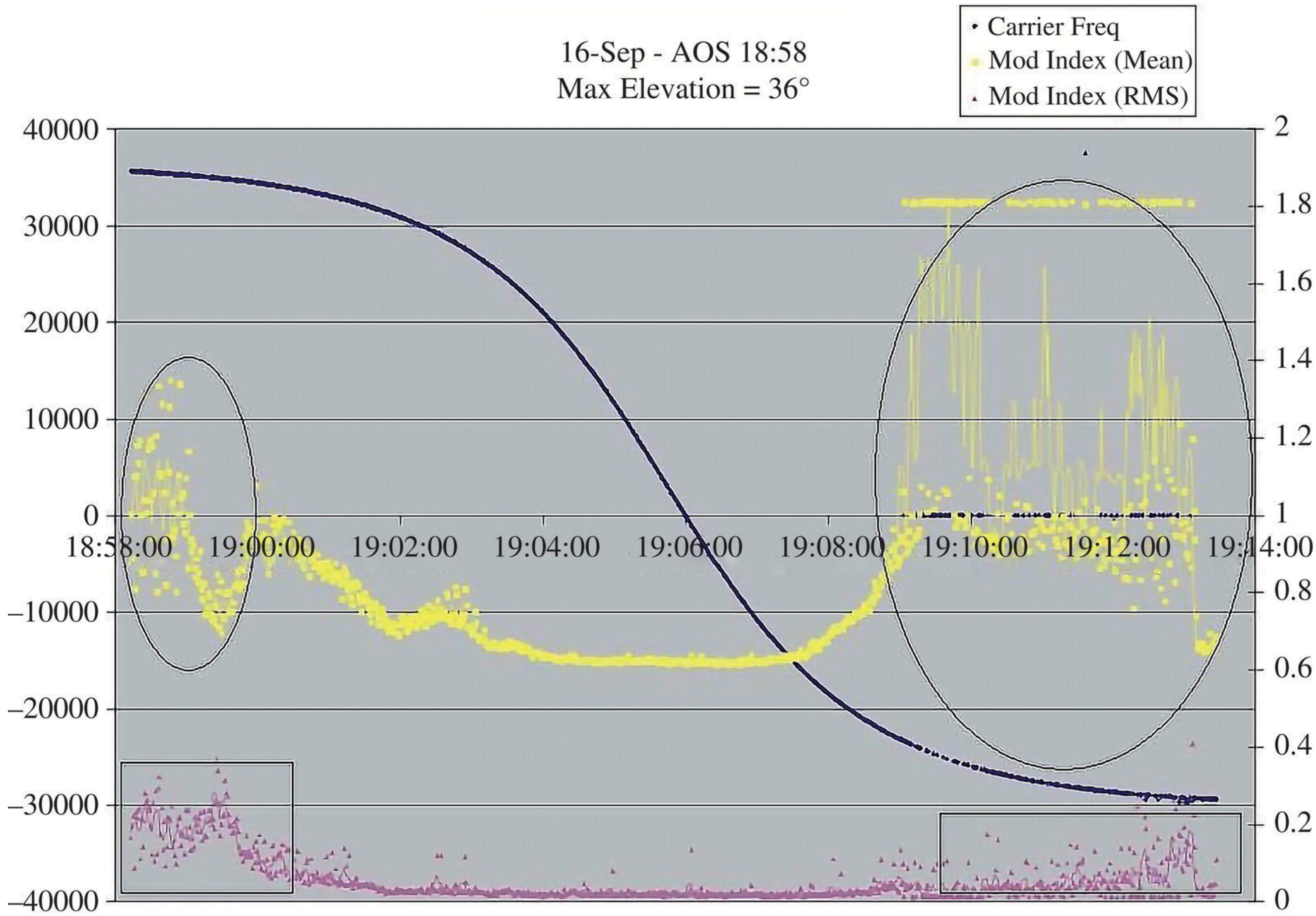


Figure 9.19 Doppler curve for Maximal elevation of 36° (present interference).

9.7.1 Simulation Approach of Interference Events and Timelines

As another approach, and for results comparison, a satellite orbit analysis program (at NSOF, SARSAT, NOAA) using the known LUT antenna gain pattern is applied. Again, when the both satellites are within –3 dB beamwidth (separation angle of 4.25°) from the point of view of the LUT, it was determined that interference is possible. Considering events from Table 9.3, a period from May to December is then conducted. The beginning of the period of possible interference was designated as the first pass at a SARSAT LUT where S10 and S12 would be within 4.25° of each other, at any point during the pass. The predicted periods of interference were generated by a NOAA orbital analysis software. Table 9.7 shows the timeline of these significant events.

Table 9.7 Timeline of significant future interference events.

Satellite pair	Start of interference	End of interference	Duration (days-hh:mm:ss)
S9/S11	5.25.09, 18 : 06 : 59	5.26.09, 02 : 26 : 06	0 – 08 : 19 : 07
S9/S11	7.03.09, 13 : 11 : 29	7.03.09, 19 : 37 : 15	0 – 06 : 25 : 46
S9/S11	8.11.09, 01 : 29 : 55	8.11.09, 07 : 41 : 06	0 – 06 : 11 : 11
S9/S11	9.18.09, 09 : 20 : 34	9.18.09, 14 : 40 : 31	0 – 05 : 19 : 57
S10/S12	9.20.09, 10 : 49 : 37	9.23.09, 19 : 54 : 12	3 – 09 : 04 : 35
S9/S11	10.26.09, 10 : 28 : 57	10.26.09, 16 : 34 : 48	0 – 06 : 05 : 51
S9/S11	12.03.09, 07 : 23 : 15	12.03.09, 12 : 37 : 25	0 – 05 : 14 : 10

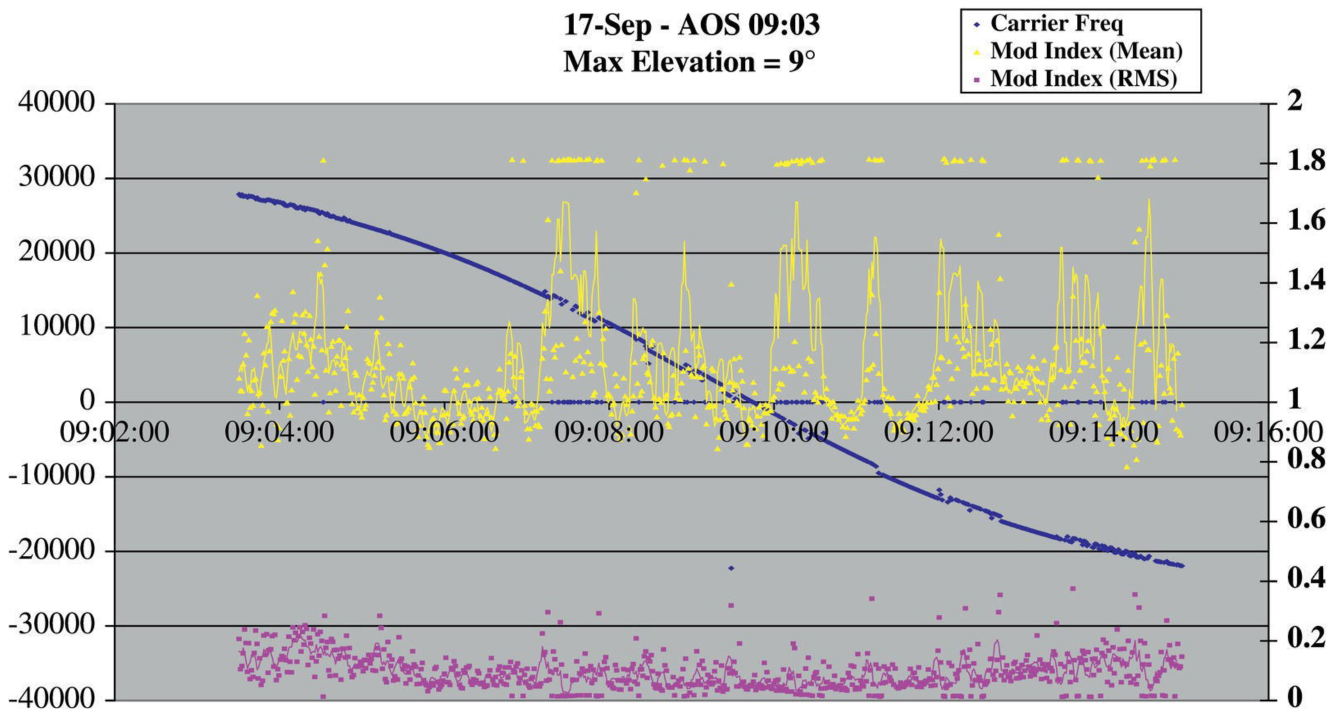


Figure 9.20 Doppler curve for Maximal elevation of 9°.

The appropriate software confirmed that the duration of the S10/S12 interference is of particular concern, and has been verified through this simulation method to be about three days. This proves the accordance between mathematical analysis results (Table 9.6) and simulation results given in Table 9.7 (Cakaj et al. 2010a). The duration of S9/S11 interference periods decreases. Periods of S8/S7 interference are negligible and therefore are not listed.

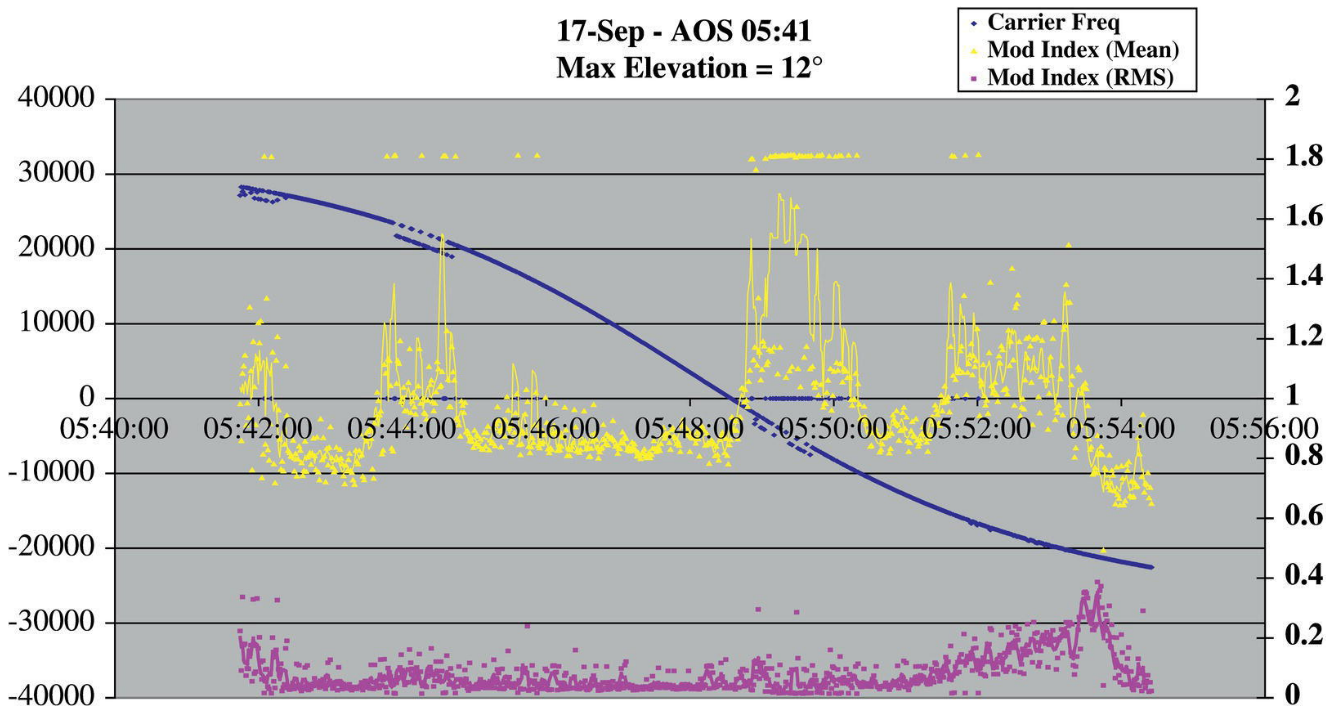
Through these two approaches, we can confirm that considering antenna pattern and satellite pass geometry, analytical models can be built to predict the time and duration of interference based on the angular separation between the two satellites (Cakaj et al. 2010a).

If operational impacts become severe, efforts must be performed to mitigate interference, specifically under low elevation. Figure 9.20 shows the case at elevation of 9°. Modulation index and root mean square index variations during the whole satellite pass, manifested in Doppler shift curve, confirm interference during the whole pass under the maximal elevation (Max-El) of 9°, which will make it much more difficult to determine a distress location, under these circumstances given in Figure 9.20.

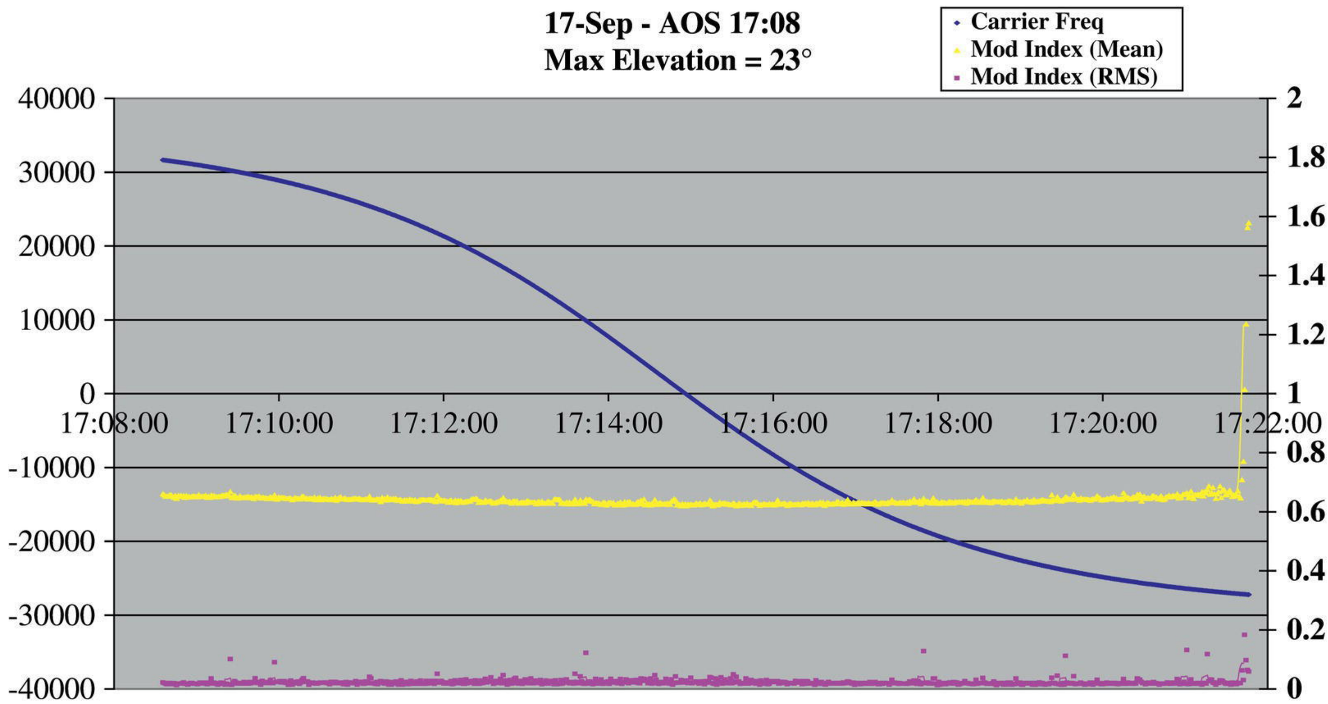
Canadian team within a COSPAS-SARSAT system developed a procedure to interrupt RF transmission from the satellite with a minimal chance of irrecoverable failure. The NOAA-SARSAT executed this procedure when the operational impacts of interference became evident. The NOAA-SARSAT analyzed the downlink characteristics during the periods both before and after the mitigation actions were taken. This process is further described.

Satellite pair S10/S12, as the worst case of adjacent interference is further analyzed. The Canadian procedure to interrupt the downlink RF transmission from the satellite is considered to be applied as a method to mitigate adjacent satellite interference. The turnoff transmission was planned for S10. The situation before turning off the planned S10 satellite is given in Figure 9.21 under Max-El of 12°, where the interference presence shows up!

In Figure 9.21 before the turnoff of the S10 downlink, the received carrier frequency can be seen jumping from one satellite's downlink to the other one, causing the degradation of downlink capabilities. The modulation indices are higher during these times since the receiver cannot lock on only one carrier. Figure 9.22 shows the same plot after the downlink of S10 had been turned off. They show that the only increase of the modulation indices occurs near the LOS, when the signal is the weakest. Figure 9.22 is typical of what would be seen during a nominal pass with no interference. The procedures developed by Canada and executed by the USA were successful in interference mitigation (Cakaj et al. 2010a).



[Figure 9.21]() Doppler curve for Maximal elevation of 12°.



[Figure 9.22]() No interference Doppler curve for Max-El 23°.

Conclusion: It is confirmed that adjacent SARSAT satellites with short differences in orbital period interfere with each other. During these interference periods, significant degradation of downlink occurs. The procedure to interrupt the downlink RF transmission from the "undesired" satellite is applied as a method to mitigate adjacent satellite interference. For newly built terminals though, larger antennas with a narrower beamwidth may also reduce the adjacent interference issue and impacts.

The DASS (Distress Alert Satellite System) is a newly developed & future approach intended to enhance the international COSPAS-SARSAT program. In this effort the satellite-aided search and rescue (SAR) system will install 406 MHz SAR instruments on the MEO navigational satellites [GPS (US), Galileo (EU), and Glonass (Russian Federation)]. With an expected 80 satellites once fully operational, new processing algorithms and interference mitigation strategies should also be considered. Because of the much higher altitudes of MEO satellites, a larger separation distance exists, and the adjacent interference will be less pronounced.

9.8 Uplink Interference Identification for LEO Search and Rescue Satellites

For a rescue operation to be successful, it is crucial that the distress location be rapidly determined. The location determination is based on Doppler frequency shift, and its accuracy depends on the signal quality received at the satellite from the distress beacon. The distress beacon signal can be disturbed by interferers, which degrade the performance of the on-board 406 MHz Search and Rescue Processor (SARP) and reduce the probability of detecting real beacon messages (COSPAS –SARSAT System Monitoring and Reporting 2008). Emergency distress beacons are essentially specialized radio transmitters for search and rescue purposes carried by airplanes, ships, and individuals. SAR (search and rescue) satellites can even "hear" faint distress signals from beacons. The beacon can be activated manually or automatically. Since February 2009, rescue beacons have transmitted on 406 MHz. Some characteristics of 406 MHz beacons are shown in Table 9.8 (Specification for COSPAS – SARSAT406MHz Distress Beacons 2008).

The 406.0–406.1 MHz band has been allocated by the International Telecommunication Union (ITU) for distress alerting using low-power, emergency radio beacons. This 100 KHz licensed band is organized in channels for multiuser random access at the satellite. Frequency spectrum lies in the band 406.0–406.1 MHz. These radio beacons emit stable, constant frequency, which is highly important for location determination. The 406 MHz carrier is phase modulated with information such as beacon identification, synchronization frame, and the nature of emergency. From the time slot of 500 ms, only 160 ms are dedicated for poor carrier and the rest is for modulated data, such are beacon type, its country of origin and the registration number of the maritime vessel, aircraft, or individual (Specification for COSPAS – SARSAT406MHz Distress Beacons 2008).

Idea: If the beacon signal at the distress location to be sent through the uplink to the satellite is disturbed, the satellite's receiver will not be able to receive the appropriate accurate (clean) beacon signal, and consequently will not yield the right Doppler curve to provide the correct rescue location. The question is to identify the impact of uplink interference on Doppler curve, and consequently on distress location determination (Cakaj et al. 2010b).

Table 9.8 Some of beacon characteristics.

Output power	**5 W**
Transmission	Burst (500 ms on every 50 sec)
Modulation	Phase
Frequency stability	High

Method: For confirmation of the above discussed effect, the records are taken from NSOF (NOAA Satellite Operation Facility), where the author did his research (NSOF 2010; National Telecommunications and Information Systems 2006).

Active signal sources in various areas of the world can produce spurious emissions in the 406 MHz allocated range, interfering with the NOAA-SARSAT system, whether or not they operate at the 406 MHz band. How severe the interference is will depend on the amount of frequency overlap between the interfering spectrums and the allocated channel passband, relative to the tolerable level of the receiver. NOAA-SARSAT satellites have 406 MHz repeaters for retransmitting emissions received from Earth in the band 406.0–406.1 MHz. As a result, the time/frequency pairs of interference emissions can be measured with specially designed LEOLUTs, which monitor 406 MHz interference using specific software in the LEOLUTs in conjunction with a 406 MHZ SAR processor. The software at the LEOLUT utilizes Fast Fourier Transform (FFT) analysis to determine time, frequency, and the power of the interfering signal.

Results: Two spectrograms are further given, extracted by the examination of the Doppler frequency shift of data transmissions from detected beacons or interfering transmitters (NSOF 2010; USTTI, Course M6-102, National Telecommunications and Information Systems 2006; Cakaj et al. 2010b).

Figure 9.23 shows the spectrogram view with no interference. The Doppler curve is related to beacon A. The number of data points (Doppler events) depends on communication duration between a satellite and LEOLUT. Satellite orbital parameters, the duration, and, consequently, the expected data points are known in advance. In Figure 9.23, Doppler points are discrete, since the beacon hits the satellite in intervals of 50s. From Figure 9.23, it is obvious a good Doppler curve was provided during the satellite pass and the distress location was obtained.

Figure 9.24 shows the spectrogram view when interference is present. Two beacons, B and C, are disturbed by interference. For beacon B, nine data points were expected and for beacon C, seven data points were expected. This indicates a medium duration of communication between a satellite and a LEOLUT. The interfering signal is shown in Figure 9.24.

The interfering signal is continuous for a long period of time as compared to the periodic 500 ms beacon bursts. The continuous interfering signals may produce a Doppler curve, but no identification code can be extracted from an interfering signal since its modulation, if any, would not be in the correct format. The lack of identification code is an interference indicator. Interference caused insufficient data points to be captured for a Doppler curve, and, consequently, no distress location for these two beacons was obtained.

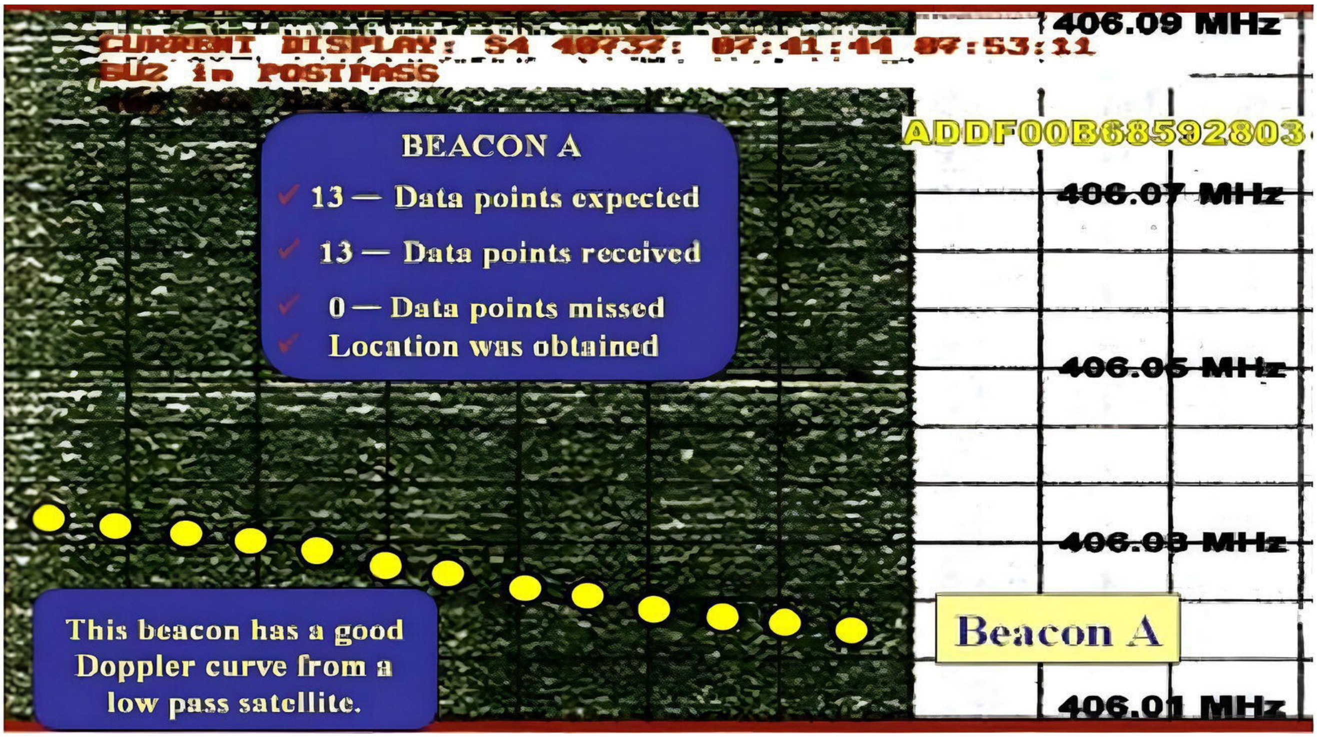
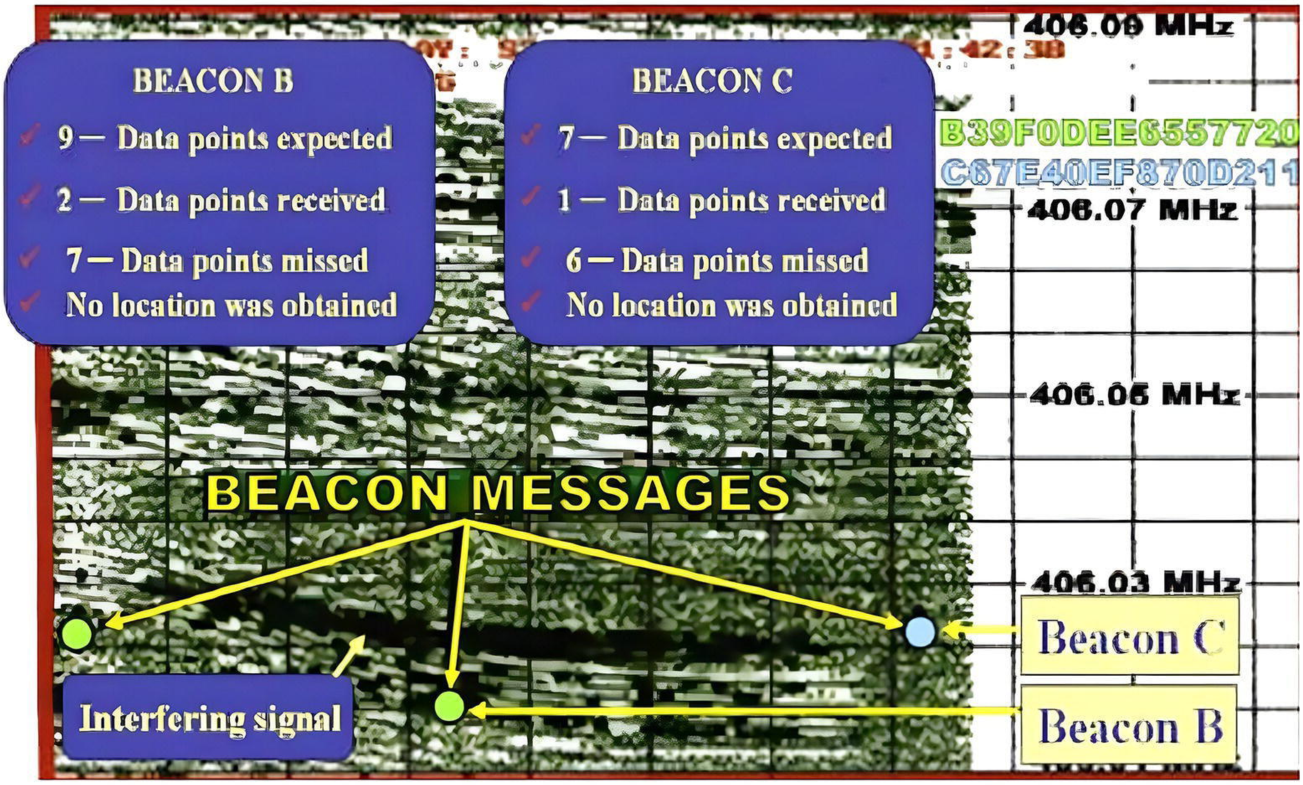


Figure 9.23 No interference spectrogram view.



[Figure 9.24] Interference spectrogram view.

Conclusion: NOAA-SARSAT is a data communication system dedicated for search and rescue purposes, oriented on determination of distress locations worldwide. Since uplink interference can disturb the satellite's receiver, blocking the location of the distress location, thus a very sophisticated method has been developed and applied at LEOLUTs to identify uplink interference, providing spectrograms above applied. This method provides data about frequency, power, and time of interference.

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