Radioelectric compatibility of the Future Aeronautical Communication System

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Abstract—The aeronautical community has recently decided to develop a new digital aeronautical communication system, named L-DACS, in order to fulfill the new air traffic requirements. This system, which will operate in the L frequency band (960 to 1164 MHz), would be internationally deployed from 2020. Many technologies were considered for this new aeronautical system but only two among them were preselected by the International Civil Aviation Organization (ICAO): candidate one, named L-DACS1, is based on a FDD-OFDM technology and candidate two, named L-DACS2, is based on a TDD-GMSK technology. One of the most important issues for both candidates is the electromagnetic compatibility (EMC) with the legacy systems operating in the same band or/and in adjacent bands. Different scenarios have to be evaluated due to the fact that these systems will be implanted either in the airplanes (on board) or in ground stations. In this paper, we propose to evaluate the air-air scenario, where we focus on the signals generated by onboard L-DACS transmitters on onboard victim receivers, taking into account the L-DACS antenna radiation pattern and the frequency mask. The study emphasizes that the interference phenomenon can be one of the main limitations for the L-DACS development.

Index Terms—L-DACS, EMC, radioelectric compatibility, aerospace scenario, aeronautical environment, interference level, interference threshold, aeronautical antenna pattern, interference worst case, air to air scenario.

I. INTRODUCTION

Commercial and general aviation authorities have been using VHF amplitude modulation analog communication systems for more than 70 years in the 118-136 MHz band. The study of a future communication system has been proposed due to the new air traffic requirements since 2002. This project is lead by the American National Aeronautics and Space Administration (NASA) and the European Organization for the Safety of Air Navigation (EUROCONTROL). During the 2007 World Radiocommunications Conference (WRC) organized by the International Telecommunication Union (ITU), it was decided that the 960 to 1164 MHz frequency band will be allocated to Aeronautical Mobile (Route) Service (AM(R)S). The FCS component dedicated to the continental communications is expected to provide that service.

This system is called the L-Band Digital Aeronautical Communication System (L-DACS). Far from the current VHF system, L-DACS is assumed to guarantee additional services, such as air/air communication and data exchange. Both NASA [1] and EUROCONTROL [2] conducted studies to identify, among many proposals, the most adapted technology which would support the L-DACS services [3]. Two candidates have been preselected by the International Civil Aviation Organization (ICAO); they are called L-DACS1 and L-DACS2. Both of them fulfill the main requirements despite they have different specifications [4]. However, for each evolved technology, the electromagnetic compatibility (EMC) with the legacy systems, operating either in the L-band or adjacent frequency bands, must be ensured. Such a topic is called the Radioelectric Compatibility. In fact, it should be noted that many aeronautical radio systems operate in these bands and their coexistence with L-DACS is fundamental not only for regulation issues but also for flight safety. As a consequence, it is necessary to carry more detailed studies before the final choice which will be held by 2011.

Evaluating the L-DACS interference over onboard and ground receivers is very complex because the aeronautical environment has to be represented by a 3D grid [4] with very specific characteristics. Any two dimensions model is no longer appropriate for this application since the vehicles may have very different altitudes and high speeds. Moreover, the aeronautical community has imposed safety norms to regulate the spatial separation among the different airplanes. In addition, since the aeronautical network is expected to manage correctly communication among a huge number of stations, the victim may suffer of interference from many L-DACS interferers and each one has to respect the mentioned conditions.

This preliminary work aims to evaluate on board L-DACS transmitters and ideal legacy system victim receivers capability to coexist, in case that the interferer and the victim are located in distinct aircrafts. The presented systems are assumed to be far from airport zones. The main idea of this study is to compare the L-DACS highest generated interference level and the interference threshold of the perfect receiver. For this, the paper takes into account particularly the transmitter/receiver separation distance in space and in frequency. As a result, this work gives a determinist approach to determine the spatial positions of the corresponding interferers as well as the offsets of their carriers from the receiver central frequency. Finally, the analysis is performed considering diverse antenna radiation...
patterns for L-DACS.

In the previous publication [6], we detailed a numerical approach and provided results regarding the air to air worst case scenario. Based on these elements, we develop in this work a similar methodology aiming to determine the highest interference level when moving the L-DACS distribution away from the receiver in both space and frequency domains.

We organize this paper as follows. First, we present the two L-DACS candidates with their available specifications. After that, we model the aeronautical environment and detail the methodology adopted to build the radioelectric compatibility study. Finally, through simulation results, we give solutions to solve the frequency sharing problems.

II. THE L-DACS CANDIDATES

L-DACS is the Future Communication System part dedicated to the continental communications. The two L-DACS candidates, called L-DACS1 and L-DACS2, respect most of the new air traffic requirements such as data rate, spectral efficiency and network capacity (the maximum number of aircrafts simultaneously connected).

L-DACS1 is an evolution of two technologies: the European Broadband Aeronautical Multi-carrier Communication System (B-AMC) and the American Telecommunications Industry Association (TIA-902), known as Project 34 (P34). It includes a Frequency Division Duplex (FDD), i.e. ground and airborne components can transmit information simultaneously but using distinct frequency channels. According to L-DACS-1 system specifications [7], the transmission and reception carriers associated to equipment are 63 MHz separated. This technology uses also Orthogonal Frequency Division Multiplexing (OFDM) modulation.

L-DACS2 is derived from two technologies: the European All-purpose Multi-channel Aviation Communication System (AMACS) and the American L-Band Data-Link System (LDL). It employs a Time Division Duplex (TDD), i.e. ground and airborne components can transmit information using the same frequency channel, but during different time intervals. Moreover, this technology uses Gaussian Minimum Shift Keying (GMSK) modulation.

In this paper, we present some of the characteristics of on board L-DACS equipments. Although some similarities can be noticed from their specifications [7] and [8], the two L-DACS options are quite different. One main divergence is that L-DACS1 and L-DACS2 will operate in distinct frequency bands included in the 960-1164 MHz band, allocated to ATM(R)S within the ITU. If on board L-DACS1 emits in 1048-1164 MHz, L-DACS2 uses the 960.5-975 MHz band. For L-DACS2, it should be noticed that a 500 KHz external guard band is imposed in order to reduce its mutual interference with mobile telephony signals (925-960 MHz).

Therefore, the transmit power and the transmit channel bandwidth of the two L-DACS technologies are different. In table I, we depict some of system parameters that we will be used in the next sections of this document.

### Table I

<table>
<thead>
<tr>
<th>Parameter, Symbol (unit)</th>
<th>L-DACS1</th>
<th>L-DACS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable Losses, $L_C$ (dB)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Transmit power, $P_t$ (dBW)</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Lower frequency, $F_{low}$ (MHz)</td>
<td>1048</td>
<td>960.5</td>
</tr>
<tr>
<td>Upper frequency, $F_{high}$ (MHz)</td>
<td>1164</td>
<td>975</td>
</tr>
<tr>
<td>Transmit bandwidth, $B_T$ (MHz)</td>
<td>0.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

In addition, even the largest part of the total power at the L-DACS transmitter output (given in table I) is transmitted in its band pass, the total signal spreads also over a large number of adjacent channels. Thus, the L-DACS spectral mask limits the unwanted power, in order to ensure that out of band as well as spurious emissions do not exceed the levels specified by the ITU recommendation [9]. For both L-DACS candidates, the transmission masks were defined in dB$_C$ and given in figure 1, with 100 kHz resolution and 100 kHz reference bandwidth.

![Fig. 1. L-DACS1 and L-DACS2 spectral transmission masks](image)

III. THE INTERFERENCE ENVIRONMENT

The paper aims to diagnose the radioelectric compatibility between L-DACS transmitter and L-Band receiver. The two radio systems are compatible if they can coexist in the same electromagnetic environment. In this work, we analyze the impact of L-DACS transmitter over a perfect receiver. To achieve such a result, the following steps should be considered to model the aeronautical environment.

A. Interference scenario

The paper deals with the air to air scenario. For this configuration, the victim and the interferer are necessarily located in distinct aircrafts. Because the aeronautical network is assumed to manage communication among a high number of airborne stations (see the traffic requirements [5]), the victim may receive interference from many L-DACS transmitters.

According to the previous work [6], the potential L-DACS interferers to take into account are the in band transmitters.
Moreover, the unwanted radiations should not exceed the transmit bandwidth and frequency range are given in table I. In figure 1, masks used for L-DACS transmitters, in dB, are those precised levels recommended by the ITU [4]. The spectral transmission below illustrated in figure 2, with a resolution of 1 degree. Their number is given by equation 1, where $B_R$ is the receiver bandwidth, expressed in MHz and $E(x)$ is the greatest integer below $x$:

$$N = E \left( \frac{B_R}{B_f} \right) + \gamma_R \quad (1)$$

Finally $\gamma_R$ is computed using equation 2:

$$\gamma_R = \begin{cases} 0 & \text{if } \exists k \in N / B_R = kB_f \\ 1 & \text{else} \end{cases} \quad (2)$$

### B. Interferer characterization

During this study, we consider onboard equipments. The transmit bandwidth and frequency range are given in table I. Moreover, the unwanted radiations should not exceed the levels recommended by the ITU [4]. The spectral transmission masks used for L-DACS transmitters, in dB, are those precised in figure 1. $H_R(f)$ is the corresponding mask in linear scale. In this study, we consider that each transmitting channel is occupied by only one L-DACS transmitter. In addition, for both L-DACS candidates, no guard band is expected between two successive transmission channels.

In addition, according to the aeronautical community, both L-DACS candidates are assumed to use the same antenna. In fact, in this paper, we propose two options. The first one is to consider an isotropic antenna, named antenna 1, with a 0 dBi gain. The second proposal is to consider a conventional aeronautical L-Band antenna. It should be noticed that such an antenna is omnidirectional in the azimuthal plane and its gain depends strongly on the elevation angle. The antenna recommended by ITU [10] for L-DACS, named antenna 2, has 5.4 dBi maximum gain and its associated radiation pattern is illustrated in figure 2, with a resolution of 1 degree.

### C. Victim characterization

In this paper, the victim is an onboard ideal receiver. For the radioelectric compatibility study, the most important parameter is the interference power density threshold $I_{\text{max}}$, expressed in dBW/MHz. This protection criterion is the maximum interference density at the equipment antenna port, above which the victim would not operate properly in the interferer presence. $I_{\text{max}}$ is directly related to the sensitivity $S_R$ (dBW), the thermal noise floor $N_R$ (dBW), and the useful received power level $P_R$ (dBW) at receiver operating range. $I_{\text{max}}$ is given by equation 3.

$$I_{\text{max}} = 10 \log_{10} \left( 10^{\frac{S_R + N_R - L_R}{10}} - 10^{\frac{S_R}{10}} \right) - 10 \log_{10} (B_R) \quad (3)$$

The noise floor and the sensitivity depend on the receiver bandwidth and are computed owing to equations 4 and 5, respectively:

$$N_R = 10 \log_{10} (kTB_f) \quad (4)$$

$$S_R = \text{SNR}_R + N_R + L_R \quad (5)$$

The temperature $T$ is set by IEEE standard to be 290°K, and $k$ is Boltzmann Constant ($k = 1.38 \times 10^{-23}$ Joule/°K). $\text{SNR}_R$ in dB, is the minimum required signal to noise ratio at the receiver.

In addition, the receiver is characterized by its central frequency $f_R$ and its antenna cable insertion losses $L_R$. Its antenna radiation pattern is isotropic in both azimuthal and elevation planes. Finally, the spectral reception mask $H_R(f)$ is given by the following equation 6:

$$H_R(f) = \begin{cases} 1 & \text{if } f \in \left[ \frac{B_R}{2}, F_R + \frac{B_R}{2} \right] \\ 0 & \text{else} \end{cases} \quad (6)$$

### D. Interference path definition

Our study is based on the worst case scenario, in which the victim receives the maximum possible power in the presence of the potential interferers. The main objective of this part is to determine the relative position between the victim and each one among these, realizing this scenario.

For this, we have to precise first the adopted propagation model. The most appropriate one for aeronautical applications is the free space propagation model. The associated path loss for each transmitter, expressed in dB, is given by equation 7. Its carrier $f$ is expressed in GHz, and its path to the receiver $r$ is expressed in meters.

$$L(f, r) = 20 \log_{10} \left( \frac{0.075}{\pi f r} \right) \quad (7)$$

Taking into account the victim characteristics, the power generated by one in band transmitter over the victim is computed using equation 8:
\[ I(f, r, \varphi) = P_\tau - L_\tau + G_r + G_s(-\varphi) + L(f, r) - L_k \] (8)

\( G_s(\varphi), \) expressed in dB, represents the transmission antenna gain relative to the maximum gain, for the elevation angle \( \varphi. \)

In order to compute this interference, one important step is to model the aeronautical environment. It is a 3D space that we represent by a three-dimension spherical system centered on the receiver, in which each airplane corresponds to one point. Thus, each transmitter is determined by its path \( r, \) its azimuth \( \theta \) and its elevation \( \varphi. \) It must also respect the separation standards imposed by the aeronautical community. In fact, the minimal separation between any two vehicles is 0.3 km vertically and 9.25 km horizontally, far from airport zones.

Based on the fact that the two L-DACS antennas that we considered are omnidirectional in the azimuthal plane, and as explained in the previous work \([6],\) we propose a 2D grid model. Each L-DACS interferer is determined by its altitude (i.e. flight level) \( z \) and its latitude \( x \) from the victim:

\[ x = r \cos(\varphi) \] (9)
\[ z = r \sin(\varphi) = 0.3k, \quad k \in \mathbb{Z} \] (10)

In these conditions and following \([6],\) we identify numerically the positions of the strongest L-DACS interferers, considering one or two airplanes per flight level. Then, we sort them according to the generated power into the victim (see equation 8). For the worst case scenario, we select the \( N \) first transmitters, where \( N \) is the number of L-DACS vehicles given in IILA. Computations are performed for both L-DACS antenna patterns that we proposed in III.B.

Finally, we associate the \( N \) adjacent L-DACS transmitting channels with the interferers to ensure maximum interference. The channel assignment is detailed in \([6].\)

**E. Link budget analysis**

In these conditions, each L-DACS interferer generates the following interference on the victim:

\[ I_k = I_0 + 10 \log_{10} \left\{ \frac{1}{S_k^-} \int_{S_k^-} C(f') df' \right\} \] (11)

\( C \) is the correlation function between transmission and reception spectral masks, in the receiver bandwidth:

\[ C(f') = \int_{f'} H_k(f + f').H_k(f)df' \] (12)

As a result, the aggregate received power density in the presence of the \( N \) interferers and at the victim receiver input is computed owing to equation 13, in which \( I_0(k) \) designs the power generated by the \( k^{th} \) strongest L-DACS interferer.

\[ I_d = -10 \log_{10}(B_k) + 10 \log_{10} \left( \sum_{k=1}^{N} \frac{I_0(k)}{10} \right) \] (13)

This power should be compared to the victim interference threshold. If \( I_d \) is lower than \( I_{\text{max}} \), no harmful interference is caused from L-DACS. If this condition is not fulfilled, equipments must be more separated. Two solutions can be adopted: either geographic separation or frequency separation.

**IV. RADIOELECTRIC COMPATIBILITY RESULTS**

In this section, we give the results associated to the worst case when considering the air-air scenario. The computations are performed for both L-DACS candidates and for the two proposed antennas.

Following the approach detailed in III.D, we identify numerically and sort in descendent order the positions of the interferers generating the highest power. The maximum number of identified equipments is \( N_{\text{max}} = 61 \) while using antenna 1 and \( N_{\text{max}} = 13 \) while using antenna 2. The \( N \) first ones correspond to our L-DACS worst case. They are identical for L-DACS and L-DACS2, because both of the two technologies use the same antenna pattern.

We chose a 1 MHz bandwidth perfect receiver. Using (4) the noise floor is \( N_R = -144 \) dBW. We assume also \( \text{SNR}_0 = 10 \) dB and \( P_R = -74 \) dBW. Moreover, no cable insertion losses are taken into account. Owing to (5), the receiver sensitivity equals \( S_R = -134 \) dBW and from (3), the interference threshold is \( I_{\text{max}} = -84 \) dBW/MHz.

In addition, according to III.A, the aeronautical environment can be modeled by the receiver and \( N = 2 \) L-DACS1 airplanes (respectively \( N = 5 \) L-DACS2 airplanes). Their positions are illustrated in table II. The associated total received powers are computed using (13) and the corresponding results are summarized in table III.

From this table, it can be inferred that the generated interference with the isotropic antenna is higher than for the ITU recommended antenna. In fact, the interference level generated by the first identified transmitter using antenna 1 or
antenna 2 are close. However, due to the path loss profile, the power generated by the second identified transmitter is lower for antenna 2 than for antenna 1.

In all cases, the interference density is higher than the receiver threshold. Consequently, either a frequency separation or a geographic separation is required for the radioelectric compatibility.

As a first option, we fix the channel assignment (described in [6]) and we modify the relative position between the victim and the strongest L-DACS transmitter. All the possible values are the localizations of the strongest \((N_{\text{max}} - N - 1)\) identified interferers. For each value \(1 < k < (N_{\text{max}} - N)\), to determine the associated useful L-DACS positions, we suppress the \((k-1)\) identified equipments above and we follow the same algorithm defined in III.D. Consequently, using (13), we compute the interference density and we compare it to the interference threshold. The computations are made for both L-DACS candidates and both antenna patterns and the results are summarized in figure 3. The X-axis represents the altitude \(z_T\) of the strongest interferer. The Y-axis corresponds to the total interference density \(I_d\) in the presence of the \(N\) worst L-DACS transmitters.

![Fig. 3. L-DACS interference density over a perfect receiver with only geographic separation. All the transmitters are in band interferers](image)

Figure 3 emphasizes that the use of the isotropic antenna for L-DACS provides higher interference over the victim. That is why a greater minimal geographic separation is needed to ensure that there is no harmful interference caused by L-DACS into the receiver.

Therefore, the received power due to L-DACS2 interferers is higher than the one generated by L-DACS1 equipments. In addition to the fact that there are more in band L-DACS2 transmitters within the receive bandwidth, this is explained by the systems specifications presented in section II. In fact, from table I we notice that the power transmitted by one L-DACS2 vehicle is higher than for L-DACS1, and that the L-DACS2 transmitter carrier as well as the path loss is lower according to (7). Consequently, as illustrated in figure 3, if a geographic separation is efficient to protect the receiver from L-DACS1 signals, this is not the case for L-DACS2 interferers. More precisely, if the strongest L-DACS1 transmitter flies at least 1.8 km above or 0.9 below the receiver, the interference density becomes lower than the interference threshold. To achieve this objective for L-DACS2, it is necessary to look for a frequency separation.

As a result and to complete our study, we intend to analyze the interference density variations by modifying the channels assignment. For instance, according to (1), \(N\) adjacent transmit channels are included in the receiving bandwidth. The idea is to associate some interferers with channels outside \(B_R\). Thus, three configurations are possible for L-DACS1 transmitters according to the number of in band interferers and six cases can occur when considering L-DACS2 vehicles. The out of band interferers use necessarily the closest channels to the boundaries of the receiving bandwidth.

In these conditions, we compute the interference density and we compare it to the same threshold. Calculations were performed for antenna 1 and antenna 2 but only those related to antenna 2 (typical aeronautical antenna) are shown in the figures 4 and 5, respectively for L-DACS1 and L-DACS2.

From these figures, it should be noticed that as expected, reducing the number of in band interferers decreases the aggregate received power. In addition, for the worst case scenario, the strongest transmitter is the main interferer as explained in [6]. That is why the curves corresponding to 1 in band interferer and \(N\) in band interferers are very close. However, owing to the path loss profile, the higher is the distance between the strongest interferer and the victim, the higher is the contribution of the other in band L-DACS transmitters relatively to the strongest one. Indeed, for the most distant spatial distribution of the interferers, the gap between these two curves is about 2.3 dB for L-DACS1 and 5.5 dB for L-DACS2.

Based on this result, we infer that by reducing the number of in band interferers, it is possible to protect the receiver from L-DACS interferers with a less restrictive geographic separation. For example, with one in band L-DACS1 transmitter, if the strongest interferer flies 1.5 km above or 0.6 below the victim, the interference is lower than the threshold.

![Fig. 4. L-DACS1 interference density over a perfect receiver with geographic and frequency separations.](image)
The resulting localizations of the interferers are identical for L-DACS transmission masks and antenna radiation patterns.

characteristics of the aeronautical environment as well as the spatial distribution, taking into account the specific
detailed a deterministic approach to identify the L-DACS studied its impact on a 1MHz bandwidth perfect victim. We considered L-DACS as an interference source and we board L-DACS and on board ideal receiver. More precisely, in order to evaluate the radioelectric compatibility between on board L-DACS and 50 dB for L-DACS1. Consequently, in case of adjacent frequency usage, no harmful interference is caused by L-DACS into the ideal receiver.

Finally, both of figures 3, 4 and 5 emphasize that to protect the fixed perfect receiver; the required distance/frequency separation with L-DACS2 is more restrictive than with L-DACS1, due to the fact that the interference generated by L-DACS2 is higher than L-DACS1. However, this study is not sufficient to affirm which technology is the best or the worst for radioelectric compatibility. According to the systems specifications [7]-[8], L-DACS1 and L-DACS2 are foreseen to operate in disjoint bandwidths, with different information rates and independent modulation techniques.

V. CONCLUSION

In this paper, we presented the methodology to follow in order to evaluate the radioelectric compatibility between on board L-DACS and on board ideal receiver. More precisely, we considered L-DACS as an interference source and we studied its impact on a 1MHz bandwidth perfect victim. We detailed a deterministic approach to identify the L-DACS spatial distribution, taking into account the specific characteristics of the aeronautical environment as well as the L-DACS transmission masks and antenna radiation patterns. The resulting localizations of the interferers are identical for L-DACS1 and L-DACS2. Based on these results, we determined the total received power and we proposed some solutions to reduce the interference density and solve the frequency sharing problem. In fact, to protect the victim from L-DACS radiations it is possible either to take away the airplanes from the victim or to reduce the number of the in band interferers.

To complete the radioelectric compatibility analysis, it is necessary to study the reverse sense, in which the victim is on board L-DACS equipment. The guidelines presented below should be adopted for this case as well as the other scenarios. In addition, it is interesting to conduct the compatibility studies considering actual aircraft distributions and real victim receivers, such as the Distance Measuring Equipment (DME), which is very commonly used in aeronautics. This will be the objective of the further work. Finally, more detailed analysis taking into account temporal aspects will be conducted.

REFERENCES