

A Survey on Electromagnetic Interferences on Aircraft Avionics Systems and a GSM On Board System Overview

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ABSTRACT

Recent years have been characterized by an increase in the air traffic. More attention over micro-economic and macro-economic indexes would be strategic to gather and enhance the safety of a flight and customer needing, for communicating by wireless handhelds on-board aircrafts. Thus, European Telecommunications Standards Institute (ETSI) proposed a GSM On Board (GSMOBA) system as a possible solution, allowing mobile terminals to communicate through GSM system on aircraft, avoiding electromagnetic interferences with radio components aboard. The main issues are directly related with interferences that could spring-out when mobile terminals attempt to connect to ground BTS, from the airplane. This kind of system is able to resolve the problem in terms of conformance of Effective Isotropic Radiated Power (EIRP) limits, defined outside the aircraft, by using an On board BTS (OBTS) and modeling the relevant key RF parameters on the air. The main purpose of this work is to illustrate the state-of-the-art of literature and previous studies about the problem, giving also a good detail of technical and normative references.

Keywords: Electromagnetic field, Interference, Aircraft Avionics Systems, GSM

1. INTRODUCTION

Telephony Services on board airplanes are available since long time. The increase of technology and mobile computing led wireless devices to become a common requirement for every consumer. It raised the issue of the possible coexistence between the strict ElectroMagnetic Compatibility (EMC) standards, required for an aircraft system, and any possible ElectroMagnetic Interference (EMI). Besides, even if the potential risk on avionic systems of wireless devices use cannot be excluded, the probability of interference with flight critical systems is low [1]. A potential EMI source for the navigation and communication system on board aircraft could be any WiFi, GSM/WCDMA, Bluetooth, UWB Portable Electronic Device (PED) active on board, that could potentially interfere with Communication Navigation Surveillance (CNS) aircraft system in such critical flight phases. Also High Altitude Platforms are becoming important features for large coverage communications and many topics related to them are subject to heavy research activity [2], [3], [4]. This paper will inspect the real effects of PED interferences, moreover the political choice of security rules to be followed in a civil flight, in order to keep passengers safety. Many airplanes manufacturers thought and deployed their own integrated cellular or wireless system offer, usually based on a satellite link [5] from the airplane (as Boeing Connexion, TFTS, Aerosat, Airfone, Aircell, JetConnect, IRIDIUM, etc.) even more of them failed due to the lack of market demand. A GSMOBA system instead, goes over the limitation of the manufacturer or flight company hardware rent necessary for the use of the service, by allowing passengers to use their own mobile device for outgoing/incoming call or GPRS such as a personalized user experience. Some flight companies' offers (Lufthansa FlyNet, SITA OnAir) include these kind of services, which could restrict the use of the call in GSM. Different are SMS and GPRS services which are permitted during the fly [6]. The paper is organized as follows: section II gives a deep overview of the possible electromagnetic effects and the related regulation, section III gives a description of the GSMOBA system, then section IV concludes the paper.

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2. ELECTROMAGNETIC INTERFERENCE TO AIRCRAFT CRITICAL SYSTEMS

As wireless technologies have become increasingly companions to air travelers, many researches and specialized works have been addresses to the recommendations and regulations regarding PED related anomalies. Several disparate agencies like the Federal Communications Commission (FCC), the Federal Aviation Administration (FAA), the Radio Technical Commission for Aeronautics (RTCA), or airplane manufacturer as Boeing, have deployed reports and studies over the years. They substantially agree on the prohibit use of electronic devices on airborne aircraft, claiming these devices could potentially interfere with wireless networks on the ground, while the likelihood of interference to aircraft avionics electromagnetic components is low [7], [8], [9], [10]. In 1992, the U.S. Government requested to RTCA to solve outstanding questions on PEDs to ensure air safety, and to gain an understanding of multiple effects from intentional radiators, such as cell phones and other potential EMI devices. Thus, in 1996, RTCA issued report DO-233, containing four important recommendations, followed by the vast majority of civic aviation agency [10]. As consequence, the use of PEDs on board has been considered by the whole world community and the European Organization for Civil Aviation Equipment (EUROCAE); they formed a working group, WG-58, in order to study any possible coexistence of new technologies related to PED and electromagnetic compatibility on board aircraft. The main issue was to consider both intentional and unintentional radiations from PEDs, and their coupling to electronic systems and antennas, and as result of this work, EUROCAE WG-58 released report ED-118 [11]. As illustrated in fig. 1, a flight mainly consists in five main phases: taxiing, take-off, cruise, descent and landing



Figure 1. Flight phases cycle.

While FCC prohibits the use of PED “at all”, FAA allows the use of them in stable phases of the flight, typically in Cruise, such as tablets or laptop are allowed for the use, and 802.11 support is also available on certain airplanes during this phase. On one hand, FCC forbids the use and operation of cell phones in Cruise phases, on the other hand FAA allows them; this is because of the cellular ground base system susceptibility to a cell phone in the air which could grant a big coverage transmitting to several BTS simultaneously and the same frequency. Due to the signal capability of propagation for long distances as the radio path is clear from the radio horizon, a phone might have to transmit at its maximum power to be received, by increasing the risk of EMI with electronic equipment on the aircraft. In a air- to-ground scenario, the radio horizon can be obtained with formula:

$$R = \sqrt{2h_a} + \sqrt{2h_b} \quad (1)$$

where R is the distance measured along the horizon, h_a the aircraft altitude above average terrain and h_b is the ground station antenna from the average local terrain. Therefore:

$$R = R_1 + R_2 \quad (2)$$

can be larger if h_a is high.

The radio path is clear from the radio horizon and because it is between airplane and ground, is typically under the line-of-sight conditions and follows the 6 dB free space path loss (FSL) rule. Each 6 dB increase in EIRP is relative to a doubling of distance. Conversely, a 6 dB reduction in system losses, translates into a doubling of range, by way of transmission line loss and on receiver or transmitter end. If there is not any obstacle which creates any type of reflection or diffraction, the free space path loss is the loss in signal strength for a line-of-sight path through free space. Hence, FSL is proportional to the square of the frequency of the radio signal, and is expressed by:

$$FSL = \left(\frac{4\pi d}{\lambda} \right)^2 = \left(\frac{4\pi d f}{c} \right)^2 \quad (3)$$

where λ is the wavelength in meters loss exponent, d is the transmission distance in km, f is the frequency in MHz and c is the speed of light. The total free space loss is also defined as the ratio between total transmitted power and received power, as in formula:

$$FSL = 10 \log \frac{P_t}{P_r} \tag{4}$$

When the aircraft flies away from its ground station, it enters in a shadow-diffraction zone beyond the radio horizon. After a transitional region in which loss ranges between 15 and 20 dB, it occurs a Fresnel-zone phenomena in the light-of-sight region; as result of direct and ground reflected waves being added or canceled at time. In air-to-ground communications, there is fading because of Fresnel zone, thus the signal to interference ratio S/I would be equivalent to the land-to-mobile one, from 18 to 20 dB at cell borders of 210 km. Fig. 2 shows a minimum isolation of 20 dB between two macro-cell in which boundary of one co-channel cell is separated from another one by 20 miles (32 km) beyond the radio horizon.

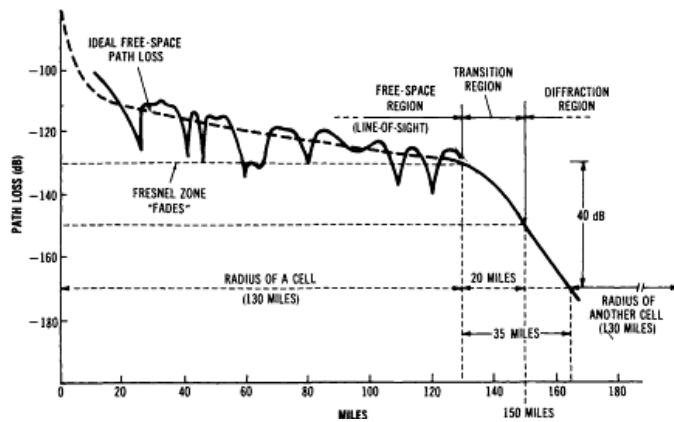


Figure 2. Loss variation in air-to-ground.

Remembering the Co-Channel Interference Ratio (CCIR) definition:

$$\frac{C}{I} = \left(\frac{R}{D} \right)^{-\alpha} \tag{5}$$

then, the co-channel separation for one interferer becomes:

$$D = 2R(h_a, h_b) + 20 \text{ miles} \tag{6}$$

Assuming six co-channel interferers:

$$10 \log_{10} \left(\frac{C}{I} \right) = \log_{10} \left(\frac{C}{6I_i} \right) = 10 \log_{10} \left(\frac{C}{I} \right) - 7.78 \text{ dB} \tag{7}$$

$$10 \log_{10} \left(\frac{C}{I} \right) \cong 28 \text{ dB} \tag{8}$$

Hence, due to path-loss model for air-to-ground scenario and as result of eq. 8, the relevant airspace is divided into six zones based on the aircraft altitude. The transmitted power is varied in six steps, depending on the zone where the aircraft is, and the difference between the first zone and the last one is about that 28 dB [12]. Power differences are based on the free space loss rule and co-channel interference is significantly reduced due to the excellent propagation conditions in the free space [13]. FCC allocates spectra in the 450 and 800 MHz frequency bands for use by equipment designed and tested as safe for air-to-ground services and these systems use widely separated ground stations. While 450 MHz service is limited to general aviation users, mostly in corporate jets, the 800-MHz spectrum can be used by airliners

as well as for general aviation. But the most important point is: how PED, as cell phones, can interfere with avionics electronics and is there a way to prevent this. There are five critical navigation frequency bands to monitor in order to keep the safety of the EMC avoiding any EMI: VHF Omni-Directional Range (VOR) and Instrument Landing System (ILS) Localizer (LOC), range frequency 108 – 118 MHz; ILS Glide Slope (GS), range 329 – 335 MHz; Distance Measuring Equipment (DME) and Traffic Alert and Collision Avoidance System (TCAS), range 960 – 1215 MHz; and Global Positioning System (GPS), 1227.5 MHz and 1575.42 MHz. There are four frequency ranges identified as likely to experience emissions from passenger electronics use: cellular uplink, 824 – 849 MHz; Personal Communications System (PCS) uplink, 1.85 – 1.91 GHz; and Industrial, Scientific, and Medical (ISM), 902 – 928 MHz and 2.4 – 2.485 GHz. Limited monitoring was conducted in the ILS GS, GPS L2 (1227.5 MHz), and DME and TCAS bands. Investigations have been conducted by many researchers and useful experimental results have been reported, as in [14] NASA detected any possible EMI from CDMA and GSM wireless phone likely to interfere with aircraft VOR, LOC, GLS, or GPS navigation radios. Authors in this work accommodate RTCA/DO-233 recommendations as the prohibition of the use of any PED during critical flight phases of takeoff and landing, and it is proven that cellular phone usage are mostly implicated in affecting instrument landing systems [15]. The prohibition is extended to the use of them at all, unless they are verified to operate in safety with aircraft EMC. Using GSM (ETSI GSM 11.22, 880-915 MHz) and CDMA (IS-95, 824-849 MHz), three terms are considered for assessing the potential risk of wireless phone electromagnetic interference to aircraft radio receivers: a) Source emissions P_{PED} (dB); b) Interference path loss IPL (dBm) and c) Interference threshold power at the aircraft radio connector P_{RecvIT} (dBm). Hence, defining P_{RecvThreat} (dBm) as the threat power related to the connector of an aircraft radio receiver, the following formula is obtained:

$$P_{RecvThreat} = P_{PED} - IPL \quad (9)$$

where IPL represents the interference path loss in terms of antenna, cable and propagation loss between aircraft radio connector and wireless devices (attenuation). Low IPL could result in strong interference signals at the receiver, causing an increased likelihood of interference [15]. In order to keep target electromagnetic components safe, the susceptibility threshold must satisfy the following condition:

$$P_{RecvIT} > P_{RecvThreat} \quad (10)$$

keeping the threat power lesser than the interference threshold power. Authors of [15] intended to analyze spurious radiated emissions from CDMA and GSM wireless handsets, upholding DO-233 directive using a semi-anechoic chamber for standard radiated emission measurement. Isotropic approximation is more valid in a semi-anechoic room than the passenger cabin of an airplane, allowing radiated emission data to be more accurately applied to the measured path-loss data between passenger cabin and aircraft radio receiver antenna. Thus, to calculate effective isotropic radiated power of a PED, at a given frequency, the following formula were used:

$$P_{PED} = P_{Meas} + A_{RecvPath} + (AF + 2.23) \quad (11)$$

where P_{Meas} is the received power amplitude, A_{RecvPath} is the cable loss from receiver antenna connector to the receiver, AF is an antenna factor relative to manufacturer, and the value 2.23 is a tuning factor calculated in [16]. Measuring radiated emissions from cell phones is different from measuring a generic PED emission, and it is also more difficult. In measurement tests in [14], a reverberation chamber was used to identify whatever signals from multiple devices that could produce spurious radiated emissions, and all cell phones were set to radiate at maximum available power, at the same time. As result, any combination of GSM emissions (880-915 MHz) and CDMA (824-849 MHz), produces inter-modulation between GSM and other wireless handset types, with GPS and DMA band emissions. Another work investigating the quantification of interference threat with cellular network is represented by [17], in which authors consider a 800 MHz frequency system into an electromagnetic environment (EM) proposing a model and simulation instead of a real test environment, representing the aircraft internal ElectroMagnetic Environment (EME). As results of simulation though an A319 EM model, we still obtain that avionics system could be sensible to EMI made by PEDs, but the likelihood of interference is low. Another related important work is represented by [18] and it was issued by FAA, who conducted an assessment of the potential use of on-board EMI to upset critical and essential aircraft functions. The tests executed IPL measurements, exposed in DO-233, reaching some interesting results: a) Reflections from wing and engine are not significant to passenger cabin-to-aircraft antenna coupling data; b) Effect of coupling through cockpit door was determined to be insignificant for VOR, VHF Com, UHF, Com, DME and the GPS aircraft radios. The effect of ILS coupling through the cockpit door was determined to be secondary to coupling through passenger cabin windows;

c) Applying aluminum tape to all aircraft windows resulted in up to 35 dB increase in *IPL*; d) Direct interference effects were demonstrated to aircraft VOR, VHF Com, UHF Com, GS and GPS when using a low-powered transmitter. Figure 3 illustrates a typical radio receiver interference phenomenon with coupling paths.

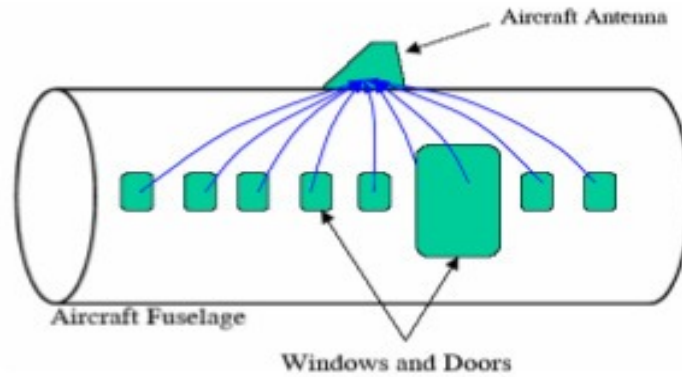


Figure 3. A typical radio receiver interference and coupling paths

3. GSM ONBOARD AIRCRAFT

A possible solution for GSM communication on-board of civil aircrafts is presented by ETSI in [19], as an adaptation of the terrestrial GSM. As seen in previous cited studies, cellular networks themselves do not affect directly critical avionic systems, rather spurious radiated emissions in certain contexts and in some flight phases. Thus, the main feature of this kind of systems is to avoid damaging of ground networks by creating interference on the Radio Access Channel, consequently reducing any possible EMI on the aircraft including standards and guidelines as appropriate. Controlled power at aircraft eliminates the near-end-to-far-end interference, and ground stations have not to control their power level. Instead of business satellite aircraft telephony service offered by flight companies, GSMOBA system allows passengers to use their mobile terminals during flight, except in the critical flight phases, according to DO-233 and ED-118. Functionality is transparent to the mobile user on board, because any operation within the cellular network is like roaming, offered by a licensed operator. GSMOBA is based on normative references [20], [21] and it is standardized in [22]. Technical Specification 102-576 supplies a method to derive power values at the antenna output door of the system, in conformance to any EIRP limits defined outside the aircraft. Deriving the maximum EIRP that an airborne source can have without interfering with ground stations, prevents any noise from the aircraft and the system itself is designed to obtain a controlled electromagnetic emissions from wireless phone devices. GSMOBA cellular network is in the GSM 1800 MHz frequencies band. Because emissions at higher frequencies result in higher path loss, ETSI chase the 1800 MHz band due lower minimum transmission power of a mobile terminal transmitting in this band, instead of the 900 MHz, respectively of 0 dBm and 5 dBm. The large support of GSM 1800 by mobile terminals also ensures full compatibility with large scale device models. As seen before, energy radiations at passengers cabin windows is a fundamental parameter to consider and also GSMOBA considers this. In TS 102 776 are specified measurement methodologies that allows defining the key RF parameters of the aircraft. Those parameters are: a) Aircraft attenuation observer at the windows; b) Aircraft attenuation in combination of the antenna system observed at the antenna system feeding point; c) Effective cabin coupling loss within the aircraft cabin. The system, as shown in fig. 4, is divided in three main segments: Airborne, Satellite, and Ground. An On board pico BTS OBTS is included in the airborne segment, and mobile terminals would connect to that Base Station using GSM radio interface. A satellite link connects the airborne segment to the ground one, and this architecture is projected to avoid air-to-ground and ground-to-air attempts to connection by mobile terminals on board and either by the pico BTS. According from test results in [20] made by the “Conférence Européenne des administrations des Postes et des Télécommunication” (CEPT), a minimum altitude of 3000 meters has to be considered in order to derive the maximum EIRP that source from aircraft can have without interfering with ground subjects. A trade-off between the attenuation and the minimum height of operation occurs and it is in the interest of system operators to comply requirements at the lowest minimum height.

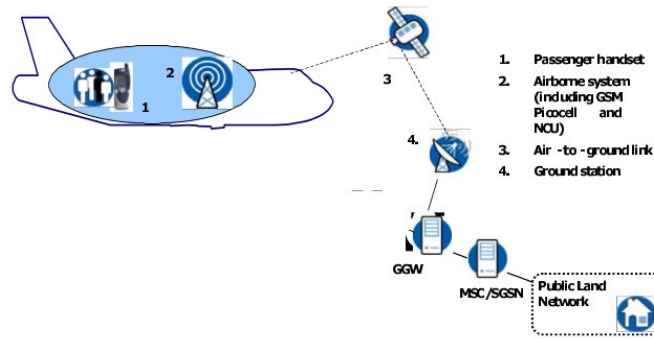


Figure 4. GSMOBA communication overview.

The architecture of a GSMOBA system is represented in fig. 5. The satellite segment is considered as part of the other two, while doing only transportation and linking between them. The airborne segment contains two domains, a Local Access domain and a Cabin Network domain. The first domain contains the OBTS and provide the access to the GSM at 1800 MHz. Another component is the Network Control Unit NCU, responsible with the OBTS of the mobile terminals attempts prevention to connect to ground networks. The NCU also ensures safety of critical avionic systems controlling emissions in bands of CNS. The second domain (Cabin Network) contains an Aircraft GSM Server (AGS) that integrates components of the first domain and a modem for satellite connection.

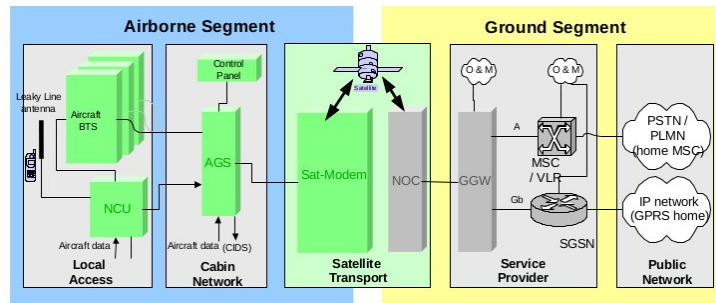


Figure 5. GSMOBA architecture.

Ground segment has also two domains, and they are respectively a Service Provider domain and the Public Network domain. Service Provider domains handles communication controller functions that join AGS features in the aircraft. Thus, a Ground Gateway (GGW) and GSM components as Visited Mobile Switching Center VMSC and Serving GPRS Support Node SGSN are provided. Service Provider also performs the routing towards the aircraft and interconnects the aircraft traffic with terrestrial backbone networks of the Public Network Domain.

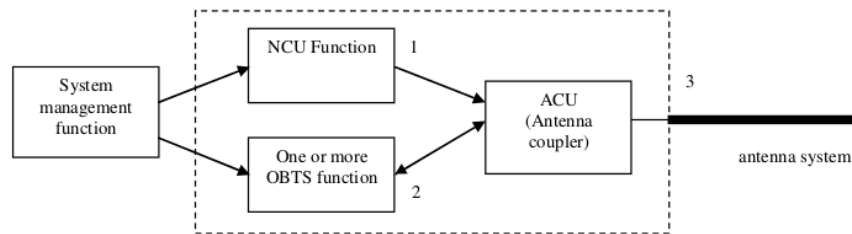


Figure 6. Functional organization of a GSMOBA system

The most relevant segment of this system is the airborne, as capable of GSM communications and RF isolation characteristics. OBTS provides GSM connectivity by a pico-cell and supports either GSM and GPRS services in the DCS1800 band (1710 to 1785 MHz and 1805 to 1880 MHz). Because the system is intended to work with all GSM, UMTS (WCDMA (UTRA FDD)), FLASH-OFDM and CDMA2000 technologies, NCU prevents connection attempts to ground raising the RF noise floor inside the cabin to a level that effectively covers the signals from the ground base stations. The signal generated by the NCU is a band-limited white noise and affects the following frequencies in

European configuration: a) GSM and WCDMA/UMTS-900 downlink (921 – 960 MHz); b) GSM and WCDMA/UMTS-1800 downlink (1805-1880 MHz); c) UMTS UTRA-FDD 2GHz downlink (2110-2170 MHz); d) CDMA-450/FLASH-OFDM downlink (460-470 MHz). GSMOBA (fig. 6 shows a generic structure) has its own operating requirements in terms of power: a) NCU must transmit at a level sufficient to effectively cover with noise the signals from ground base stations; b) The OBTS has to transmit at higher power than the NCU to avoid being interfered by it; a 12 dB value over NCU is assumed; c) The transmit power of the terminals will be nominally 0 dBm, as result for the 1800MHz choice. As explained before, NCU will not transmit below 3000 meters. Emissions power level depends on the frequency band and on the altitude, see Table I. Another key system components is the Cabin Antenna. The antenna is shared between the NCU and the OBTS and the typical implementation is a leaky feeder running along the cabin. Due to the altitude and line of sight propagation, the interference caused by transmissions from equipment on board, may reach couples ground stations very far away, thus TS 102 576 ensures that mobile terminals will not connect to ground based mobile networks. The factor that relates power radiated from the transmitters inside the aircraft to the EIRP values outside the aircraft is the effective attenuation. Measurement is not simply and depends on components on board as antennae, cabin characteristics or hull attenuation. Test results concluded also that the effective attenuation of signals by an aircraft, also depends on the aircraft type. Because system compliance or RF components cannot be ensured with any aircraft type, a methodology is described in [20] to obtain conformance, thought three criteria: a) Minimum power at NCU antenna connector must be sufficient to inhibit connection to all relevant terrestrial networks at the height above ground the system is to be operate; b) The far field E.I.R.P. outside the aircraft from the OBTS/NCU must be low enough to ensure non-interference with terrestrial mobile terminals; c) E.I.R.P. outside the aircraft from mobile terminals must be low enough to ensure non-interference with terrestrial base stations. As relevant radio engineering aspects, many important issues shown in [19] has been studied and standardized. Aircraft RF shielding has been discussed in [20] as shielding of the aircraft fuselage to further attenuate the signal entering and leaving the fuselage. Then, multiple aircraft interference sources have been covered by CEPT in [19], considering a minimum number of GSM1800 channels available on board of about 10 GSM channels and 50.

Table I. Maximum EIRP produced by NCU/OBTS outside aircraft in dBm/channel

Altitude (m)	460-470 MHz Channel Bandwidth = 1.25 Mhz	921-960 MHz Channel Bandwidth = 200kHz	1805-1880 MHz Channel Bandwidth = 200kHz	2110-2170 MHz Channel Bandwidth = 3.84kHz
3000	-17.0	-19.0	-13.0	1.0
4000	-14.5	-16.5	-10.5	3.5
5000	-12.6	-14.5	-8.5	5.4
6000	-11.0	-12.9	-8.9	7.0
7000	-9.6	-11.6	-5.6	8.3
8000	-8.5	-10.5	-4.4	9.5

4. CONCLUSIONS

Electromagnetic interferences to aircraft avionics systems is the main argument for banning passengers portable electronic devices on the airplanes. Many studies demonstrated that, even if the likelihood is low, PEDs cannot ruled out as a potential risk to aircraft avionics. While RF shielding of the aircraft can be useful, airplanes are not a Faraday cables; cell phones could attempts connections to ground and vice versa; due free space loss waves propagation, they could get long distances interfering with ground base stations, as signal bouncing off multiple BTS simultaneously. A GSM On Board Aircraft System using GSM 1800 MHz frequencies was proposed by ETSI in 2007 and recently standardized. The system provide an on board cellular network segment with a pico-BTS and a Network Control Unit raising the RF noise floor inside the cabin, in order to avoid any terrestrial or airborne interferences and prevent EMI to avionics navigation systems, that in some flight phases and in some conditions could affect flight safety. The GSOMBA provide GSM and GPRS support for voice, SMS and internet access thanks to the ground segment of the system, connected through a satellite link. GSM operation are transparent to the user that acts as in a roaming context, supported by some licensed mobile carrier. The evolution of technologies and data communication standards led PEDs to become

extremely diffused. A common effort by manufacturer, researchers, government agencies and non-profit associations, could join the development in a better standardized devices and protocols evolution, allowing new PEDs, adjusting their frequency use and power levels to fit local and international RF spectrum restrictions, allowing the most possible and useful coexistence.

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