Airborne Operation of Portable Electronic Devices

Lin Li[1,3], Jingsong Xie[4], Omar M. Ramahi[1,2,3], Michael Pecht[1,3], and Bruce Donham[5]

[1]Mechanical Engineering Department, [2]Electrical and Computer Engineering Department, and
[3]CALCE Electronic Products and Systems Center
University of Maryland, College Park, MD 20742, USA
Tel: +1 (301) 405-5261; Fax: +1 (301) 314-9477; E-mail: oramahi@calce.umd.edu; www.enme.umd.edu/~oramahi

[4]Microsoft Corporation
One Microsoft Way, Redmond, WA 98052 USA

Abstract

Rapidly improving electronic technology has led to a worldwide proliferation of portable electronic devices (PEDs). These have received a portion of the blame (or suspicion) for unexplained aircraft electronic-system anomalies. A significant concern about PED interference with airplane electronic systems, as well as ground communication networks, has brought about many debates; many people question the rationale and the existence of a solid scientific basis for current regulations and policies. The purpose of this paper is to provide a broad view of the issues associated with airborne operation of PEDs.

Keywords: Aircraft communications; aircraft control; aircraft electronics; antennas; portable electronic devices; electromagnetic interference; electromagnetic compatibility; land mobile radio cellular systems; aircraft navigation; flight safety; public safety; Federal Aviation Administration; Federal Communications Commission

1. Introduction

Rapid advances in new technologies have led to a proliferation of both single- and multiple-purpose portable electronic devices (PEDs). What was once clearly identified by casual observers as specifically a laptop computer, cell phone, radio, CD player, or an electronic game may actually be a combination device. "The idea of wearable electronics is being taken seriously by a growing number of clothing and electronics makers, which are envisioning fabrics that conduct electricity and connect audio equipment and pocket computers" [from *The Wall Street Journal Interactive Edition*, "Philips and Levi Strauss Team Up to Create Ready to Wear Electronics," August 22, 2000]. Most airline policies make a distinction between intentional and non-intentional transmitting devices. How will airline personnel know when their policy is being violated or, even worse, when the airplane's electromagnetic compatibility is being jeopardized?

As with any passenger portable electronic device, the controls and restrictions of the electromagnetic emissions are not as rigid as equipment installed on certified aircraft. Therefore, the airline industry incorporated what it believed was a prudent and practical policy [1]. As a result, Boeing (the largest US commercial aircraft manufacturer) and the Requirements and Technical Concepts for Aviation (RTCA) have not seen an increase in reports of suspected PED anomalies. However, with faster processor speeds, more circuitry packed into smaller space, and wireless technology, electromagnetic-energy profile of today's PEDs is changing. Will reports of interference to aircraft systems (e.g., traffic alert and collision avoidance system (TCAS), tactical navigation (TACAN), distance measuring equipment (DME), GPS, weather radar with predictive wind-shear...) that were previously unaffected now be generated?

2. PEDs

A portable electronic device (PED) is defined as any kind of electrical or electronic device that can be carried onboard an airplane by a passenger. PEDs can be classified as either intentional or non-intentional transmitters. Intentional transmitters are devices that intentionally transmit signals outside the devices, and that must do so to accomplish their functions. Non-intentional transmitters are devices that accomplish their functions without the need to transmit electromagnetic signals outside the devices [2].

Typical examples of intentionally transmitting PEDs are cellular phones, wireless local-area networks (such as "Bluetooth" and IEEE 802.11), personal area networks, Citizens-Band (CB) two-way radios, remote-control toys, and two-way pagers. Non-intentional transmitters include portable computers, such as laptop computers, palmtop computers, and electronic organizers. Some other examples are Global Positioning System receivers (GPS), tape recorders, CD players, handheld TVs, electric shavers, game players, cameras, MP3 players, DVD players, and camcorders. Medical devices, such as hearing aids, heart pacemakers, blood-pressure monitors, electronic-device-embedded man-made human organs, and other human-body-monitoring sensors and devices, are typically non-intentionally transmitting PEDs. However, medical devices with wireless technology – such as RF-activated infusion pumps for the treatment of people with diabetes mellitus, which can only be programmed by means of a remote RF transmitter – would be classified as intentional transmitters, when the remote is being used.

3. The PED Problem

Electromagnetic emissions from passenger-carried PEDs on commercial airplanes have been reported as being suspected or actually confirmed as responsible for anomalous events during flight. The operation of PEDs produces electromagnetic emissions that can interfere with airplane systems.

3.1 Flight Reports

The National Aeronautics and Space Administration (NASA) maintains a database, the Aviation Safety Reporting System (ASRS) [3], wherein avionics problems that may have resulted from the influence of passenger electronic devices are recorded. The director of the reporting system mentions that the reports contained in this database are submitted voluntarily, and the information provided by the reporter is not investigated further. Such information may or may not be correct, in any or all respects. At best, it represents the perception of a specific individual, who may or may not understand all of the facts involved in a given issue or event. Identification is removed from the reports, and the process does not allow the ability to identify the individual who submitted the report. This voluntary submittal is the process used with several databases.

The Requirements and Technical Concepts for Aviation (RTCA), which began its latest study in 1992, sifted through a decade's worth of such reports from four different databases, covering both commercial and private flights. Boeing continues to monitor its fleet and receive reports submitted by operators. Another major source of such safety reports is the International Society of Air Safety Investigators (ISASI) [4]. Table 1 provides a sampling of suspected cases of PED interference, along with the systems affected and the suspect device.

3.2 Frequency Overlap

Portable electronic devices typically operate at frequencies from DC to thousands of megahertz (MHz). The active electrical/electronic components of these devices emit frequencies, usually with harmonics, which can overlap with the frequencies used on the airplane for communication and navigation. The antenna frequency bands used by avionics systems also span the electromagnetic spectrum from a few kilohertz to several thousand megahertz. At the very low end is the old Omega navigation system, which is used to determine aircraft position through ground-based transmitters, and operates in the frequency range of 10-14 kHz. At the very high end is the weather radar system, which provides the weather patterns, and usually includes a predictive wind-shear feature. The system operates at 5440 and 9350 MHz. Table 2 shows the various aircraft antenna systems, their frequency range of operation, and their function.

4. Regulations and Recommendations on Airborne Operation of PEDs

In the US, regulations and recommendations on airborne use of PEDs are established by the RTCA, the Federal Aviation Administration (FAA), and the Federal Communications Commission (FCC), and are classified as either for intentional transmitting PEDs or non-intentional transmitting PEDs.

4.1 FAA

In the United States, the governmental agency responsible for regulating aviation is the Federal Aviation Administration (FAA). The FAA's mission is to secure the safety, security, and efficiency of aviation systems during operations. This is accomplished, in part, by the issuance of Federal Aviation Regulations (FARs). The FAA regulation on the airborne operation of PEDs is described in FAR Section 91.21 [8].

FAR Section 91.21 (formerly, 91.19) was initially established in May, 1961, to prohibit the operation of portable frequency-

Table 1. Examples of suspected PED-caused EMI events [4, 5, 6].

System	Suspected Device	Interference
Autopilot	Walkman, computer	Aircraft abruptly banked right
CDI	Laptop computer and portable radio	EFIS screens blanked suddenly, then indicated missed approach fail along with loss of all auto navigation functions
Compasses	Phone, laptop computer	Compasses lost synchronization and moved off course
HSI	Phone	Discrepancy between Captain's HSI and First Officer's HSI
ILS	Stereo	ILS signal was disrupted
Omega	Tape player, phone, Nintendo, computer	Omega vector was off course
EFIS HSI	Cellular phone	Discrepancy in Captain's and First Officer's EFIS-type HSIs
EFIS	Cellular phone	Captain versus First Officer's headings indicated approximately 10° difference
VOR	Walkman, computer, TV	Erroneous VOR signal caused aircraft to vector off course

CDI: Control/display indicator, or course deviation indicator (Honeywell); HSI: Horizontal situation indicator;
ILS: Instrument landing system; EFIS: Electronic flight system; VOR: Very-high-frequency omni-directional range

Table 2. Systems having aircraft antennas [7].

Frequency Range	System	Function
10-14 kHz	Omega	Long-range navigation
190-1750 kHz	Automatic Direction Finder (ADF)	Bearing information
2-30 MHz	High Frequency (HF) Radio	Communication over 200 nautical miles (nm)
75 MHz	Marker Beacon	Indication of range to touch-down along an instrument landing path
108-112 MHz	Localizer (LOC)	Runway center line guidance – precision approach
108-118 MHz	VHF Omnidirectional Range (VOR)	Bearing and deviation signals relative to ground stations
118-137 MHz	Very High Frequency (VHF) Radio	Communication within 200 nm
329-335 MHz	Glide Slope	Descent profile guidance – precision approach
962-1213 MHz	Distance Measuring Equipment (DME)	Provides slant distance (line-of-sight) to a ground station
1030, 1090 MHz	Air Traffic Control (ATC)	Provides information to ground facilities to track airplane movement through controlled airspace
1030, 1090 MHz	Traffic Alert and Collision Avoidance (TCAS)	Alerts flight crew to potential conflicts with other airplanes
1530-1660 MHz	Satellite Communication (SATCOM)	Satellite communication
1575.42 MHz	Global Position Satellite (GPS)	Position through satellite navigation
4235-4365 MHz	Radio Altimeter	Provides terrain-clearance altitude, used primarily at low altitudes, usually during approach, landing, and takeoff
5031-5091 MHz	Microwave Landing System (MLS)	Course and descent guidance
5440, 9350 MHz	Weather Radar	Weather pattern

modulated radio receivers aboard US-carrier aircraft and US-registered aircraft, when a very-high-frequency omni-directional radio was being used for navigation purposes. Later, laptop computers, electronic games, and CD players became items of concern. In the last ten years, cell-phone usage onboard aircraft has become an item of much interest. In 1993, the FAA issued an Advisory Circular, AC 91.21-1, "Use of Portable Electronic Devices Aboard Aircraft," and it released a revision in 2000. This advisory circular provides guidance to the airlines in establishing compliance to FAR 91.21, as well as recommended procedures for airlines and test criteria for manufacturers. The FAA does not prohibit use of cell phones in airplanes while on the ground, if the operator has determined that they will not cause interference with the navigation or communication system of the airplane on which they are to be used [9].

4.2 FCC

The US Federal Communications Commission (FCC) has charge of all activities and establishes policies to govern interstate and international communications by radio, television, wire, satellite, and cable. It's concern is the cooperation and coordination of radio and wired communication systems for obtaining maximum effectiveness from the use of the systems in connection with the safety of life and property. Therefore, the Federal Communication Regulations (FCRs) apply to the operation of PEDs, if the operation imparts or potentially imparts any negative effect on the normal operation or the operational efficiency of the nation's communication network. The associated regulation is the US Code of Federal Regulations, Title 47, Part 22, Subpart H, "Cellular Radiotelephone Service," Section 22.925, "Prohibition on Airborne Operation of Cellular Telephones." This regulation states that cell phones, installed in or carried aboard airplanes, must not be operated while such airplanes are airborne (i.e., not touching the ground). When any airplane leaves the ground, all cell phones must be turned off, and the use of cell phones while airborne is prohibited by FCC rules [10]. The use of cell phones on the ground and in the airplane is also subject to FAA regulations.

4.3 RTCA

Requirements and Technical Concepts for Aviation (RTCA), Inc., is a private, not-for-profit corporation that develops consensus-based recommendations regarding communications, navigation, surveillance, and air-traffic-management-system issues. RTCA functions as a federal advisory committee. The Federal Aviation Administration (FAA) uses RTCA recommendations as the basis for policy, program, and regulatory decisions. From the work of a special committee, RTCA released its first report regarding PEDs, DO-119, in 1963 [11]. The report resulted in the revision of the FAA Federal Aviation Regulations (FAR) by establishing a new rule (FAR 91.19, now 91.21). This states that the responsibility for ensuring that PEDs will not cause interference with airplane navigation or communication systems remains with the operator of the airplane. In the 1980s, a second special committee was formed. Their report, RTCA DO-199, released in 1988, made the following recommendations [12]:

- Acceptable limits of radiation and associated test methods for PEDs should be established.
- The FCC should specify a new classification for PEDs that may be operated onboard airplanes.
- The FAA should initiate a regulatory project to revise FAR 91.19, providing guidance for acceptable methods of compliance, and to develop methods to enhance public awareness.
- Standardized reporting of suspected interference by PEDs should be implemented.

In 1992, the US government requested that the RTCA resolve outstanding questions on PEDs to ensure air safety. The government specified that unnecessary restrictions should not be placed on untested PEDs, and it sought to gain an understanding of multiple effects and emissions from intentional radiators, such as remote-control devices and cell phones. For various reasons, intentional radiators were not evaluated. In 1996, the committee issued its report, RTCA DO-233, which made the following recommendations [13]:

- The FAA should modify FAR 91.21 so that the use of any PED is prohibited on airplanes during any critical phase of flight; and so that the use of any PED having the capability to intentionally transmit electromagnetic energy is prohibited in an airplane at all times, unless testing has been conducted to ascertain its safe use.

- PED testing efforts should be continued, and should include existing and new-technology devices, such as satellite communications, embedded communications devices, and two-way pagers.

- A public-awareness campaign should be initiated on the potential hazards from PEDs.

- Research should be pursued into PED detection systems.

4.4 Regulations on Intentional Transmitters

According to FCR Section 22.925, "Cellular telephones installed in or carried aboard airplanes, balloons or any other type of aircraft must not be operated while such aircraft are airborne (not touching the ground). When any aircraft leaves the ground, all cellular telephones on board that aircraft must be turned off" [10]. FCR Section 22.925 also requires that the following notice be posted on or near each cellular telephone installed in any aircraft: "The use of cellular telephones while this aircraft is airborne is prohibited by FCC rules, and the violation of this rule could result in suspension of service and/or a fine. The use of cellular telephones while this aircraft is on the ground is subject to FAA regulations."

There are no corresponding regulations in the FARs to specifically outlaw the airborne operation of cellular phones. However, the FARs do ban the use of cellular phones in US-registered civil aircraft in the following two senses: the FAA supports the FCC regulations on the airborne operation of cellular phones, and the FARs prohibit the operation of any PEDs classified as intentional transmitters abroad aircraft. FAR Section 91.21 requires that no person operate, nor any operator or pilot in command of an aircraft allow the operation of, any intentional transmitting PEDs on any US-registered civil aircraft [8]. FAA Advisory Circular AC 91.21-1 states that the operation of PEDs classified as intentional radiators or transmitters – including, but not limited to CB radios, cellular telephones, and remote-control devices – is prohibited, unless otherwise authorized [9].

Boeing's latest service letter on PEDs states, "Boeing has no technical objection to the use of cellular phones while the airplane is parked (including during refueling) and the airline operator or pilot in command of the aircraft has given approval for such use. Operators may also choose to allow the use of wireless Internet devices when an airplane is parked and pilot in command approves" [21].

A cellular phone is called "cellular" because the system uses many base stations to divide a service area into multiple "cells." Radio cells, with a base station at the center of each cell, are distributed in clusters, with an allowed overlap of coverage. Cellular calls are transferred from base station to base station as a user travels from cell to cell. To avoid interference, each cell is assigned a different set of frequencies to all its adjacent cells (in some systems; in other systems, notably CDMA, orthogonal coding is used to permit the use of the same frequencies in all cells). Because cellular phones and base stations use low-power transmitters (or because of the coding used in CDMA systems), the same frequencies are reused in non-adjacent cells to save spectrum resources.

In prohibiting the airborne use of cellular phones, in 1991, the FCC's primary concern was the potential air-to-ground interference to cellular networks. Normal operation of a cellular phone on the ground only allows its access to the one or two cells that provide service to the phone at a time. An airborne cellular phone could make contact with many cells at once, because of the height and speed of the aircraft. If allowed, this could result in serious interference to transmissions at other cell locations, because the systems re-use the same frequencies. The cellular signal from the air can also be strong compared to most ground-based cellular signals, because it is unimpeded by buildings or other ground clutter. That often means it can over-power the transmission of a handset on the same frequency already in use on the ground in some systems, causing interruptions or hang-ups [8].

According to the latest FAA Advisory Circular, "Currently, FAA does not prohibit use of cellular phones in aircraft while on the ground, if the operator has determined that they will not cause interference with the navigation or communication system of the aircraft on which they are used. An example is the cellular phone operation at the gate or during an extended wait on the ground, when specifically authorized by the captain. A cellular telephone will not be authorized for use while the aircraft is being taxied for departure after leaving the gate. The unit will be turned off and properly stowed, otherwise it is possible that a signal from a ground cell could activate it. Whatever procedures an operator elects to adopt should be clearly spelled out in oral departure briefings and by written material provided to each passenger to avoid passenger confusion [9]." This regulation leaves room for airlines to have their own policy, and for operators to authorize the use of intentionally transmitting PEDs on a case-by-case basis when the airplane is on the ground. Delta Air Lines, for example, allows passengers to use cellular phones onboard any Delta aircraft while the plane is parked at the gate with the boarding door open.

The FAA advisory circular further states, "Telephones which have been permanently installed in the aircraft, are licensed as air-ground radiotelephone service frequencies. In addition, they are installed and tested in accordance with the appropriate certification and airworthiness. These devices are not considered PEDs provided they have been installed and tested by an FAA-approved repair station or an air carrier's approved maintenance organization and are licensed by the FCC as air-ground units." These phone systems use a single airplane antenna to which the onboard phones are wired. The size of the cells used by an air-phone system is much larger than those of ordinary cellular-phone systems, and thus an air phone will only access one or two air-phone cells at a time.

4.5 Regulations on Non-Intentional Transmitters

Boeing has performed many laboratory and airplane tests on a wide variety of laptop computers. Laboratory-test results have found that laptop emissions generally exceed the aircraft-equipment emission limits, while airplane test results have shown no interference to the communication/navigation radios after eighteen tests. Boeing has "no technical objection" to operators permitting the use of laptops or other non-intentionally transmitting PEDs during non-critical phases of flight (above 10,000 feet) [21]. It has been generally accepted in the aviation industry that there is still some small probability of interference, but at cruising altitudes, the flight-deck work load is low enough and the response time of the aircraft is long enough for the pilot to accept the remaining risk of interference (ultimately, it is the pilot's responsibility to permit or deny the use of the device). At lower altitudes, the pilot's workload is much higher, and there is higher risk to the safety of the airplane if he/she were to miss a critical communication. Boeing recommends that use of non-intentional transmitters should be prohibited during takeoff and landing (critical stages of flight). Additionally, the operation of non-intentional transmitters should be allowed for use during non-critical stages of flight, unless the operator of the airplane has determined otherwise.

FAA regulations require that no person may operate, nor may any operator or pilot in command of an aircraft allow the operation of, any portable electronic device on any US-registered civil aircraft. Exceptions to the "portable electronic device" mentioned above are portable voice recorders, hearing aids, heart pacemakers, electric shavers; or any other portable electronic device that the pilot in command or operator of the aircraft has determined will not cause interference with the navigation or communication system of the aircraft on which it is to be used [8]. It is under this latter exception that the operation of laptop computers during non-critical stages of flight, discussed in the previous paragraph, is permitted. FAA Advisory Circular AC 91.21-1, RTCA Document DO-233, and the Boeing Service Letter all recommend prohibiting the operation of any portable electronic devices during the takeoff and landing phases of flight.

5. Testing and Analysis of PEDs and Airplane Systems

Generally, all electrical and electronic airplane systems are qualified to meet stringent requirements for electromagnetic susceptibility, and sufficient margins exist between the qualification susceptibility test levels and the expected airplane-environment noise levels. However, susceptibility can still occur in the airplane if an uncontrolled source of electromagnetic energy radiates emission levels above the susceptibility level to which the airplane systems were tested. Table 3 shows that the emissions of FCC-certified PEDs exceed the lower limit of avionics navigation-frequency operating-band sensitivity. Airplane systems with a receiving-antenna component have an exception from the susceptibility requirements. The RF radiated susceptibility test is performed on the system over a full frequency spectrum, but not in the designed operating frequency band of the antenna, because the system is designed to respond to signals in this band. PEDs can radiate non-intentional noise within the airplane antenna's operating frequency band, and can cause EMI. Because the basic function of an antenna-based system is to respond to low-level EM signals in a certain frequency band, the probability of interference to these systems is more likely than for the systems not connected to an antenna [2].

The emissions from PEDs can pass through aircraft windows, door and hatch seams, and can be picked up by the antennas for navigation and communication at various points outside the skin of aircraft (Figure 1). Although the wires connecting the antenna and the instrument are generally shielded, there is a chance that the shielding could be damaged during servicing, or could degrade over time [16]. The effectiveness of shielding also depends upon good grounding, which is difficult to maintain over time, because the surface of aluminum oxidizes rapidly in air, thereby increasing the resistance of the electrical connection to ground [17].

The RTCA DO-160, an internationally agreed upon aviation standard, is implemented for qualifying aircraft equipment with respect to their operating environment, including the electromagnetic environment. Susceptibility tests verify whether or not airplane equipment will respond as designed, or in an adverse manner. The radiated susceptibility tests are based upon the electromagnetic energy from other aircraft equipment, and from high-intensity radiated fields (HIRF), existing in the environment in which the airplane may fly. As indicated in Table 4, the RF radiated susceptibility levels have increased over time. Prior to DO-160C, high-intensity radiated fields were not considered an issue for commercial airplanes. All new airplane models, and older critical/essential equipment undergoing significant changes, are tested

Table 3. Navigation-frequency operating bands/sensitivities of avionics, and PED emission limitations [15].

Equipment	Frequency	Minimum Level in Service	Part 15 Limit for PED at 3 m
VOR	108-118 MHz	90 μV/m	150 μV/m
GLS	328-335 MHz	400 μV/m	200 μV/m
DME	978-1213 MHz	1375 μV/m	500 μV/m
GPS	1500 MHz	48 μV/m	500 μV/m
MLS	5031-5091 MHz	237 μV/m	500 μV/m

VOR: Very-high-frequency omni-directional range
GLS: Glide slope system
DME: Distance measuring equipment
GPS: Global Positioning System
MLS: Microwave landing system

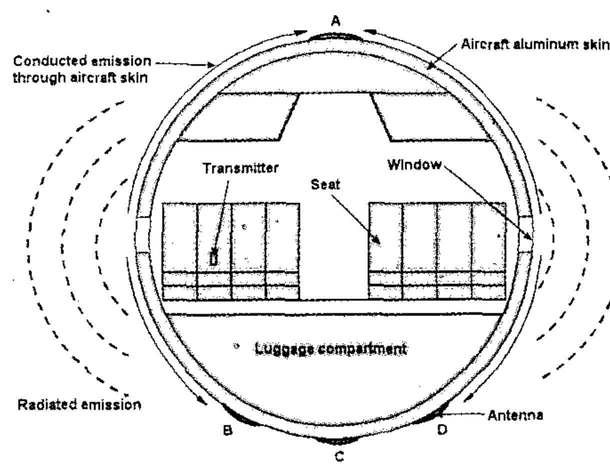

Figure 1. EMI mechanisms (A, B, C, D are the possible antenna locations)

Table 4. RF radiated susceptibility levels of DO-160.

Standard Version	Date of Issue	Test Class	Interference Environment	Maximum Interference Test Level	Highest Test Frequency
DO-160	1975	Z	Highest test level of protection	≤ 0.2 V/m	1215 MHz
DO-160A	1980	Z	Highest test level of protection	Mostly ≤ 0.2 V/m except VHF range: 1.0 V/m	1215 MHz
DO-160B	July 1984	Z	Where interference-free operation is required	1.0 V/m	1215 MHz
DO-160C	Dec 1989	Y	Severe exposed	200 V/m	18 GHz
		W	Severe exposed	100 V/m	18 GHz
		V	Moderate open	50 V/m	1215 MHz
		R	Associated with the "normal environment"	20 and 150 V/m	8 GHz
		U	Partially protected	20 V/m	1215 MHz
		T	Well protected	5 V/m	1215 MHz
DO-160D*	July 1997	P	Severe exposed	600 V/m	18 GHz
		Y	Severe exposed	200 V/m	18 GHz
		W	Severe exposed	100 V/m	18 GHz
		V	Moderate open	50 V/m	8 GHz
		R	Associated with the "normal environment"	20 and 150 V/m	8 GHz
		U	Partially protected	20 V/m	8 GHz
		T	Well protected	5 V/m	8 GHz
		S	Minimum test level	1 V/m	2 GHz

*The latest change to DO-160D is Change 1, December 14, 2000. The RF susceptibility test categories have been significantly revised. This change has produced a total of 18 categories. Only samples are mentioned above.

to the latest RF radiated susceptibility standards. These susceptibility test levels are significantly higher than the FCC Part B radiated-emission levels for PEDs. With the incorporation of the high-intensity radiated fields threat into the test, the margins are very large. However, this test is not performed in the antenna frequency bands of the particular aircraft-antenna receiving system being tested. (Note: There is one evaluation where the in-band frequencies are used in the laboratory test. This is to validate the shielding design of the cable and box. For this case, the aircraft's receiving antenna must be "dummy-loaded" while the in-band frequencies are swept.) "RF receiving equipment may show sensitivity to in-band receive frequencies during susceptibility testing. This sensitivity is normal for devices that are required to be sensitive....This sensitivity is therefore normal and such frequencies may need to be excluded or levels at these frequencies reduced during testing [18]." As shown in Table 3, the aircraft-antenna receiver sensitivity levels are very small. This is the main concern with regard to PED interference.

Unlike airplane systems, which are tested to rigorous EM standards to establish and provide control of the EM characteristics and compatibility of the systems, PEDs are not subject to the same equipment qualification and certification processes. Although all non-licensed intentional and non-intentional radiators sold and marketed in the United States must conform to Federal Communication Regulations (FCRs) Part 15 on radio-frequency devices, this does not guarantee the radiation limits of PEDs with regard to the following four aspects [19]:

- The FCRs require sampling tests, which do not guarantee all individual products to operate under the required radiation limit;
- FCR Part 15 does not preclude changes made in production or by the consumer. In particular, consumer modification, such as adding computer hardware, is not monitored or documented;
- Degradation monitoring of the EM performance of PEDs is not required by the FCRs;
- FCR Part 15 affects only PEDs sold in the United States. However, foreign travelers may legally bring non-FCR-certified devices into the United States.

Many tests and investigations have been conducted to verify the correlation between PED and airplane anomalies. Boeing is a major source of these studies. For better understanding of this issue, Boeing performed safety-report analysis and experimental investigations. In the safety-report analysis, Boeing grouped airplane anomalies into three categories of PED events [2]:

- Events where PED interference was suspected: an airplane anomaly occurred when a PED was being operated.
- Events with apparent correlation between PED operation and the airplane anomaly: the problem disappeared when the PED was turned off, either immediately or shortly thereafter
- Events showing a strong correlation between PED operation and the airplane anomaly: the problem disappeared when the PED was turned off, returned when PED use resumed, and disappeared when the PED was turned off again.

Of the reports, only a few showed a strong correlation between the airplane reaction and the suspected PED.

In the experimental investigations, Boeing conducted investigation of specific instances of suspected PED interference, ground and airplane tests of in-seat power, and cellular-phone tests and analysis. Table 5 provides a summary of those investigations and their results.

Table 5. A summary of experimental investigations conducted by Boeing in recent years in an effort of better understand the PED issue [2].

Investigation of specific instances of suspected PED interference:

Case 1: 1995, 737 airplane. A passenger's laptop computer was reported to cause autopilot disconnects during cruise. Boeing purchased the computer from the passenger, and performed a laboratory emission scan. Although the emissions exceeded the Boeing emission standard limits for airplane equipment at various frequency ranges, Boeing was unable to confirm the reported interference between the PED and the airplane system.

Case 2: 1996/1997, 767 airplane. Over a period of eight months, Boeing received five reports on interference with various pieces of navigation equipment (un-commanded rolls, displays blanking, FMC/autopilot/standby altimeter inoperative, and autopilot disconnects), caused by passenger operation of a popular handheld electronic game device. The same unit was used on another flight and on a different airplane, but the event could not be duplicated.

Case 3: 1998, 747 airplane. A passenger's palmtop computer was reported to cause the airplane to initiate a shallow bank turn. One minute after turning the PED off, the airplane returned to "on course." In the Boeing navigation laboratory, the unit was placed next to the flight management computers, the control display unit, and the integrated display unit, but the reported anomaly could not be duplicated.

Ground and airplane tests of in-seat power:

Boeing conducted airplane tests where the system was fully loaded with laptop computers. Boeing tested eight airplanes: two 737s, one 747, two 767s, and three 777s. The number of laptops operating simultaneously in each test ranged from 32 to 245. Boeing found no airplane susceptibility in these eight tests, although some emissions were found to be extremely noisy in the laboratory (up to 40 dB over the airplane-equipment emission limit). As of August, 2001, a total of eighteen airplanes had been tested.

Cellular phone tests and analysis:

Boeing conducted a laboratory and an airplane test with 16 cellular phones, typical of those carried by passengers. The results indicated that the phones not only produced emissions at the operating frequency, but also produced other emissions that fell within airplane communication/navigation frequency bands (automatic direction finder, HF/VHF omni-range/locator, and VHF communications and ILS systems). However, no susceptibility of those systems was observed.

Airplane makers, like Boeing and Airbus Industrie, have tested their aircraft with cellular-phone frequencies and other PEDs, and discovered no interference with communication, navigation, or other systems.

Although there is little solid evidence of PED interference to avionics, the potential does exist. All the electronic devices must pass FCC emissions tests before marketing. The FCC emission power limits are (for some devices and frequencies) as much as 1,000 times higher than the FAA limits, which are barely low enough to prevent interference with the airplane's communications/navigation equipment. In addition, these carry-on electronic devices can be located any place in the cabin, and can possibly generate standing waves in the aircraft's aluminum skin, as a resonant cavity. What is more, the emission properties of the electronic device can be degraded with the age after its initial FCC test.

6. Debate

The use of PEDs in air flight is common. Although FAA regulations and airline policies restrict or ban airborne use of PEDs, there is no absolute control of passenger use of these devices. For instance, cellular-phone use aboard aircraft will occur, whether or not passengers are warned against their use. One airline mentioned that their biggest problem is the use of cell phones in the lavatories during flight. Another airline stated that cell phones left on in the passengers' luggage could affect airplane systems. In fact, one airline suspected this was a cause of a flight anomaly resulting in an air turn-back due to false indication of cargo fire. Two years ago, in England, a passenger who refused to switch off his cell phone on an international flight was jailed for a year. The Civil Aviation Authority in Great Britain did a study with simulated cellular phones, and concluded that airplane-equipment qualification levels need to be increased to a level of 50 V/m to ensure electromagnetic compatibility [20]. Others believe that the cell phones pose no threat at all to airplane systems, since the higher the frequency, the lower the probability of aircraft system response. In July, 2000, the United States House of Representatives Aviation Subcommittee held a hearing entitled "Portable Electronic Devices: Do They Really Pose a Safety Hazard on Aircraft." CNN reported, "There is no hard proof that cell phones and other electronic devices pose safety risks on aircraft, but bans on their use should continue as a precautionary measure, experts told Congress Thursday [21]."

In addition to cell phones, portable electronic devices that are clearly non-intentional transmitters can contain functions that intentionally transmit. This can make the current policies more difficult to enforce. New devices, operating in higher frequency bands, may produce reports of anomalies with communication/navigation equipment not previously cited. Since GPS has such a low sensitivity level, will it be affected? A technical committee in Europe has just formed the EUROCAE Working Group WG58, to look at the difficulties encountered by airlines and aircraft manufacturers in assessing the electromagnetic compatibility of new high-technology products. These will include in-flight entertainment and wireless communications. The first meeting was held in July of 2001.

Airlines don't want to bring troubles to unnecessarily inconvenience their customers unless necessary to prevent an avionics anomaly. While on the ground, there seems to be no problem, as cellular phones and walkie-talkies are used in airport lobbies and in proximity to aircraft. Only a small portion of PED-related avionics-incident reports show convincingly that repeatedly turning PEDs on and off corresponds with avionics anomalies. Although RTCA concluded that the probability of a PED interfering with an airplane receiver system is low, this issue must be treated carefully.

An issue that tends to complicate matters in deciding where to place the blame for system upsets is the lack of verification when problems are noted. From the researcher's perspective, it would be desirable to have an additional level of problem-verification performed, noting the correspondence between PED on-and-off cycling and the onset or correction of the upset condition. From the pilot's perspective, it is understandable to simply eliminate the cause of the problem, without being 100% certain of its origin.

The interesting fact is that it is very difficult to duplicate the effects of PED interference with aircraft. In 1995, Boeing purchased the laptop computer that was reported to have caused autopilot disconnects during cruising, but the problem could not be duplicated, in spite of operating the laptop in the same seat and during the same flight route. Later, Boeing repeated the test on the same airplane, with the exception of there being no revenue-paying passengers. This allowed the laptop to be moved throughout the aircraft but, again, no interference was observed. Boeing then performed a laboratory emission scan on the suspect laptop, from 150 kHz to 1 GHz. The emissions exceeded the Boeing emission-standard limits for airplane equipment at various frequency ranges up to 300 MHz. However, a large margin was confirmed between the autopilot system-susceptibility test level and the laptop emissions. The airplane and laboratory investigative testing could not confirm the initially reported scenario.

Boeing has performed a tremendous amount of testing of a wide variety of laptop computers. Boeing found that modern laptops tend to emit EMI at levels that are within acceptable limits to reasonably assure, but not guarantee, non-interference to aircraft communication/navigation radios. Boeing has also performed tests in the laboratory, and in an on-the-ground airplane, with 16 typical cellular phones. The results show that no susceptibility was observed [2]. There are many factors in the avionics interference incidents. These include the frequency range of transmitting and receiving, the place and angle of antennas, the shielding performance of electronic devices, and the electromagnetic environment. Any of these factors could affect the interference mechanism. The vibration during a flight might change the contact properties of shielding, so that the shielding performance could be degraded. Different working modes of complex electronic devices, such as laptops, can change their emission characteristics. Airplanes are packed with a huge amount of electronic equipment, from radios and navigational equipment to smoke detectors and in-flight video. These systems can interfere with one another. Moreover, planes in the air are constantly flying through areas where electromagnetic emissions from television and radio towers, satellite transmissions, and other emitters, are strong. These factors can make the interference between PEDs and avionics become difficult to duplicate and analyze.

7. Summary

The FCC's ban on the airborne use of cellular phones is intended to avoid air-to-ground interference within the cellular system. The FAA supports the restriction of the airborne use of cellular phones and other intentional-transmission PEDs for reasons of potential interference to critical aircraft systems. The FAA does not prohibit the use of cellular phones in aircraft while on the ground, if the aircraft operator has determined that they will not cause interference with the navigation or communication systems of the aircraft. The FAA prohibits the operation of any portable electronic devices during the takeoff and landing phases of flight. The FAA prohibits the operation of any intentional radiators or transmitters aboard aircraft, while use of unintentional emitters is not prohibited when the plane is above 10,000 feet.

PEDs on commercial airplanes will continue to present a source of uncontrolled emissions. Although there is a lack of hard evidence, PEDs could be potentially hazardous to aircraft communication and navigation equipment if operated aboard aircraft. PEDs will continue to be blamed for some anomalies, regardless of whether they are the true cause. As a result, regulatory agencies and operators continue to offer the current policy for PED use on airplanes as the best safety measure.

8. Acknowledgement

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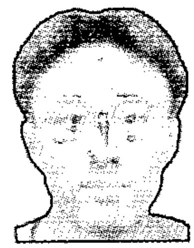
Introducing the Feature Article Authors



Lin Li received the BS degree from Tsinghua University, Beijing, China, and the MS degree from the Chinese Academy of Sciences. He is currently a Graduate Research Assistant with the CALCE Electronic Products and Systems Center, University of Maryland, College Park. Mr. Li is a student member of IEEE and IMAPS.

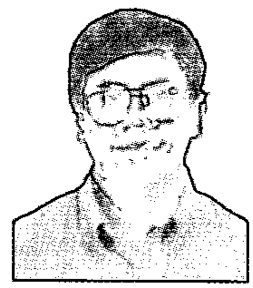
Jingsong Xie received the BS degree from Tsinghua University, Beijing, China; the MS degree in Naval Architecture and Ocean Engineering from Tokyo University, Tokyo, Japan; and a PhD in Mechanical Engineering from the University of Maryland, College Park. He is currently with Microsoft Corporation.

Omar M. Ramahi received the BS degrees in Mathematics and Electrical and Computer Engineering from Oregon State University, Corvallis, Oregon, in 1984. He received his MS and PhD in Electrical and Computer Engineering in 1986 and 1990, respectively, from the University of Illinois at Urbana-Champaign. From 1990-1993, Dr. Ramahi held a visiting fellowship position at the University of Illinois at Urbana-Champaign. From 1993 to 2000, he worked at Digital Equipment Corporation, where he was a member of the Alpha server product-development group. In August of 2000, he joined the faculty of the James Clark School of Engineering at the University of Maryland at College Park, where he is also a faculty member of the CALCE Electronics Products and Systems Center.

Dr. Ramahi has served as a consultant to several companies. He was instrumental in developing computational techniques to solve a wide range of electromagnetic radiation problems in the fields of antennas, high-speed devices and circuits, and EMI/EMC. His interests include experimental and computational EMI/EMC studies, high-speed devices and interconnects, biomedical applications of electromagnetics, novel optimization techniques, and interdisciplinary studies linking electromagnetic applications with new materials. He has authored and co-authored over 90 journal and conference papers and presentations. He is a co-author of the book *EMI/EMC Computational Modeling Handbook* (Kluwer Academic, 1998). Dr. Ramahi is a Senior Member of the IEEE and a member of the Electromagnetics Academy.

Michael Pecht has a BS in Acoustics, an MS in Electrical Engineering, and an MS and a PhD in Engineering Mechanics from the University of Wisconsin. He is the Director of the CALCE Electronic Products and Systems Center at the University of Maryland, and a Professor with a three-way joint appointment in Mechanical Engineering, Engineering Research, and Systems Research.

He is a registered Professional Engineer, an IEEE Fellow and an ASME Fellow. He served as Editor-in-Chief of the *IEEE Transactions on Reliability* for eight years, and on the advisory board of *IEEE Spectrum*. He is currently the Editor-in-Chief for *Microelectronics Reliability*, an Associate Editor for the *IEEE Transactions on Components, Packaging, and Manufacturing Technology*, and on the advisory board of the *Journal of Electronics Manufacturing*. He serves on the board of advisors for various companies and consults for the US government, providing expertise in strategic planning in the areas of electronic product development and marketing.



Bruce J. Donham received his BS degree in Electrical Engineering from the University of Illinois, Urbana-Champaign, in 1979, and his MBA degree from Seattle University in 1996. Since 1982, he has worked in the electromagnetic effects (EME) group (electromagnetic compatibility, high-intensity radiated fields, and lightning protection) for Boeing Commercial Airplanes. His roles have included lead engineer, prime research engineer, portable electronic device (PED) focus/spokesman/technical expert, Federal Aviation Administration (FAA) Designated Engineering Representative (DER) for EME, past committee member on RTCA Special Committee SC-177 studying the effects of PEDs on aircraft systems, and team member studying wireless applications to aircraft systems.

Editor's Comments *Continued from page 29*

of those members, I can certainly support the idea! Historically, I feel that AP-S has benefited substantially from the more-or-less equal distribution of its membership among industry, academia, and government employers. We've always tried to encourage those in industry to share their work in the *Magazine*. Doing a quick count, I was pleased to discover that exactly half of the feature articles we've published so far this year have had one or more authors from industry.

Those in academia, and those doing unclassified work for the government, often have incentives to publish their work built into their jobs. However, it can be more difficult for those in industry. Classification and the US ITAR (International Traffic in Arms Regulations) can be limiting factors, particularly for the areas in which some AP-S members work. Fear about the disclosure of proprietary or competitively valuable information discourages some, and others have difficulty convincing management that time spent preparing and submitting a contribution for publication will help the corporate "bottom line." I have always had a very straightforward response to that last concern: Publishing in your field is quite simply some of the most effective advertising there is – and, in one sense, it's free. How else can you reach the 10,000 or so leaders in the field of antennas and propagation with a demonstration of your expertise, and/or a demonstration of the value and capability of your products, in a venue where they are focused on reading what you have to say? If you work in industry and have some good engineering you'd like to share, please submit it to the *Magazine*. The benefits are many.

There is one area in particular where we need more participation, regardless of the source: antenna measurements. If you can share a contribution with us in this area, please contact Don Bodner. Also, the Antenna Measurement Techniques Association (AMTA) is holding its annual symposium November 3-8, 2002, in Cleveland, Ohio. If you hear a good paper there (or even better, if you're presenting one), please encourage the author(s) to submit it to the *Magazine*.

This is the time of year where many things begin, at least in much of the world: the school year, government and some corporate fiscal years, and even a new year, by some people's calendars. I hope it brings you new opportunities: for success, for professional growth, and to share your accomplishments with our community.

Ross