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Emission analysis of large number of various passenger electronic devices in aircraft

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Abstract. The ever increasing use of PEDs (passenger or portable electronic devices) has put pressure on the aircraft industry as well as operators and administrations to reevaluate established restrictions in PED-use on airplanes in the last years. Any electronic device could cause electromagnetic interference to the electronics of the airplane, especially interference at receiving antennas of sensitive wireless navigation and communication (NAV/COM) systems.

This paper presents a measurement campaign in an Airbus A320. 69 test passengers were asked to actively use a combination of about 150 electronic devices including many attached cables, preferentially with a high data load on their buses, to provoke maximal emissions. These emissions were analysed within the cabin as well as at the inputs of aircraft receiving antennas outside of the fuselage.

The emissions of the electronic devices as well as the background noise are time-variant, so just comparing only one reference and one transmission measurement is not sufficient. Repeated measurements of both cases lead to a more reliable first analysis. Additional measurements of the absolute received power at the antennas of the airplane allow a good estimation of the real interference potential to aircraft NAV/COM systems. Although there were many measured emissions within the cabin, there were no disturbance signals detectable at the aircraft antennas.

1 Introduction

The electromagnetic compatibility (EMC) of electronic devices with aircraft systems is a subject of great concern due to the hazardous consequences that may arise from failures. Not only depend aircraft on more functions provided by electronic systems, the number of possible sources of electromagnetic emissions has also increased on board. These include portable electronic devices (PEDs) carried by passengers. The society nowadays has become accustomed to the availability and constant usage of devices such as laptops, tablets, mobile phones and music players. Therefore, the question whether PEDs should be allowed on board has been of interest not only to aircraft manufacturers, aviation operators and regulatory agencies, but also to the general public. An electronic device can fundamentally cause interference by means of emissions conducted on wires or radiated through space. Conducted emissions by PEDs are controlled in aircraft with sufficient isolation and filtering between interfaces to PEDs and aircraft power or data networks (RTCA, 2008). Regarding radiated emissions, a portable electronic device can interfere with aircraft systems in two different ways. Firstly, any electronic device emits unintentional radiation in an uncontrolled way. If affected frequencies fall into the operation bands of navigation and communication (NAV/COM) systems of aircraft, interferences may occur due to coupling into corresponding antennas (front-door coupling) (EUROCAE, 2006). NAV/COM systems are designed to be very sensitive in their operation bands, and can be perturbed even by spurious emissions of low levels, as will be shown later in this paper. Secondly, PEDs with transmitting function (T-PEDs) additionally emit signals via antennas for communication purposes. These intentional radiations are normally much stronger than spurious ones, and therefore can couple directly into cables or units of aircraft equipment (back-door coupling) (EUROCAE, 2006). A difficulty is posed by the fact that passenger devices are not tested according to aeronautical standards or subjected to quality control after purchase.

In the last years, new regulations have been issued with a trend of allowing the expanded use of PEDs on board. Lastly, both the Federal Aviation Administration of the United States (FAA) (FAA, 2014) and the European Aviation Safety Agency (EASA) (EASA, 2014a, b) decided to allow PED usage throughout the whole flight, provided that the operators demonstrate aircraft tolerance to PEDs (Schmidt et al., 2004; EUROCAE, 2006; RTCA, 2008). While the aviation industry now possesses more knowledge and experience on the subject, there is little information on the actual influence of various current PEDs on navigation and communication systems in an aircraft. Studies were mostly devoted to investigating either the emissions of electronic devices (Fuller and Satterlee, 1999) or the interference path coupling (Nunes and Schüür, 2012) separately, or by combining both analytically (Ely et al., 2004; Schüür and Nunes, 2012; RTCA, 2008). In addition, PEDs have significantly changed in the last years. This work addresses the issue of PED interference on NAV/COM systems by means of a practical ground test with conditions very similar to those which may happen during a flight. A large number of commercially bought PEDs with different characteristics from different owners were brought and operated on board an Airbus A320.

In order to investigate the impact of PED emissions on NAV/COM systems, measurements were performed with antennas positioned inside the cabin as well as at the aircraft's antennas connections to the NAV/COM receiver inputs. Thus, a direct comparison of PEDs spurious emission power levels between the inside of the cabin and at the NAV/COM antennas mounted on the outside of the fuselage was made possible. The main objective of the test was to demonstrate and verify the assumption of a sufficient interference path loss (IPL) between the PEDs in the cabin and the external aircraft antennas for a practical worst-case PED scenario (i.e. many persons operating many different PEDs with many attached cables having a large amount of data transmissions).

This paper is organized as follows: Sect. 2 describes the types and number of PEDs operated in the aircraft. In Sect. 3, the measurement setup of the campaign is presented. The analysis of the measured data follows in Sect. 4. There, both the intentional and the unintentional electromagnetic emissions by the PEDs are shown as they were received inside the cabin and at two representative aircraft antennas. Finally the paper ends with a conclusion.

2 Types and number of PEDs

For the measurements presented in this paper, 69 passengers on board used one or more PEDs, in total there were 42 laptops, 65 smart phones, and 22 tablets of various manufacturers, see in Table 1. Intentional wireless transmissions are listed as well.

Table 1. Type of PEDs operating in the aircraft.

Type of PEDs	Count	Wireless connection
Smart phone	65	GSM, UMTS, LTE, WLAN, Bluetooth
Laptop/notebook	42	WLAN, Bluetooth
Tablet computer	22	UMTS, LTE, WLAN, Bluetooth
Hand held game player	5	WLAN (partly)
Digital camera	6	–
MP3 player	6	WLAN (partly)
E book reader	3	–
Ham radio receiver	1	Ham radio
Cassette player	1	–

Table 2. Accessories connected with PEDs.

Accessories	Count	Remarks
Head phone	40	1 device wireless (Bluetooth)
Ext. hard disk	8	
Mice	6	3 devices wireless
Ext. batteries	7	
USB stick	2	
DVB-T stick	1	
Ext. card reader	1	
Ext. fan unit	1	
Game pad	2	

The PEDs had partly wire-connected accessories. In total, 76 cable connections were used, including 12 between smartphones and laptops. Table 2 lists the accessories connections.

All PEDs were supplied with built in or external batteries. In the airplane, there was no connection for external power or external analog/digital signal. During the campaign, in a break, there was the possibility to recharge all PEDs to keep the same condition for the whole measurement campaign. The passengers were instructed to operate their PEDs maximizing energy consumption and data communication. It is important to mention that cable connections between PEDs and accessories faciliate radiated emissions because of the cable length and should be included in such a study as much as possible.

3 Setup for measurement

Measurements were performed with the research aircraft "ATRA" (a modified 38 m Airbus A320) at the ground, positioned at the apron of Braunschweig-Wolfsburg airport. The aircraft was electrically supplied by an external ground power unit. The aircraft doors were always closed. For the measurement of the emissions of the PEDs, two antennas were placed inside the cabin. A long wire antenna was

Table 3. Frequency ranges investigated in this paper.

Port	Antenna	Explanation of abbreviation	Measured frequency range
1	Long-Wire		50–6000 MHz
2	Discone		50–6000 MHz
3	MKR1	Marker (antenna #1)	69–86 MHz
4	VHF2	Very High Frequency – communication (antenna #2)	117–146 MHz
5	DME2	Distance Measuring Equipment (antenna #2)	962–1213 MHz
6	VHF1	Very High Frequency – communication (antenna #1)	117–146 MHz
7	ATC1Top	Air Traffic Control – transponder (antenna #1, top antenna)	1025–1035 MHz
8	GS	Glide Slope – instrument landing system	329–335 MHz
9	LOC	Localizer – instrument landing system	108–118 MHz
10	ATC1Bottom	Air Traffic Control – transponder (antenna #1, bottom antenna)	1025–1035 MHz

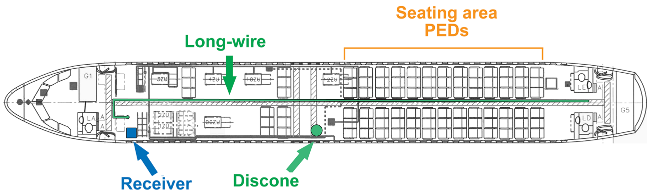

Figure 1. Placing of antennas and PEDs inside the cabin.

mounted at the ceiling along the aisle, and a discone antenna was placed as shown in Fig. 1. The objective of these antennas located in the cabin is to better determine the intentional and unintentional radiations of the PEDs as well as to detect frequency points with maximum emissions which might couple into aircraft antennas. Measurements at aircraft antennas are strongly influenced by transmissions from external sources (e.g. ground stations, other aircraft, ground equipment), so that possible contributions from sources located inside of the cabin are difficult to identify. Due to the electromagnetic loss posed by the aircraft fuselage, external transmissions are attenuated and internal emissions are measured with higher power by means of antennas located inside the cabin.

The seating of the passengers and the discone antenna is also shown in Fig. 2. At this configuration, PEDs were located in different areas of the cabin, including near many cabin windows, the emergency exits and the aft passenger doors. These are points of preferential coupling of emissions to the exterior.

The emission of the PEDs is measured by a spectrum analyzer which can be switched into an EMI test receiver with built in narrow band filters. Both modes have relevant advantages with regard to the data acquisition. The spectrum analyzer has a faster sweep time as it covers the whole frequency range in large steps and depending on the chosen bandwidth of the intermediate frequency (resolution bandwidth: 30 kHz below 1 GHz, 1 MHz above). The EMI test receiver always covers the whole frequency band with a very fine frequency step. This stepping is chosen coupled to the given receiver

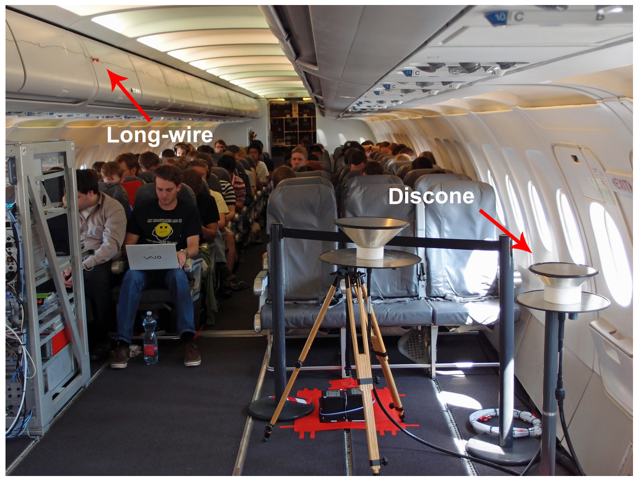

Figure 2. Picture of measurement.

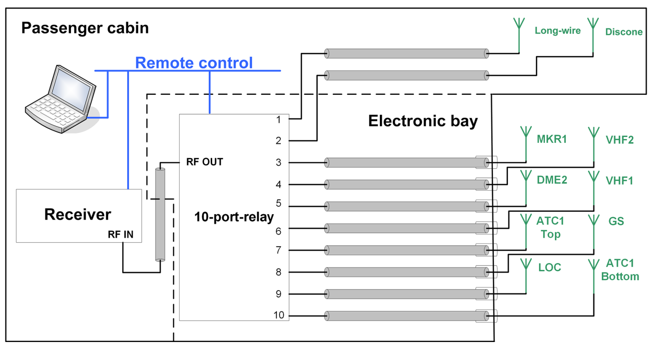

Figure 3. Measurement setup.

bandwidth. Measuring in the very fine stepping takes more time and time is a very limited factor while measuring in an aircraft. To be time efficient, both antennas and some selected aircraft antennas (see Table 3) are connected via relay to the receiver as shown in Fig. 3.

First only measurements inside the cabin with relay port 1 and 2 were used to detect emissions inside the cabin.

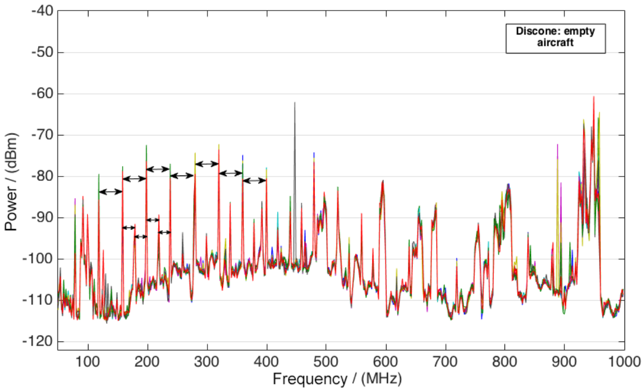

Figure 4. Emission in empty airplane received by the discone antenna.

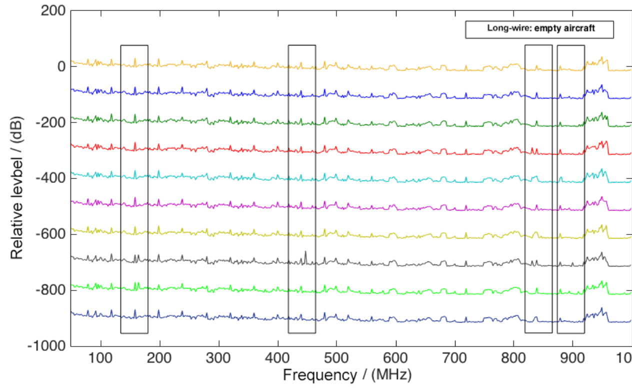

Figure 5. 10 emission measurements in empty airplane received with the long wire antenna.

After the identification of possible interferences emitted in the cabin at aircraft NAV/COM frequency ranges, the corresponding aircraft antenna can be added to the measurement. While the setup with the passengers and operated PEDs is an effort to maximize emissions which could happen during flight, the power measured by the aircraft antennas may have been influenced by reflections on the ground. However, as indicated by Nunes (2014) by means of comparative measurements inside and outside of a hangar, reflections externally to the aircraft statistically decrease the interference path loss to NAV/COM antennas. This means that the power measured at the aircraft antennas tends to be increased on the ground, being conservative in comparison to flight conditions.

4 Analysis of data

In this section, the measurements are presented and discussed. In order to better grasp the results and their implication, this section is structured according to the types of measurement. First the measurements with the empty airplane are presented in Sect. 4.1. It is necessary to understand the background noise, which may have an impact on the further measurements. Secondly, in Sect. 4.2, the emissions of operated PEDs are presented as measured by the antennas located inside the cabin. This way, the behavior of the combination of PEDs can be better assessed regarding intentional and unintentional emissions. After that, based on the detected frequencies with most conspicuous emissions which could impact NAV/COM systems, the measurements of power at the aircraft antennas are presented (Sect. 4.3). Finally, as shown in Sect. 4.4, the operation of PEDs divided in areas of passenger seats illustrates the impact that single devices may have on the overall emission pattern caused by a combination of multiple PEDs.

4.1 Empty airplane

Firstly, the analysis of the electromagnetic background noise in the aircraft is carried out. This may have two dominant sources: the emission of the electric system of the aircraft (lights are switched on, basic aircraft systems are working) and second sources transmitting outside of the aircraft as mobile phone network, radio and TV-broadcast, mobile phones, etc. These measurements are done without passengers or PEDs in the cabin. The spectrum analyzer is used as the time for these measurements is limited. Figure 4 shows the received power at the discone antenna within the empty aircraft.

In the frequency range below 1000 MHz, many signals are visible – it is quite possible that the equidistant peaks (connected with arrows) have the same emission source as often clock frequencies lead to spurious harmonic components in the spectrum.

Furthermore, this spectrum is highly variant in time. Figure 5 shows 10 repeated measurements received with the long wire antenna. For better visibility between one and the next curve, an offset of 100 dB is added for each plot.

In four frequency ranges, there are time variant emissions visible, marked with a box. If an emission is shown at least once here, it is known that this emission could also appear in the measurements with working PEDs. At this point, it is confirmed this is not an emission from a PED. The source of this emission must be an aircraft electronic system or otherwise an external source. These measurements show the electromagnetic environment inside of the cabin, already with several peaks. Emissions caused by later operation of PEDs will add to this environment.

4.2 Active PEDs

The most important step is the detection of PED emissions. As noted before, both the background noise and the emissions of PEDs are time variant and may not occur in ev-

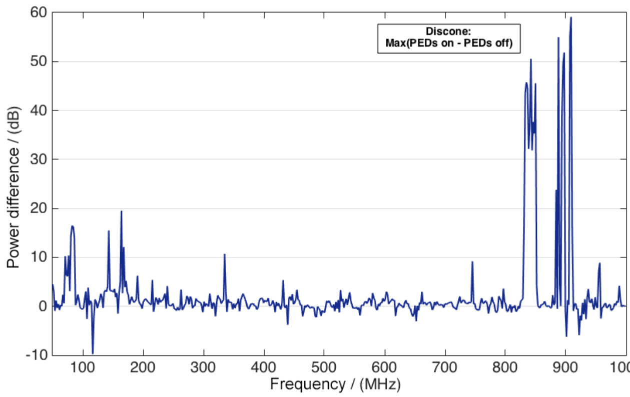

Figure 6. Difference in received power of operating PED to noise floor below 1 GHz.

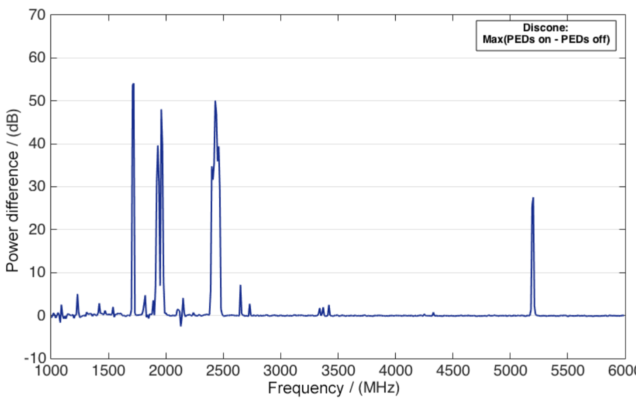

Figure 7. Difference in received power of operating PEDs to noise floor above 1 GHz

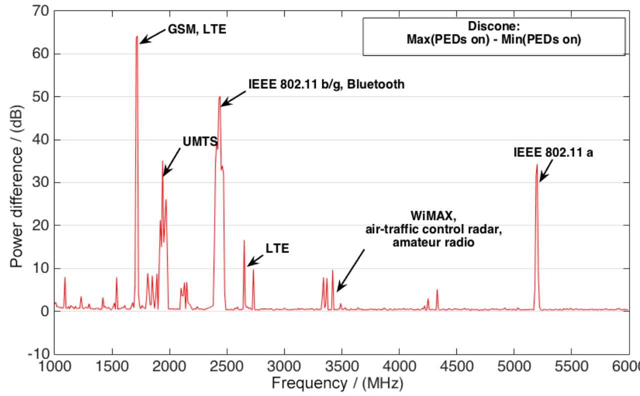

Figure 8. Intermittent emissions of operating PEDs above 1 GHz.

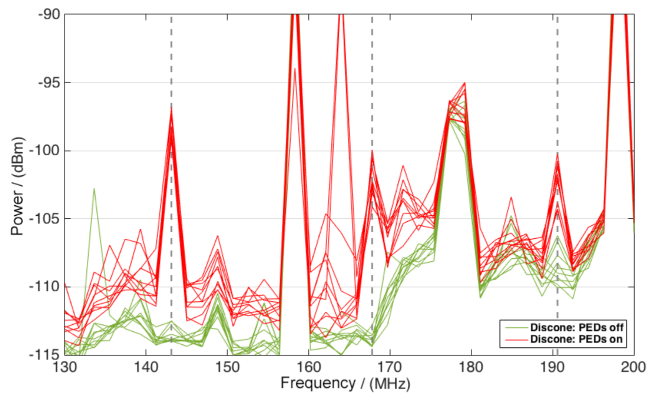

Figure 9. Emission measurements in airplane with operated (red) and disabled (green) PEDs recorded with a frequency step of 1.9 MHz.

ery measurement. Therefore, the measurements are repeated ten times. The maximum difference between noise and PED measurement is shown in Fig. 6 for the frequency range below 1 GHz. The noise measurements considered here were performed with passengers on board but with all PEDs completely turned off.

In the lower frequency range, GSM transmissions around 800 and 900 MHz are significant. Few emissions are visible in the range of 60 to 200 MHz. The higher frequency range is shown in Fig. 7.

In the higher frequency range (above 1 GHz), the transmissions of GSM, UMTS, and WLAN (2.4 and 5 GHz) are significant. Figure 8 shows the difference between the maximum and minimum level measured within a series of 10 measurements with PEDs turned on. The large differences indicate that the signals are intermittent. The corresponding wireless communication standards are noted.

These transmissions in allocated frequency ranges are intentional emissions whose impact on aircraft systems is handled by a special test procedure for front-door coupling (EUROCAE, 2006). Emissions in other frequency ranges, not assigned to intentional PED transmissions, have to be analyzed in detail, because they may affect NAV/COM systems. In this regard, the most relevant frequency range is below 200 MHz, where the unintentional emissions in Fig. 6 have significant power. To check whether these emissions are really caused by the PEDs, all ten curves with PED emission and other ten curves without emission are plotted together in Fig. 9.

At three frequencies (marked with vertical dashed lines), PED emissions are recorded. As all ten lines with active PEDs have the same level, the emissions of the PEDs are not pulsed. At other frequency ranges pulsed emissions can be noted. An overview of the pulsed PED emission is given in Table 4, which lists the frequency ranges, in which those emissions are measured inside the cabin.

As expected, peaks are mostly due to transmissions according to different wireless standards. Because of the PED antennas, the field levels (and the corresponding power measured by the long-wire and discone) caused by intentional radiations are relatively high. Nonetheless, considerable peaks not related to any wireless standard were also measured. These were found especially in the lower frequency range.

Table 4. Frequencies with pulsed PED emissions.

Start frequency	End frequency	Antenna	Mobile service of PEDs
70 MHz	90 MHz	Discone/Long wire	–
162 MHz	165 MHz	Discone/Long wire	–
830 MHz	850 MHz	Discone/Long wire	LTE
880 MHz	910 MHz	Discone/Long wire	GSM/UMTS
1700 MHz	1730 MHz	Discone/Long wire	GSM/LTE
1910 MHz	1980 MHz	Discone/Long wire	UMTS
2390 MHz	2480 MHz	Discone/Long wire	IEEE 802.11b/g Bluetooth
2650 MHz	2650 MHz	Discone	LTE
3330 MHz	3420 MHz	Discone	WiMAX
5180 MHz	5220 MHz	Discone/Long wire	IEEE 802.11a

Some affected frequencies may fall into the operating bands of NAV/COM systems and cause interference. The analysis of the impact on aircraft antennas is presented next, in Sect. 4.3.

4.3 PED emission measurement at aircraft antennas

The frequency ranges with most significant PED emissions are summarized in Table 4. Most of them refer to intentional emissions and differ from the aircraft NAV/COM frequencies. Detailed investigation is required for the 70 MHz frequency range because here the marker receiver of the airplane is sensitive to possible disturbances. In addition, even though not directly affecting the frequency band of VHF (117–137 MHz), emissions falling near the upper VHF frequency could also couple into aircraft antennas and are also analyzed in this paper. Next, the power at the aircraft NAV/COM antennas listed in Table 3 is recorded in the EMI receiver mode. The resolution bandwidth (RBW) used in each measurement is indicated in the caption of the following graphs. Other aircraft systems besides those of the Marker and VHF were also measured and assessed.

The received power in the cabin at the marker frequency range is shown in Fig. 10.

In this frequency range, the emissions in the cabin with activated PEDs (PEDs on) are quite high. In the empty aircraft, only noise is detected. The received power of the discone is compared to the power received by the long wire antenna in Fig. 11 in detail.

The long wire antenna receives more power than the discone antenna in some frequency ranges. Nevertheless, at the aircraft marker antenna there is no power of the emissions detected in all measurements with operating PEDs as seen in Fig. 12.

The one peak at about 74 MHz is recorded within a noise measurement without active PEDs. Anyway, this small peak and the observed noise floor are well below the sensitivity threshold of the Marker receiver at the relevant measuring bandwidth (−80 dBm).

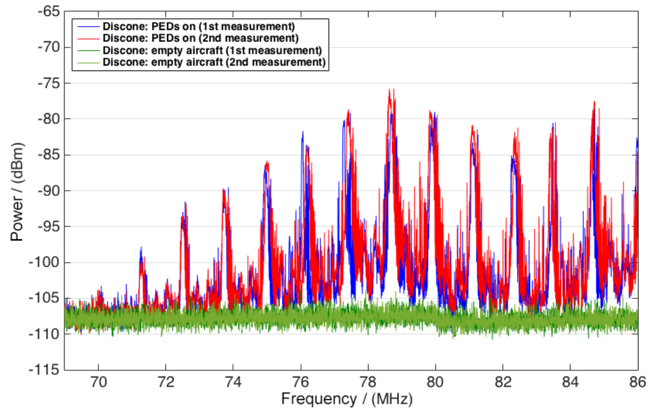

Figure 10. Emission in the 70 MHz frequency range at discone antenna (noise floor in green) recorded with a resolution bandwidth of 30 kHz.

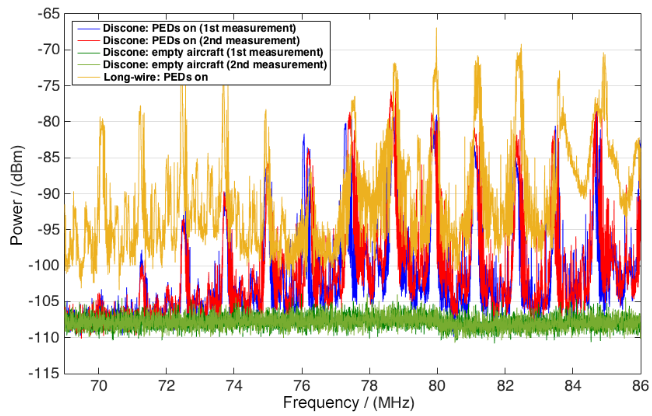

Figure 11. Emission in the 70 MHz frequency range at discone antenna repeated and at long wire antenna (noise floor in green) recorded with a resolution bandwidth of 30 kHz.

The Marker receiver is characterized by a moderate sensitivity. Conversely, other NAV/COM receivers, such as the VHF, have a higher sensitivity (lower sensitivity threshold). Therefore, even spurious emissions of low levels coupling

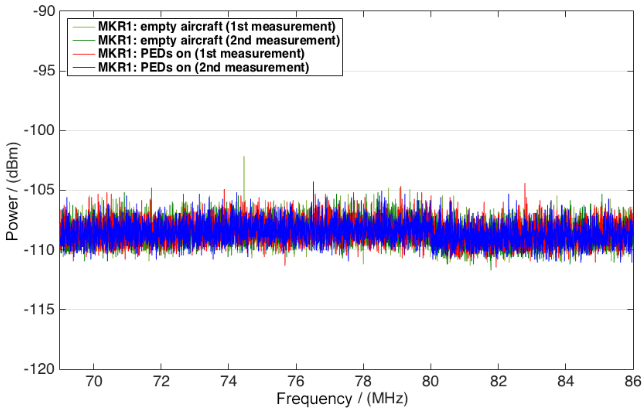

Figure 12. Received power at marker antenna (sensitivity threshold of Marker receiver: −80 dBm) recorded with a resolution bandwidth of 9 kHz.

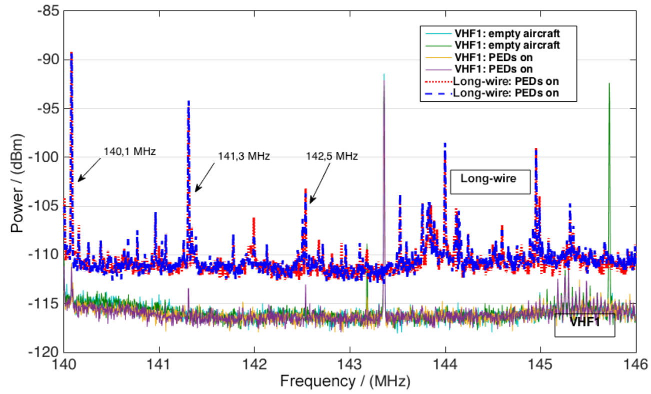

Figure 13. Analysis for 140 to 146 MHz with the VHF1 and the long wire antenna (sensitivity threshold of VHF receiver: −113 dBm) recorded with a resolution bandwidth of 9 kHz for VHF1 and 30 kHz for the long wire antenna.

into the corresponding NAV/COM antennas could perturb the operation of these systems. One example is the coupling into the VHF1 antenna, which is analyzed next. The displayed frequency range for the VHF1 was selected according to frequencies at which maximum peaks were measured with the long wire antenna in the cabin, i.e. frequencies at which maximum PED emissions occurred in the initial measurement.

The VHF1 antenna detects lots of signals (with and without operating PEDs) as shown in Fig. 13. Some signals occur only in one situation (PEDs switched on or off) and some are measured in all cases – especially the large peaks above 143 MHz and below 146 MHz are present in all cases. As these peaks are received at the VHF1 antenna only, the origin must be outside of the fuselage. The strong signals received inside the fuselage at 140.1, 141.3 and 142.5 MHz are also received by the VHF1 antenna, but with a very weak level. Nevertheless, some signals are above the receiver sensitivity, which is −113 dBm. This is much more sensitive compared to the marker receiver. However, some additional measurements with PEDs turned off also revealed that the long-wire captured peaks at exactly these frequencies. This leads to the conclusion that these peaks are not generated by the PEDs, but by other sources. Because of the much larger power received by the long-wire in comparison with the VHF1 antenna, it is probable that they refer to emissions from an aircraft system. The fact that the measurements in Fig. 13 with the empty aircraft do not show these peaks at the VHF1 antenna is supposedly due to the intermittence of the emissions. Anyway, these peaks are located above 137 MHz where the civil VHF frequency range ends. Therefore, only really strong signals could influence the VHF1 receiver by blocking.

The measurements shown in Figs. 12 and 13 indicate that the emissions of the operated PEDs had no significant coupling on the MKR1 and VHF1 antennas. These results are representative for all other aircraft antennas at which measurements were performed (positions as shown in Fig. 14). Even with the high number of active PEDs, operated with high energy consumption and data communication, no influence was identified at any of the eight investigated aircraft antennas. This is a result of the combination of the PED emission power and the coupling to the aircraft antennas. The aircraft fuselage, even with different leakage points of windows and doors, provides a sufficient attenuation for the spurious signals coming from the PEDs before they reach the aircraft antennas. The interference path coupling of different aircraft was measured in further campaigns (Schüür and Nunes, 2012 and Nunes, 2014) and, although dependent on the characteristics of each aircraft, their results support the findings of the measurements of the present study.

4.4 Partial operation of PEDs

As noted, about 150 active PEDs were operated in this test. It may be possible that only few of the PEDs are causing the emission pattern analyzed in the marker frequency range. For the investigation, the passenger section is split up into four sections as shown in Fig. 15.

A detailed measurement in the EMI test receiver mode is recorded at 82 to 84 MHz for operating PEDs (PEDs on) in selected sections and deactivated PEDs (PEDs off) as seen in Fig. 16. This frequency range was selected for detailed measurements as part of the range displayed in Fig. 10 where notable emissions had been noticed.

The source of the emission must be in the Block #1 or #2 and can not be in the other sections as the level of the noise measurement equals the level while the PEDs were turned on only in Section #3 and #4. Unfortunately, no further measurement time was available to identify the individual emitting PED or PEDs. However, these results in general suggest that the overall spurious behavior from a combination of PEDs

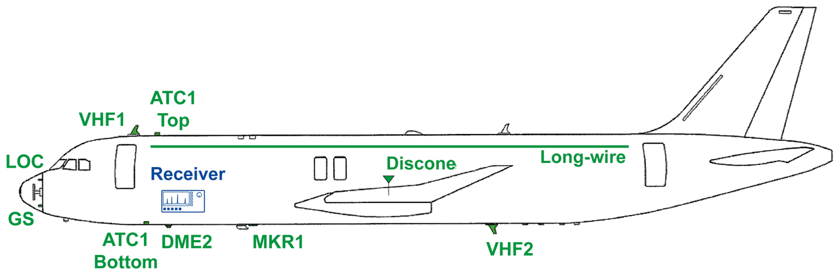

Figure 14. Placing of receiving antenna.

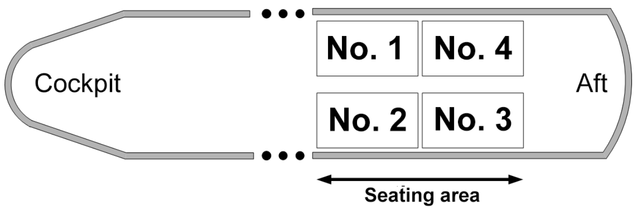

Figure 15. Block of PEDs for finding the source.

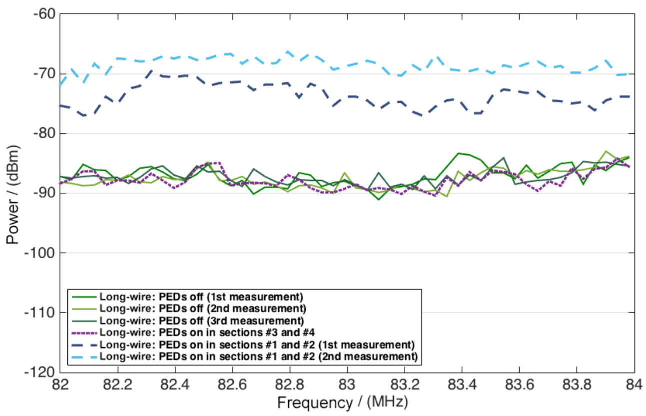

Figure 16. PEDs deactivated/operating in listed sections only recorded with a resolution bandwidth of 120 kHz.

may be dominated by emissions coming from just one or a few of the PEDs. They also support the use of high percentile values of PED emissions in RTCA (2008), statistically derived from the results of different PED measurements, as part of the process of determining the target IPL (the minimum i.e. worst case interference path loss which shall be achieved for establishing compliance to front-door coupling requirements).

5 Conclusions

In this paper, a PED emission test in an A320 is presented. The many different types and manufacturers of PEDs, the high concentration of PEDs as well as their provoked intense use simulate an extreme situation compared to real flight PED use. By means of measurements using antennas placed inside the aircraft, the background noise and the contribution of PED emissions can be determined in the cabin. The internal aircraft electromagnetic environment is already characterized by emissions from aircraft systems and from external transmitting stations, but additional PED emissions are recorded in many frequency ranges. These PED emissions can be split in intentional and unintentional emissions where only the unintentional emissions partly cover frequency ranges of aircraft NAV/COM systems. Considerable unintentional radiated emissions in the cabin are found especially in the lower frequency ranges (70–90 and 140–190 MHz). The overall spurious behavior is found to be dominated by emitting PEDs in the front section of the passenger seating area. Even with the high number of active PEDs and data communication, unintentional radiated emissions at these and other frequency ranges are not detectable at any of the eight investigated aircraft antennas. This shows the sufficient attenuation provided by the fuselage to the spurious radiations coming from the operated PEDs. Although not covering all sorts of possible PEDs in the market or all aircraft types, the accomplished setup is representative for a severe, nearly worst-case condition which may be found in current flights, with additional intense use of many different PEDs. By considering the combined effect of critical PED emissions and interference path coupling in a practical test, this work therefore supports the decisions regarding the expanded use of PEDs onboard and especially helps to substantiate the approaches used nowadays to establish compliance to front-door coupling.

6 Data availability

The data analyzed in this publication are not publicly available. In case of interest the data may be provided on request by the authors.

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