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Wireless Phone Threat Assessment and New Wireless Technology Concerns for Aircraft Navigation Radios

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Contents

Abstract

To address the concern for cellular phone electromagnetic interference to aircraft radios, a radiated emission measurement process was developed for two dominant digital standards of wireless handsets. Spurious radiated emissions were efficiently characterized from devices tested in either a semi-anechoic or reverberation chamber, in terms of effective radiated power. Eight representative handsets (four from each digital standard) were commanded to operate while varying their radio transmitter parameters (power, modulation, etc.). This report provides a detailed description of the measurement process and resulting data, which may subsequently be used by others as a basis of consistent evaluation of other portable transmitters using a variety of wireless transmission protocols. Aircraft interference path loss and navigation radio interference threshold data from numerous reference documents, standards, and NASA partnerships were compiled. Using these data, a preliminary risk assessment is provided for wireless phone interference to aircraft Localizer, Glideslope, Very High Frequency Omni directional Range, and Global Positioning Satellite radio receivers on typical transport airplanes. The report identifies where existing data for device emissions, interference path loss, and navigation radio interference thresholds need to be extended for an accurate risk assessment for wireless transmitters in aircraft.

1 Executive Summary

Wireless phones and wireless Local Area Network (LAN) products have become increasingly present companions to today's travelers. Wireless technology has brought a revolution in personal accessibility and productivity, and has created new markets for products and services. However, this wireless revolution also presents a growing concern to airlines, the Federal Aviation Administration (FAA), and the National Aeronautics and Space Administration (NASA) for potential electromagnetic interference (EMI) to aircraft electronic systems. Although passengers are currently prohibited from using radio transmitters onboard aircraft, it is clear that such unauthorized use is increasing.

In some cases, it is reasonable to suspect that certain new-technology transmitters may be no more threatening to aircraft navigation radios than non-intentionally transmitting portable electronic devices (PEDs) that passengers are currently allowed to operate. In fact, wireless product manufacturers and service providers have advocated modifications to international regulations to allow various classes of wireless voice and data transmitters to be used by aircraft passengers. Given these circumstances, an expanded effort to address the technical and operational implications of passenger use of new wireless products onboard aircraft is warranted.

This report initiates a comprehensive technical evaluation of the EMI issues related to portable wireless transmitter use onboard airplanes, and expands upon several technical areas addressed by the technical and operational PED threat assessment already underway between NASA and Delta Air Lines (DAL) (Cooperative Agreement NCC-1-381). Both NASA and the FAA have established an ongoing interest in addressing this safety-critical area. An existing NASA/FAA Interagency Agreement (IA

DFTA03-96-X-90001) was modified to include the following two tasks, which are addressed in this report:

Task 1: Develop a comprehensive technology assessment and follow-on research plan for quantifying the threat of these and other new-technology wireless transmitters to all aircraft radio receivers.

Task 2: Develop a radiated emission measurement process for Code Division Multiple Access (CDMA/IS-95, 824-849 MHz) and Global System for Mobile communications (GSM) European Telecommunications Standards Institute (ETSI) (GSM 11.22) wireless phones, and provide a preliminary risk assessment for their potential interference to aircraft Localizer (LOC), Glideslope (GS), Very High Frequency Omni directional Range (VOR), and Global Positioning Satellite (GPS) radio receivers.

NASA teamed with the University of Oklahoma (UOK) Wireless Electromagnetic Compatibility (EMC) Center to develop a radiated emission measurement process for CDMA and GSM wireless phones. UOK provided a standard protocol for operating CDMA and GSM wireless handsets in estimated worst-case modes, and provided eight handsets for a three-week radiated emission measurement program at NASA Langley Research Center (LaRC), in Hampton, Virginia. The UOK team provided CDMA and GSM base station simulator equipment and keypad/connector programming capability to accomplish these tests. NASA developed a process for measuring peak spurious radiated power from the wireless handsets into aircraft radio frequency bands. A standard instrumentation package and custom software were developed to quickly characterize spurious radiated emissions in terms of peak-radiated power, when measured in either a semi-anechoic or reverberation chamber. This flexibility is intended to facilitate use of the measurement process by any qualified EMC measurement facility, and can be applied as a basis of consistent evaluation of wireless handsets and other portable transmitters.

When wireless handset spurious radiated emissions data are adjusted by estimates of aircraft interference path loss (IPL: attenuation from passenger cabin location to aircraft navigation radio connector), the interference power can be found at various aircraft navigation radio inputs. NASA researchers compiled IPL measurement data and navigation radio interference thresholds from numerous reference documents, standards, and NASA partnerships. From these data, a preliminary risk assessment was obtained for CDMA and GSM wireless phone interference to aircraft LOC, GS, VOR, and GPS radio receivers on typical transport airplanes.

To provide a comprehensive technology assessment and follow-on research plan to quantify the threat of all new-technology wireless transmitters to all aircraft radio receivers, NASA researchers acquired and performed preliminary measurement evaluations of Institute of Electrical and Electronics Engineers (IEEE) 802.11b, Bluetooth, and Ultrawideband (UWB) transmitters. The technology assessment included attending wireless product conferences, obtaining reference standards, and dialog with manufacturers, industry and government representatives to generate recommendations for an effective and relevant follow-on research plan.

Summary of Task 1 Results and Conclusions: Technology Assessment

1. Technologies for versatile and inexpensive wireless voice and data devices are rapidly expanding. Air travel passengers continue to become increasingly comfortable with existing and emerging wireless transmitters. Most intentional transmitters are not required to meet more rigorous FCC standards applicable to non-intentional transmitters. While limited data indicate that many wireless voice and data transmitters do not emit excessive signals in aircraft radio frequency bands, there is no

guarantee that this will continue to be the case. Reports of unauthorized use of wireless transmitters onboard aircraft have become increasingly common.

2. Deficiencies were identified in available data to perform a detailed statistical risk assessment for wireless transmitters in aircraft.

   a. Spurious radiated emission data are not available for typical and emerging wireless transmitters. While FCC and International Special Committee on Radio Interference (CISPR) emissions standards must be met for products sold in the United States (US) and Europe, they are not intended, and are therefore inadequate, for protecting aircraft spectrum from passenger-generated EMI.

   b. Available aircraft IPL data are insufficient for estimating the minimum possible IPL in US airline passenger airplane fleets. IPL data need to be collected on more airplane types, and incorporated into a statistical assessment of expected IPL, based upon aircraft type and passenger location.

   c. Inadequate aircraft navigation radio receiver susceptibility data are available for estimating signal-to-interference radios required to thoroughly assess the threat from PED-type EMI.

3. Past studies of EMI to aircraft systems from passenger-carried PEDs have recommended evaluation of detection devices for unauthorized PED use onboard aircraft. While the threat has increased and product standards have remained stagnant, little work has been performed in the design, implementation and demonstration of PED detection devices for use on passenger aircraft. It is becoming increasingly difficult for flight attendants and passengers to discern whether today's highly integrated and multi-function devices are designed to transmit or not. Observations suggest that passengers are increasingly likely to knowingly operate unauthorized transmitters while onboard aircraft. There are numerous political and operational issues to resolve before PED detection systems can be integrated into a viable airline PED policy plan.

4. More detailed analysis and testing of UWB device impact upon flight-essential aircraft navigation and communication systems and ground-based air traffic control is strongly recommended, particularly before unlicensed devices are widely available.

Summary of Task 2 Results and Conclusions: CDMA/GSM Mobile Unit Threat Assessment

1. The NASA/UOK team demonstrated a viable process for measurement of spurious radiated emissions of CDMA and GSM wireless handsets, in both semi-anechoic and reverberation chamber test facilities. The process can easily be extended to measure spurious radiated emissions from all existing and emerging wireless voice and data devices.

2. None of the four CDMA and four GSM wireless handsets tested would individually be likely to interfere with aircraft VOR, LOC, GS, or GPS navigation radios. Table 1 and Table 2 illustrate safety margins using measured data.

3. If a CDMA or GSM wireless handset radiates spurious signals equal to the maximum allowable Federal Communications Commission (FCC) limits, it would result in <u>large NEGATIVE safety margins,</u> even when considering "reasonable minimum" radio receiver interference thresholds:

4. Each handset was commanded according to an extensive matrix of operational modes, while spurious radiated emissions were measured. CDMA handsets were commanded to multiple power output levels, puncture rate settings, and voice coder (vocoder) rate settings. GSM handsets were commanded to multiple power output levels, discontinuous transmit (DTX) and discontinuous receive (DRX), and speech coder/decoder (CODEC) settings. While the operating mode often resulted in discernable differences in the spurious radiated spectrum, dominant spectral components did not vary appreciably due to mode changes. Interestingly, repeatedly turning the handset power on-and-off caused the most significant changes in the spurious radiated spectrum.

Table 1: CDMA (IS-95, 824-849 MHz) Handset Threat Assessment

<u>**Data Type**</u>	**VOR**	**LOC**	**GS**	**GPS**
Nav Radio Minimum Interference Threshold (dBm) (reasonable min / absolute min)	-106/-159 [a]	-112/-159 [a]	-102/-145 [a]	-126.5[b]
Path Loss Data (average of fleet minimums)[c] (dB)	62	56	59	59
CDMA Radiated Emission Level (EIRP max.) (dBm)	-86	-86	-76	-80
Safety Margin (reasonable min / absolute min) (row 1+ row 2 – row 3) [a] (dB)	**+42/-11** [a]	**+30/-17** [a]	**+33/-10** [a]	**+12.5**

Table 2: GSM (ETSI GSM 11.22) Handset Threat Assessment

<u>**Data Type**</u>	**VOR**	**LOC**	**GS**	**GPS**
Nav Radio Minimum Interference Threshold (dBm) (reasonable min / absolute min)	-106/-159 [a]	-112/-159 [a]	-102/-145 [a]	-126.5 [b]
Path Loss Data (average of fleet minimums) [c] (dB)	62	56	59	59
GSM Radiated Emission Level (EIRP max.) (dBm)	-91	-91	-71	-78
Safety Margin (reasonable min / absolute min) (row 1+ row 2 – row 3)[a] (dB)	**+47/-6** [a]	**+35/-12** [a]	**+28/-15** [a]	**+10.5**

Table 3: Threat Assessment for Emissions up to FCC (22.917, 24.238) Limits for Cellular & Personal Communication Services Wireless Handsets

<u>**Data Type**</u>	**VOR**	**LOC**	**GS**	**GPS**
Nav Radio Minimum Interference Threshold (dBm)	-106/-159 [a]	-112/-159 [a]	-102/-145 [a]	-126.5 [b]
Path Loss Data (average of fleet minimums) [c] (dB)	62	56	59	59
Spurious Emission Limits (for 1 Watt Transmitter) (dBm)	-13	-13	-13	-13
Safety Margin (reasonable min / absolute min) (row 1+ row 2 – row 3) [a] (dB)	**-31/-84** [a]	**-43/-90** [a]	**-30/-73** [a]	**-54.5**

[a] "Reasonable Minimum" interference threshold was taken to be the RTCA (formerly Radio Technical Commission for Aeronautics)/DO-192, DO-195, DO-196 specified minimum receiver sensitivities, with a required 26 dB signal-to-interference ratio for localizer and Glideslope receivers. (Defined as "Type 2" in RTCA/DO-233. RTCA/DO-233 provided data only for the localizer receiver, but the ratio is assumed to be the same for Glideslope due to similarities between the two systems.) "Absolute Minimum" interference threshold was taken as the minimum sensitivity of a known commercial radio receiver, with a required 46dB signal-to-interference ratio for localizer and Glideslope. (Defined as "Type 1" in RTCA/DO-233. Again, RTCA/DO-233 only provided data for the localizer receiver, but the ratio is assumed to be the same for Glideslope due to similarities between the two systems.) For VOR, the "Absolute Minimum" signal-to-interference ratio was measured as 46 dB, and published in RTCA/DO-199.

[b] RTCA/DO-229B, Narrow-band en-route interference threshold for GPS/Wide Area Augmentation System (WAAS).

[c] Path Loss data shown, are an average of the minimum coupling values measured from various airplanes' passenger cabin locations, to particular navigation radio receiver avionics bay RF connections.

5. Each handset was commanded according to an extensive matrix of operational modes, while spurious radiated emissions were measured. CDMA handsets were commanded to multiple power output levels, puncture rate settings, and voice coder (vocoder) rate settings. GSM handsets were commanded to multiple power output levels, discontinuous transmit (DTX) and discontinuous receive (DRX), and speech coder/decoder (CODEC) settings. While the operating mode often resulted in discernable differences in the spurious radiated spectrum, dominant spectral components did not vary appreciably due to mode changes. Interestingly, repeatedly turning the handset power on-and-off caused the most significant changes in the spurious radiated spectrum.

6. It was demonstrated that intermittent spurious radiated emissions would sometimes increase up to 10 dB when touching the keypad, touching the antenna, or retracting the antenna on the test handsets. However, when compared to the highest emission levels in all operating modes, these manipulations resulted in only a 3 dB increase for the highest emission levels.

7. It was demonstrated that GPS and Distance Measuring Equipment (DME) band emissions occur, due to intermodulation between GSM and other wireless handset types, when the handsets were placed in close proximity to one another. It was identified that other combinations of common passenger transmitters could potentially produce intermodulation products in aircraft communication and navigation radio frequency bands.

8. It was identified that the FCC does not restrict airborne use of Personal Communication Services (PCS) wireless handsets. FCC limits for spurious radiated emissions for PCS handsets are the same as for cellular handsets, however only cellular handsets are restricted from airborne operation by the FCC (47CFR22.925) (Code of Federal Regulations-CFR).

Recommendations for Subsequent Analysis and Action

This report is intended to fit into an overall strategy for demonstrating assessment and EMI mitigation techniques for assisting the FAA in setting future policies regarding wireless transmitter use onboard aircraft. Items 4 & 5 of the following recommendations fit this strategy, but do not specifically result from the PED signal threat assessment to aircraft navigation radios described within this report.

1. Quantify Threat from Existing and Emerging PEDs:

    a. Build upon the measurement process reported herein to establish a standard set of procedures for measuring spurious radiated emissions in aircraft navigation radio frequency bands (VOR, LOC, GS, DME, TCAS, GPS) from common and emerging wireless transmitters (Citizen's Band-CB, Family Radio Service-FRS, General Mobile Radio Service-GMRS, Cellular, PCS, GSM, third generation (3G), Bluetooth, IEEE 802.11X, etc.) Incorporate techniques to identify signal characteristics other than peak amplitude (i.e., modulation types and parameters, duty cycle, bandwidth, etc.), to more accurately quantify the potential for EMI to aircraft communication and navigation systems.

    b. Use the radiated emission process established in this report to measure numerous off-the-shelf devices. Build a device emissions database to establish confidence in signal compatibility for certain product types, and identify particular products that threaten aircraft signals.

    c. Establish a fast-response capability for suspected PED EMI incidents.

d. Study the potential for devices transmitting on different frequencies, and possibly regulated by different national standards, to generate intermodulation products in aircraft navigation radio frequency bands.

2. Expand Database of Aircraft Path Loss Measurements:

   a. Acquire existing measurement data funded by other sources. (B-737, B-767, B-777, DC-10).

   b. Explore new partnerships for further path loss measurements (i.e., United, USAirways, American, Airbus, Boeing, etc.)

   c. Perform a statistical analysis of path loss probability distributions based upon seat location, airplane type, and airplane version.

3. Determine Limits for Aircraft Navigation Radio Susceptibility to PED-Type EMI:

   a. Develop a susceptibility measurement process for aircraft navigation radios.

   b. Measure multiple types of aircraft navigation radios to establish a database of typical susceptibility to PED-type EMI.

   c. Assess different susceptibility threshold requirements for different minimum service levels and Instrument Flight Rule (IFR) conditions, and different types of PED EMI.

4. Health and Safety/Multi-User Analysis:

   Evaluate Specific Absorption Rate (SAR) distributions with multiple transmitters on aircraft for passenger and flight crew safety. This could be combined with studies of loading and coverage issues related to network capacity due to multi-path and reverberation.

5. Legacy Avionics Immunity Analysis:

   Evaluate close-in field-intensities generated by all classes of new wireless technology present on commercial aircraft (i.e., Wireless phones, wireless LANs, FRS, UWB, etc.). Determine limitations and restrictions that may be required for compatibility with systems certified to levels below RTCA/DO-160C requirements for passenger cabin equipment.

6. Onboard Detection and Mitigation of Unauthorized Passenger Devices

   a. Quantify and categorize approaches to threat detection. (Installed vs. portable, sensitivity vs. false alarm, public band vs. aircraft band, amplitude detector vs. modulation decoder, etc.)

   b. Evaluate existing and emerging techniques for threat mitigation (i.e., remote power control and deactivation, jamming, etc.).

   c. Collect data on aircraft passenger cabin radio frequency (RF) environments during flight.

   d. Demonstrate existing detection systems.

   e. Collect data on in-use systems.

7. Provide technical data and advocate aircraft EMI concerns to consumer device regulatory agencies and working groups.

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2 Introduction

2.1 Background

Beginning with the introduction of the first commercially available transistor radios decades ago, numerous analyses have been conducted to address the potential for PED signals to interfere with airborne equipment. The most authoritative studies were performed by RTCA, Inc. in 1988 (RTCA/DO-199 [1]) and 1996 (RTCA/DO-233 [2]). These reports and subsequent publications commonly agree that the potential for interference is real, but infrequent [1-7]. The RTCA reports form a foundation for current regulatory and advisory guidance from the FAA in the US [8,9].

The RTCA/DO-233 report contained four recommendations: 1) prohibit all PED usage during critical flight phases, and prohibit the usage of intentionally-transmitting PEDs at all times (unless a particular device has been specifically verified to be safely operated); 2) continue and expand testing emissions from new-technology PEDs; 3) educate the public, airline industry, and consumer electronics manufacturers regarding the potential interference hazards from PEDs; 4) research the feasibility of using PED monitoring devices onboard commercial airplanes.

Figure 2.1: "February 13, 2001 – The Seven Wireless Wonders of 2000 were unveiled at the Wireless/Portable Symposium & Exhibition in San Jose, CA. Selection of the winning products was based on functionality, integration or miniaturization, expected impact on productivity and ease of use." Of the seven wireless wonders, six operate on wireless phone networks, and are shown above. All are prohibited for use on aircraft per Advisory Circular (AC) 91.21-1, but only one looks like a wireless phone.

Neither of the RTCA reports addressed the issue of wireless phone spurious radiated emissions into aircraft communication and navigation radio frequency bands. Coincidentally, wireless voice and data radios are being integrated into multifunction packages, often making it difficult for flight crews and passengers to identify them as intentional transmitters. (Figure 2.1 provides a good example of this recent proliferation.) Thus, as the RTCA/DO-233 recommended prohibition of portable transmitter operation during flight is becoming less enforceable, the lack of technical analysis regarding wireless phone threat to aircraft radios is becoming more critical.

On the other hand, most new-technology portable transmitters incorporate spread-spectrum techniques and/or transmit power control for improved signal quality, range and capacity. These techniques tend to reduce the potential for interference between devices, including nearby equipment. It is reasonable to suspect that certain new-technology transmitters may be no more threatening to aircraft systems than unintentional transmitters.

"New wireless technology" can (currently) be divided into three categories: wireless phones, wireless LANs, and UWB devices. Within these categories, there are numerous technology implementations. Each implementation has unique time- and frequency-domain characteristics. While the radiated emissions from these devices are well regulated for typical consumer applications, existing product certification standards are inadequate to assure that spurious radiated emissions do not interfere with aircraft communication and navigation receivers. In order to achieve an interference risk assessment, it is necessary to quantify: 1) the radiated emission characteristics of each device technology; 2) the RF coupling characteristics between passenger cabin locations and aircraft receiver antenna locations; and 3) aircraft receiver interference susceptibility characteristics.

Various aviation-industry companies have initiated efforts to study new-technology wireless devices in an effort to provide enhanced services to travelers, while minimizing interference potential. In June 2000, NASA entered into a three-year cooperative agreement with DAL to study EMI threat factors and evaluate operational policies to ensure the availability of aircraft communication and navigation systems while maximizing passenger freedom in using PEDs. The NASA/DAL effort provided useful data for addressing all three interference risk assessment factors, and will continue into 2003 with operational assessments and policy recommendations, regarding PED usage by passengers on aircraft.

In June 2000, the FAA contracted with the UOK Center for Wireless EMC to study the radiated emissions from select wireless phones in aircraft communication and navigation frequency bands. The purpose of this project was to quantify spurious emission levels of wireless phones and estimate the possible effect of those emissions on aircraft navigation and communication equipment. The UOK effort established a basis for measuring wireless handset spurious radiated emissions, but was limited in the number of operating modes evaluated and the ability to obtain high-sensitivity measurements quickly.

2.2 Objective

The primary objective of this work was to develop a radiated emission measurement process for CDMA (IS-95) and GSM (ETSI GSM 11.22) wireless phones, and provide a preliminary risk assessment for their potential interference to aircraft LOC, GS, VOR, and GPS radio receivers. The secondary objective was to develop a comprehensive technology assessment and follow-on research plan for quantifying the threat of other new-technology wireless transmitters to aircraft radio receivers.

2.3 Approach

This measurement and analysis project included a teaming arrangement between NASA LaRC and the UOK Center for Wireless EMC. NASA LaRC coordinated and managed the effort, provided EMI measurement facilities and instrumentation, developed radiated emission procedures usable in both semi-anechoic and reverberation test chambers, and applied aircraft coupling and receiver sensitivity data from reference documents and other NASA programs. The UOK staff provided a detailed analysis of wireless phone transmission characteristics, commercial measurement standards and operational modes, and provided and operated test phones and base-station simulators for exercising the various phone operational modes.

The complete study was divided into two tasks: wireless phone threat assessment to aircraft radio receivers and a comprehensive technology assessment. A brief description of each task follows.

Task 1: Comprehensive Technology Assessment

A comprehensive technology assessment for the portable wireless transmitter threat to aircraft communication and navigation systems was performed. While Task 2 establishes a process by which particular wireless transmitters (CDMA and GSM phones) can be evaluated for their threat to particular aircraft navigation systems, Task 1 assesses the current state of wireless communication and network devices that may be used on aircraft, and predicts trends for the next several years. Future study is proposed to address other wireless technologies, including wireless phone standards (i.e., Advanced Mobile Phone System-AMPS, Total Access Communications System-TACS, Digital Communication System-DCS, PCS, Personal Digital Cellular-PDC, etc.) wireless LAN standards (IEEE 802.11, Bluetooth), and UWB transmitters. Future study is proposed for other aircraft communication and navigation (nav) systems, including DME, VHF communication (comm), TCAS, and satellite communications (SATCOM). As a result of this technology assessment, Task 1 outlines a plan for extending the test and analysis process used in Task 2 to include other wireless technologies and other aircraft communication and navigation systems.

Because of the specialized and proprietary nature of portable wireless transmitters and avionics receivers, this task involved coordination between manufacturers, industry committees, academia, and government agencies. This task evaluated some new wireless products (with initial emphasis on wireless LANs), established contacts with manufacturers and industry associations, and initiated a process to identify opportunities for teaming with organizations outside government. The Task 1 effort is addressed through Sections 3 and 4 of this report.

Task 2: Wireless Phone Threat Assessment to Aircraft Radio Receivers

A radiated emission measurement process was developed for CDMA (IS-95) and GSM (ETSI GSM 11.22) wireless phone standards. These standards are widely implemented, and form the basis for many new-generation technologies. The spectral and temporal modulated signal characteristics for these standards were investigated, and a comprehensive test process to quantify their spurious emissions in aircraft LOC, GS, VOR, and GPS radio receiver frequency bands was generated. These navigation radio bands are of particular interest due to their critical role for limited-visibility, low-altitude operations, and documented receiver sensitivity characteristics. Specialized keypad entry codes and base station simulation equipment were used to exercise all modes of wireless phone operation. The radiated emission characteristics of each operating mode were compared. Operating modes that are likely to produce the most severe emissions from various models of wireless phones within each standard were identified. Radiated emission measurements were performed in both semi-anechoic and reverberation test facilities, and the advantages and limitations of each are documented. Existing estimates of path loss (measured data from the ongoing NASA/DAL/EWI (NCC-1-381) measurement programs, and calculated/measured data from the RTCA/DO-199 and RTCA/DO-233 efforts) from PEDs to aircraft antennas were evaluated for the specified radio-receiver frequency bands. Existing data for interfering signal level required for corruption/denial of data on aircraft navigation radio systems were evaluated. The Task 2 effort is primarily addressed in Section 4 of this report.

2.4 Report Organization

This report is organized as follows: Section 2 provides an introduction and summary of the research work, Section 3 provides an overview of current wireless technology on aircraft and an overview of current technology standards, Section 4 presents measured data for Tasks 1 and 2; Section 5 provides recommendations for follow-on research efforts, Section 6 lists appropriate references; and, finally, the appendices provide lists of acronyms, variables, and definitions, descriptions of measurement procedures and plots of measured data.

3 Wireless Technology on Aircraft: Status and Forecast

3.1 Wireless Overview

Fixed and portable wireless technology is quickly extending into homes, offices, and public areas, such as airports and hotels providing consumers with an array of choices to accommodate mobility and communication requirements. Technology standards are constantly evolving and new devices are continuously coming to market. Radio-based wireless devices are linked together to establish networks that provide intercommunication with similar devices forming Wireless Personal Area Networks (WPANs), including connections to outside networks, forming wireless local area networks (WLANs). Wireless networking devices provide convenient access to company resources, email, and the Internet. PEDs enabled with wireless components have the capability to intercommunicate through wireless networks and to directly communicate with other wireless devices within range.

The more popular wireless technologies today are based on standards developed within the IEEE standards association, with industry cooperation, in an effort to promote compatibility and interoperability among devices produced by different manufacturers. Figure 3.1 illustrates the evolution of network standards within the IEEE 802 Local and Metropolitan Area Network Standards Committee from LANs to WLANs. IEEE 802.11a, IEEE 802.11b, Bluetooth, and Zigbee technologies follow standards from the IEEE 802 family of standards and the IEEE 802.11 wireless standards. Each technology offers unique capabilities, optimizations, and techniques in the Physical (PHY) and Data Link Layers (DLL) of the Open Systems Interconnection (OSI) Basic Reference Model. The PHY and the DLL are the lower two layers on the network protocol stack. Standards vary the specification of operating parameters, such as frequency band, allowable maximum power, and data rate. Table 4 illustrates the basic characteristics of these technologies. The selection of a particular type of device or standard is based on application, cost, and system objectives.

3.1.1 IEEE 802.11

The IEEE 802.11 standard was developed by the IEEE 802.11 Working Group for Wireless Local Area Networks and published in 1997 to define the operation of WLANs. Sometimes referred to as "Wireless Ethernet", it specifies requirements for wireless systems concentrating on the PHY and DLL layers of the OSI model. The standard actually encompasses several specifications, which are differentiated in the PHY. The PHY is responsible for transmitting messages and utilizes either Direct Sequence Spread Spectrum (DSSS) or Frequency Hopping Spread Spectrum (FHSS) modulation modes as defined by the standard. In the 802.11 specifications, the data rates are limited to one Mbit/sec, and if FHSS modulation is used, the limit is two Mbit/sec. System operations such as frequency bands,

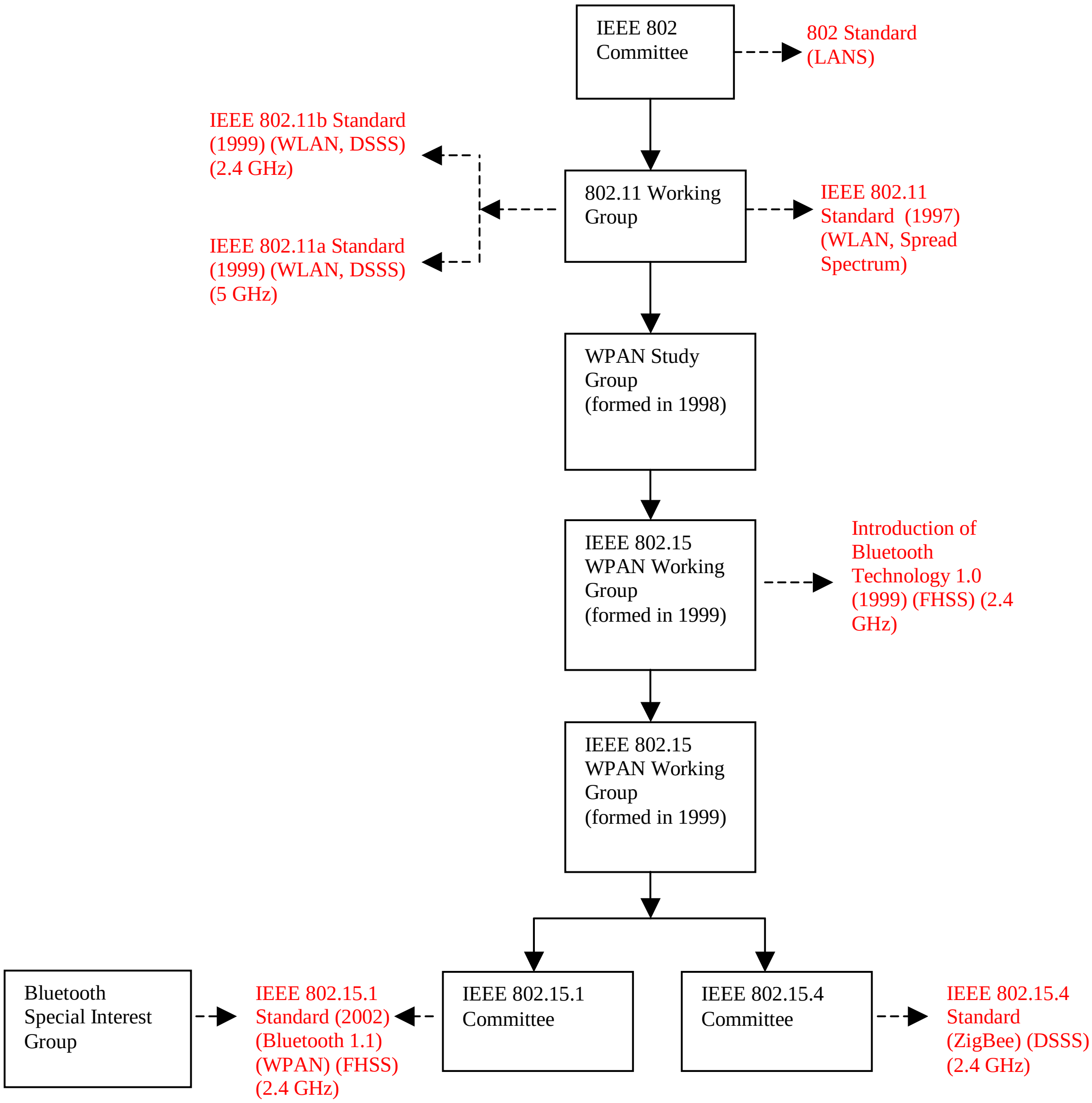


Figure 3.1: Wireless Technology Organization

allowable maximum power levels, and in-band and out-of-band spurious emissions are subject to local and FCC regulations.

802.11 systems function in one of two modes, ad-hoc or infrastructure. In infrastructure mode, a system or Basic Service Set (BSS) employs at least one Access Point (AP) connected to a wired network and several stations. An AP is the bridge between the wireless and wired networks. An extended BSS incorporates two or more BSS configurations. Ad-hoc or peer-to-peer modes allow stations to communicate directly, since no AP is required in an Independent Basic Service Set (IBSS).

The DLL is composed of two sub-layers: a Logical Link Control (LLC) and a Media Access Control (MAC). The LLC controls addressing and provides linking protocols. The MAC controls and manages the types of data services, security, communication protocols, roaming, and power conservation. The management protocols contribute to the robustness of a system, but also add to the overhead and can result in reduced data rates. The MAC layer is responsible for associating the client with an AP and managing the process for a client to join a BSS. The MAC supports power conservation by employing two modes. In the Continuous Aware Mode, the client is always on and "awake". In the Power Save Polling Mode, the client is "dozing", power is reduced, and the AP queues client data. Periodically the client wakes up to receive a beacon signal from the AP and determines if there are data waiting. If data are waiting, it receives the data, otherwise, it returns to "dozing".

Security is provided by the MAC layer, which utilizes authentication and encryption methods. Encryption mechanisms employ the Wired Equivalent Privacy (WEP) security technique. Further security may be integrated into a system and is available if needed, as current standard security specifications are deficient for particular situations. Authentication is the process of verifying a station is authorized to communicate with another station or AP.

Table 4: Wireless Technology Parameters

Wireless Technology	Class	Maximum Output Power	Frequency Band	Typical Distance Range	Maximum Data Rate	Modulation Mode	Standard	Application
Bluetooth	Class 1	100 mW/20 dBm	2.4 - 2.4835 GHz	100 m	1 Mbps	FHSS	IEEE 802.15.1 & Bluetooth SIG	WPAN
	Class 2	2.5 mW/4 dBm	2.4 - 2.4835 GHz	15 m	1 Mbps	FHSS	IEEE 802.15.1 & Bluetooth SIG	WPAN
	Class 3	1 mW/0 dBm	2.4 - 2.4835 GHz	10 m	1 Mbps	FHSS	IEEE 802.15.1 & Bluetooth SIG	WPAN
802.11b	NA	1000 mW *	2.4 - 2.4835 GHz	24 m	1 Mbps	DSSS	IEEE 802.11 & WECA	WLAN
					2 Mbps	DSSS		
					5.5 Mbps	DSSS		
					11 Mbps	DSSS		
802.11a	NA	800 mW**	5.15 - 5.25 GHz 5.25 - 5.35 GHz 5.725 - 5.825 GHz	50 m	6 Mbps	DSSS	IEEE 802.11	WLAN
					12 Mbps	DSSS		
					24 Mbps	DSSS		
					54 Mbps	DSSS		
Zigbee	Class 1	100 mW	2.4 GHz	10 m	200 kbps	DSSS	IEEE 802.15.4	WPAN
	Class 2	100 mW	2.4 GHz	50 m	10 kbps	DSSS	IEEE 802.15.4	WPAN

* 1000 mW complies with FCC 15.247
** See Reference 39

3.1.2 IEEE 802.11b

The IEEE 802.11b standard provides location-independent access to an outside network between wireless data devices, including intercommunication on a local scale. Primarily an extension of the 802.11 standard, it defines additional operational parameters for high-rate data transfers on WLANs, while maintaining 802.11 protocols. In 1999, the IEEE 802.11 committee ratified 802.11b as an amendment to the 802.11 standard. The 802.11b standard supplements 802.11 by extending the PHY and MAC specifications, which enables it to provide high-speed network access and data rates. In addition, 802.11b includes optional modes and capabilities for future technology and interoperability. The Wireless Ethernet Compatibility Alliance (WECA), composed of industry WLAN manufacturers and leaders, promotes compatibility and interoperability of 802.11b products through development of the Wireless Fidelity (Wi-Fi) standard. Products that qualify receive Wi-Fi identification, verifying compliance with the 802.11b standard.

In the PHY, 802.11b utilizes a DSSS modulation mode as defined by 802.11, and advanced coding techniques to achieve higher data rates of 5.5 Mbit/sec and 11 Mbit/sec. The coding techniques employ different modulation schemes at different data rates. If distances between devices are great or interference is heavy, 802.11b devices will revert to data rates of 1-2 Mbit/sec. Utilizing dynamic rate shifting allows data rates to automatically change to compensate for noisy environments and extended range. If greater interference is experienced by a system, the data rate will be reduced to maintain signal integrity.

802.11b operates in the unlicensed 2.4-GHz Industry, Scientific, Medical (ISM) band. While three of the 14, 22-MHz channels are non-overlapping, 11 of the channels do partially overlap. The ISM band is also shared with Bluetooth devices and microwave ovens, which could cause interference with 802.11b devices. The FCC allows a maximum output power of 1000 mW. However, if a power level greater than 100 mW is used, then power control must be provided by the system [35]. A distance range of 100 m is typical, but ranges are dependent on environmental obstacles and power.

802.11b WLANs appear in healthcare facilities, college campuses, corporate offices, conference rooms, airports, and other public areas providing access to business and network resources. A typical application of 802.11b technology is a wireless network interface card (NIC) inserted into a laptop expansion slot. The NIC converts the laptop to a wireless PED capable of intercommunication with other wireless devices or APs. The wireless NIC is composed of a radio transmitter, a baseband unit, and application software. The laptop, traditionally a nonintentional transmitter PED, then becomes an intentional transmitter PED, and is referred to as a station. In a WLAN topology, a station can also be an appliance or client with embedded wireless components.

Given the interest of industry, it is also conceivable that an 802.11b wireless network may be installed within an aircraft, offering passengers local access, including access to outside networks. Further research and analysis is needed to assess the risks to flight-critical systems by operational wireless LANs within aircraft, and to determine the effect of specialized signal encoding and modulation techniques employed by radiating wireless components on the generation of spurious radiated in-band and out-of-band emissions. The power levels and frequency-of-occurrence of spurious signals are of concern when evaluating risk factors to critical avionic systems. While signal parameters such as power limits are regulated by FCC standards for consumer usage, the power-level limits may not be adequate for protection of critical avionic systems.

3.1.3 IEEE 802.11a

IEEE 802.11a, another 802.11 variant, is a very high-speed, high-bandwidth standard that followed the 802.11b standard. Similar to the 802.11b standard, it defines WLAN operating parameters to provide access to outside networks for wireless devices, including local intercommunication. However, unlike 802.11b, it operates in the 5-GHz frequency band and uses advanced modulation techniques to achieve a typical data rate of 24 Mbits/sec. The 802.11a standard requires that data rates of 6, 12, and 24 Mbits/sec must be supported; however, maximum rates of 54 Mbits/sec are common. Each data rate uses a particular modulation technique to encode data. Wireless devices employing the 802.11b standard are not compatible with 802.11a devices. Operating in the 5-GHz band, 802.11a devices avoid the interference potential experienced by 802.11b devices, but at the cost of a reduced communication range.

Allowable power levels are defined at three specific frequency bands with a maximum power level of 800 mW at 5.7 to 5.8 GHz [34]. A typical home application of transferring audio or video data from a Compact Disc/Digital Video Disc (CD/DVD) player to a computer is an example that demonstrates its high-speed capability. Both the higher data rate and the reduced interference potential make 802.11a attractive to corporate business offices as a replacement for 802.11b systems. The same EMI issues regarding aircraft avionics expressed earlier in this report also apply to 802.11a components and systems.

3.1.4 Bluetooth

Bluetooth is a short-range radio technology with the capability to link together different wireless devices for data and limited voice communication. As a result, users are independent of device cables and proprietary protocols. Bluetooth is more widely used for intercommunication of local devices and is favored for its ease of use, low power consumption, and low cost. While Bluetooth is more efficient for local intercommunication, it can provide a link to other networks or outside devices via phone or wide-area network infrastructures. Devices with integrated Bluetooth chip sets are designed to interconnect seamlessly and to automatically synchronize with each other when within transmission range. The features of the Bluetooth standard support robust systems with low complexity, low cost, and low power requirements. The specification allows for three power classes as illustrated in Table 4. Power control is required for devices utilizing Power Class 1 levels. At power levels over 1 mW, devices must be able to control and limit the transmit power. However, for power levels less than 1 mW, power control is optional [38].

Bluetooth units operate at a frequency band of 2.4 to 2.4835 GHz, with a maximum data rate of 11 Mbits/sec, and a power level of 1 mW up to 100 mW. The nominal distance between devices is 30 cm to 30 ft (10 m); however, greater distances are achieved with higher power. It uses signal-encoding schemes combined with FHSS techniques for data transmission [37]. A Bluetooth transmitter hops among 79 frequencies at a rate of 1600 hops per sec. FHSS provides data security and a decrease in interference from other wireless devices.

In 1998 the IEEE 802.11 Working Group formed the WPAN Study Group. They were tasked to investigate the need for wireless network standards to support low-power wireless devices, such as those carried or worn by a person. In 1998 the Bluetooth Special Interest Group (SIG) was formed. This group is composed of leading wireless technology industry leaders that are interested in guiding the development of a specification for implementing the Bluetooth technology. One of their goals is to achieve interoperability among wireless devices, and thus, make Bluetooth devices attractive to product developers and businesses. The Bluetooth specification requires device manufacturers to comply with a minimum set of requirements to ensure interoperability. In order for a device to display a Bluetooth logo, it must comply with the specification. The logo signifies that a device is able to recognize and communicate with other Bluetooth-compliant devices.

In 1999 the WPAN study group reorganized into the IEEE 802.15 WPAN Working Group. The Bluetooth protocol was first introduced in 1999. It borrows features from other wireless standards such as Infrared Data Association (IrDA), IEEE 802.11, and Digital Enhanced Cordless Telecommunications (DECT). Currently, there are four IEEE 802.15 standards committees. The 802.15.1 project is concerned with WPAN and Bluetooth technology and standards. The 802.15.1 group and the Bluetooth SIG worked cooperatively to establish a Bluetooth standard, which was approved in March 2002 [38-39].

Bluetooth-enabled wireless devices found in an office may include computers and peripheral devices, printers, cell phones, personal digital assistants (PDAs), and fax machines. When Bluetooth devices are interconnected locally, they form a PAN. In a home, kitchen appliances, light controls, phones, headsets, MP3 players, and heating and air conditioning controls can have embedded Bluetooth chips allowing these devices to intercommunicate. Using Bluetooth technology, several applications can intercommunicate simultaneously, performing various functions. The application software included within the Bluetooth system provides the specialized functionality for each device.

Bluetooth technology utilizes point-to-point and point-to-multipoint network topologies. When devices are within 10 m of each other, they can intercommunicate locally through an ad-hoc or peer-to-peer network. Only two devices are necessary for a connection to occur, or one device may act as master to many other slave devices. Figure 3.2 illustrates a Bluetooth ad-hoc network, where laptop personal computers (PCs) and a PDA intercommunicate with each other, and with a printer. The printer lets the other devices know it is present to establish a connection.

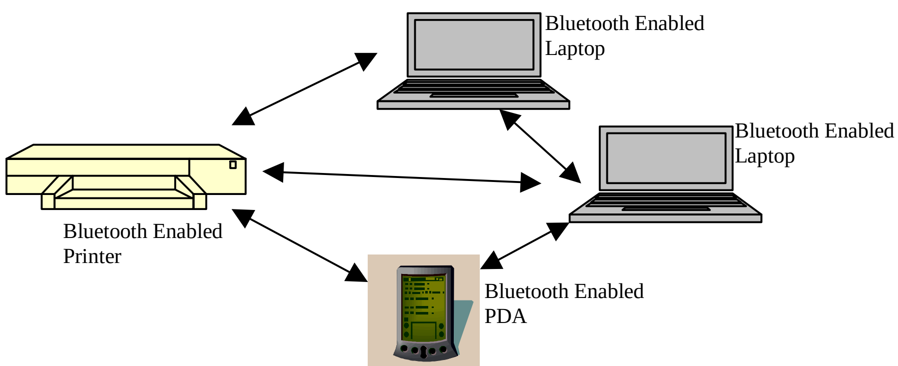


Figure 3.2: A Bluetooth ad-hoc network.

Up to eight devices can form a mini-network known as a piconet. If a device is not currently part of a piconet, it constantly "listens" for other devices. When another device is detected, the "listening" device will send an identification number to establish communication. Only the predetermined devices are allowed to interconnect. Devices on a piconet are synchronized to the same frequency-hopping sequence, where at least one device is a master and one device is a slave. Two piconets form a scatternet, but each net can still operate in close proximity with little interference because each has a different frequency-hopping sequence.

Bluetooth devices that are unconnected are in a standby mode. They periodically "listen" for other devices, wait, and then send and receive data. The "listening" process is called page scanning. Devices listen for their own identification code transmitted from another device. Inquiry scanning is a process used by a receiving device to look for access codes to determine if other units are within range. If scanning procedures are successful and a connection is made, then the devices are in an active mode and can participate on the channel. Bluetooth units are designed to maximize battery life by using power-saving modes. When not "listening" or actively transmitting and receiving data, a Bluetooth module can be in one of three power conservation states that include sniff, hold, and park. In a sniff state, a slave device decreases its "listening" rate. A module can be idle and in a hold state. If a Bluetooth module is still actively in a piconet and synchronized, but not transferring data, it is in a park state.

The Bluetooth system consists of a radio unit that sends and receives data, and a baseband unit that implements linking protocols, software stack, and application software. NICs with Bluetooth chip sets are inserted into electronic devices, such as laptop computers, to provide intercommunication with other laptops, printers, peripherals, and a host of other Bluetooth devices. Embedded Bluetooth systems will be at the core of new technologies by providing transceivers built into cell phone units that will be components of future multi-function mobile wireless devices. Further research and analysis is needed to assess the effect of emissions produced by transmitting Bluetooth devices on flight-critical systems.

3.1.5 ZigBee

ZigBee, which complies with the IEEE 802.15.4 standard, was designed for command and control in industrial environments and home automation. ZigBee provides technology for another wireless network based on DSSS operating in the populated 2.4-GHz ISM band. An advantage to ZigBee is that it consumes very little power; therefore, battery life for a Class 1 device is six months, and two years for Class 2 devices. The specifications for Class 1 are: a 200 kbits/sec data rate and a 10-m coverage area. Class 2 specifications are: a 10 kbits/sec data rate and a 50-m coverage area. Essentially, the coverage area is a complete single or multi-family residence.

Three network topologies exist for ZigBee; master-and-slave, peer-to-peer, and mesh mode. The master-and-slave and peer-to-peer modes are similar to previously described networks. Mesh mode is defined as a network established by a ZigBee device when it cannot see all other ZigBee units that exist on a network, and yet it can connect to the nearest neighbor. Eventually, other devices join a network when they are activated and within range. A ZigBee network, which supports up to 128 network-aware client devices at any given time, can consist of eight concurrent connections between client devices. Products such as light switches, smoke detectors, thermostats, toys and games, security and home-automation applications, are ideal for this technology.

3.1.6 2.5G Wireless Voice and Data Communications

The latest mobile communication technology, or intermediate second-generation (2.5G) technology, builds upon the existing second-generation (2G) digital mobile communication technology (see Figure 3.3). GSM communication, TDMA, and CDMA are the three existing 2G standards. TDMA divides a single radio frequency into numerous time slots where each call is assigned to a specific slot for transmission. With rapid switching, callers believe they are exclusively using the channel. CDMA gives a unique code to each user, and the signals from all the users can be spread over a wide frequency band. This technique of spreading a signal over a wide frequency band is known as spread spectrum, which is resistant to interference and is difficult to jam. Since GSM uses TDMA as its radio transmission technology, 2.5G has only two migration paths.

The 2.5G technologies improve data transfer rates in current digital technologies by implementing packet switching capability. Packet-switched networks divide the telephone conversation/data downloads into discrete "packets" that are sent across a path (circuit) containing an empty slot. A header with the destination address is attached to each packet. Packets arrive at different times because of the various routes each one takes. Upon arrival at their destination, they are reassembled in the correct order by a packet assembler. This approach is acceptable with the use of data downloads, since a tiny delay is hardly noticed. However, a tiny delay is very noticeable in voice transmission. Packet switching does not have a dedicated channel for the entire session. Packets are sent only when callers are speaking; and, during a pause in the conversation, the channel is filled with packets from another conversation. This system permits an "always on" connection because it doesn't monopolize the entire circuit, which is the key for a faster data rate.

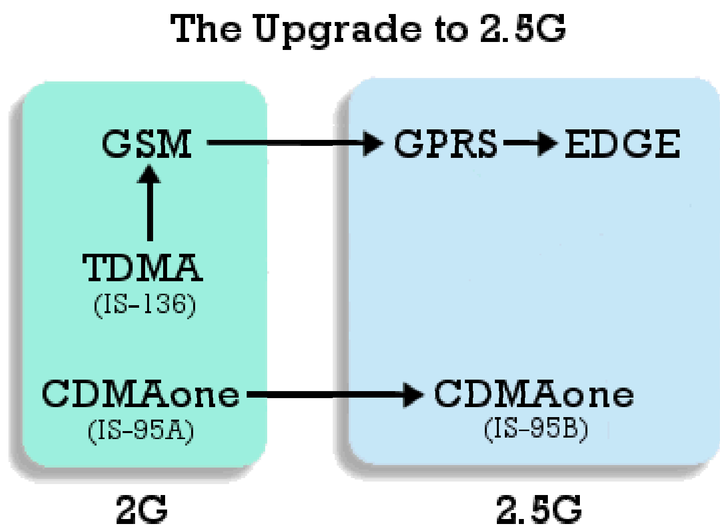


Figure 3.3 Migration Path from 2G to 2.5G (from www.three-g.net).

General Packet Radio Service (GPRS) is an upgrade of GSM technology, and is based on a circuit-switched network (requires a dedicated channel for voice). With GPRS, a user can field a phone call while using wireless data. In this case, data are paused while the user chats, and then data resume when the call is terminated. The maximum data transfer rate is 115 kbps, but a transfer rate of about 35 kbps is typical.

Another upgrade from GSM is Enhanced Data for Global Evolution (EDGE), also known as UWC-136. The advantage of EDGE over GPRS is that it has three times the data capacity to handle more subscribers and a tremendous amount of data traffic. EDGE networks offer voice, data and real-time services to areas with high population density at a maximum date transfer rate of 384 kbps.

The CDMAone (IS-95B) standard will incorporate the packet-switch capability to achieve a maximum data rate of 115 kbps.

3.1.7 3G Wireless Voice and Data Technology

The International Telecommunication Union (ITU) created the IMT-2000 standard with the intent to harmonize the proposed 3G systems for seamless global roaming. Wideband CDMA (W-CDMA), CDMA 2000, TD-CDMA/TD-SCDMA are the three options capable of being full 3G solutions, since they provide full network coverage over macro (entire city), micro (inner city), and pico (building) cells (See Figure 3.4).

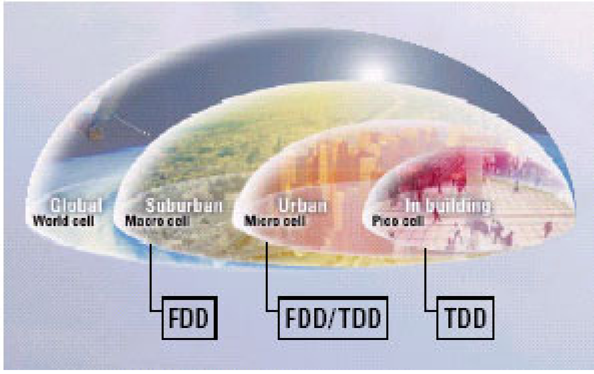


Figure 3.4 Classification of areas the separate technologies can cover (from www.siemens.com/Daten/Produkt/2001/05/23/Fdd_tdd.pdf).

W-CDMA is also known as Universal Mobile Telephone System (UMTS). This is the European and Japanese successor of GSM. UMTS has two terrestrial sub-categories called UTRA (UMTS Terrestrial Radio Access) frequency division duplex (FDD) and Time Division-CDMA (TD-CDMA). The FDD component of UTRA is based on the W-CDMA standard requiring paired spectrum, while the time-division duplex component of UTRA uses unpaired spectrum technology.

China collaborated with Siemens to develop its own Time Division Duplexing (TDD) 3G standard similar to TD-CDMA called Time Division Synchronization CDMA (TD-SCDMA). "Terminal synchronization" techniques are used to eliminate the uplink/downlink interference, which affects other TDD methods.

The US' answer to the evolving generations of faster voice and data transfer rates is CDMA2000, which is based on CDMAOne standard. CDMA2000 has two phases: 1) 1Xratio Transmission Technology (1XRTT) with a maximum data rate of 144 kbps; and 2) 3XRTT with a maximum data rate of 2 Mbps. Upgrades will continue with this standard until it achieves data and voice integration on the same frequency.

A 3G device is a multi-functional unit that will use voice, wireless email, Internet surfing, video-conferencing, and access to your business network, e-commerce, and multimedia. All these features will be packaged into a small compact size (see Figure 3.5). Table 5 shows a comparison between the 2.5 and 3G technologies.

Figure 3.5 Two conceptual examples of 3G-enabled wireless phones.

Table 5: A Comparison of 2.5G and 3G Technologies

Technology	Generation	Data Transfer Rate (bps)	Frequency Bandwidth	Group In Charge of Standardization
GPRS	2.5	115k		
EDGE	2.5	384k		UWCC/TR45
CDMAone (IS-95B)	2.5	115k		
W-CDMA (UMTS)	3	2M	1920-1980 MHz 2110-2170 MHz	3GPP
TD-CDMA/ TD-SCDMA	3		1900-1920 MHz/ 2010-2025 MHz	
CDMA 2000	3	384k (mobile)/2M (fixed)	TBD	3GPP2

3.2 EMI Standards for Consumer Products versus Airborne Equipment

3.2.1 Commercial Product Standards for Spurious Radiated Emissions

In the US, the FCC provides guidance for allowable signal emissions from consumer devices. These are published and available on the Internet, in the US CFR, Title 47 “Telecommunication”. Within Title 47, there are numerous “Parts” and “Sections” that address the full range of available product types. For example, to find guidance on spurious radiated emission limits for unlicensed, unintentional transmitters, FCC Part 15, Section 109 (or FCC 15.109) should be referenced. (Title 47 is implied by the “FCC” designation.) FCC 15.31 “Measurement Standards” specifies IEEE/American National Standards Institute (ANSI) C63.4 [27] as a measurement method for testing intentional and unintentional radiators. Table 6 identifies FCC regulations addressing spurious radiated emissions from several device types that passengers typically carry onboard aircraft.

In Europe, the International Electrotechnical Commission (IEC) provides guidance for allowable signal emissions from consumer devices. Measurement methods and test limits are provided in the IEC CISPR 22 publication. To promote free trade and facilitate technology transfer across international boundaries, the US and European Union (EU) have Mutual Recognition Agreements (MRA) which harmonize measurement processes and test limits for spurious radiated emissions. Most other nations recognize or adopt either the US or EU requirements.

In any case, these product standards address devices intended for use in residential, commercial, and industrial or business environments. Both the US and EU further designate “Class A” and “Class B”, where Class A devices are not intended for use in residential environments. Most consumer products are certified to the more rigorous Class B requirements. Table 6 provides a summary of spurious radiated emission limits for all common PEDs, including wireless voice and data transmitters (like wireless phones and LANs). It can readily be seen that there are numerous different criteria for spurious radiated emissions from consumer devices. Some are defined in terms of electric field intensity (µV/m, dBµV/m), and some in terms of power (dBm). In addition, many of the guidelines utilize different processes for measuring maximum amplitude (i.e., peak, quasi-peak, power, maximum peak output power, mean power). CISPR 22 states that “the significance of the limits shall be that on a statistical basis at least 80% of the mass-produced equipment comply with the limits with at least 80% confidence.” Clearly, there is much room for uncertainty in comparing these standards.

Table 6: A Summary of Certification Standards for Commercial Product Limits for Spurious Radiated Emissions

Standard	**Applicability**	**Limits**
FCC 15.109 Class B	Unlicensed Unintentional Transmitters	88 – 216 MHz: 150 µV/m @ 3 m 216 – 960 MHz: 200 µV/m @3 m Above 960 MHz: 500 µV/m @3 m
FCC 15.209	Unlicensed Intentional Transmitters	88 – 216 MHz: 150 µV/m @ 3 m 216 – 960 MHz: 200 µV/m @3 m Above 960 MHz: 500 µV/m @3 m
FCC 22.917	Cellular Wireless Phones	Attenuation, 90 kHz or more from carrier frequency: 43 + 10log(P) dB
FCC 24.238	PCS Wireless Phones	Attenuation, outside licensee frequency block: 43 + 10log(P) dB
FCC 95.857	Family Radio Service	Attenuation, outside assigned freq. segment more than 1250 kHz: 43 + 10log(P) dB
IEC CISPR 22	Information Technology Equipment Unlicensed Transmitters Acceptable alternative to FCC 15.109, 15.209	30 – 230 MHz: 30 dB µV/m @ 10 m 230 – 1000 MHz: 37 dB µV/m @ 10 m
GSM 11.10	GSM Wireless Phones	30 – 1000 MHz: -36 dBm 1000 – 4000 MHz: -30 dBm 1717 – 1785 MHz: -36 dBm (for DCS1800)
Bluetooth 1.1	Bluetooth Radio Specification	30 – 1000 MHz: -36 dBm 1000 – 12750 MHz: -30 dBm 1800 – 1900 MHz: -47 dBm 5150 – 5300 MHz: -47 dBm

3.2.2 Airborne Equipment (Civil) Standards for Spurious Radiated Emissions

In the US, the FAA provides guidance for allowable signal emissions from aircraft electronic systems. These are not directly stated in the US CFR (as with the FCC limits for consumer devices). Instead, 14CFR91.21 states that PEDs “may be used if the aircraft operator has determined that they will not cause interference with the navigation or communication system of the aircraft on which it is to be used” [8].

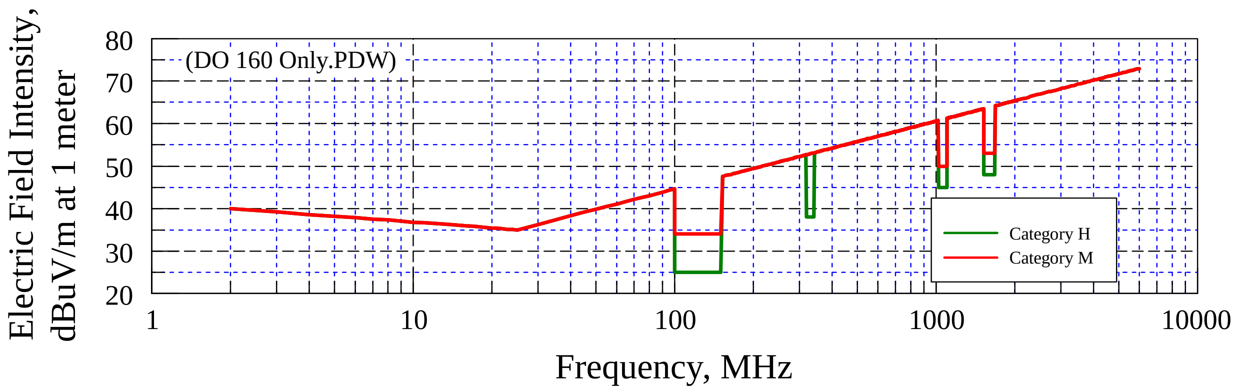


Figure 3.6: Spurious radiated emissions limits, at 1-m distance, for airborne equipment, RTCA/DO-160D, Section 21. (Identical to EUROCAE ED-14D.)

Further guidance is provided by AC91.21-1A, which states that designing and testing PEDs in accordance to RTCA/DO-160D [26] may constitute an acceptable assessment method to allow their operation onboard aircraft [9].

RTCA/DO-160D, Section 21 contains measurement procedures and test limits to determine whether electronic equipment emits excessive RF signals when installed in a particular location. The requirements are "harmonized" with The European Organisation for Civil Aviation Equipment (EUROCAE) ED-14 [40], and, therefore, technically identical and acceptable to Europe's Joint Aviation Authorities (JAA). Various equipment categories are defined in terms of location and separation between the equipment and aircraft radio antennas. The two categories applicable to potential PED locations are as follows:

Category M: Equipment and wiring located in passenger cabin and cockpit, not directly in view of aircraft radio receiver antennas.

Category H: Equipment and wiring located directly in view of aircraft radio receiver antennas.

While Category M appears to most directly address the situation of PEDs in the passenger cabin, the fact that such devices are mobile allow their positioning in optimal coupling locations within the passenger cabin. It is not uncommon for some aircraft to have antennas placed less than two meters in direct view of certain windows and door exits. Figure 3.6 shows the emissions limits for RTCA/DO-160D Category M and H. It should be noted that equipment to be installed in aircraft designs certified prior to 1997 may not be required to meet RTCA/DO-160D levels. However, only RTCA/DO-160D levels are given here as an indication of the most recent assessment of safe limits for airborne equipment. Since the DO-160D Category H limits would provide a greater margin in key frequency bands, these limits would be most applicable for ensuring non-interference with aircraft radios.

In summary, it is important to note that the goals and intentions behind commercial and airborne equipment standards are entirely different. Commercial product standards are mostly concerned with interoperability issues, whereas airborne equipment standards are primarily concerned with flight safety. Because the limits are specified differently (µV/m, dBµV/m, dBm), additional analysis is required to address their comparability.

3.2.3 Conversion Between V/m, μV/m, dB μV/m and dBm for Emission Standards

FCC Part 15 and IEC CISPR22 provide spurious radiated emission limits in terms of Electric Field Intensity (E) at a given distance. The basic units of E are Volts/meter (V/m). However, because the radiated emission limits are so low, units of either μV/m or dBμV/m are specified as follows:

$$1\,\mu\text{V/m} = 1 \times 10^{-6}\ \text{V/m} \qquad \textbf{Equation 3-1}$$

$$\text{dB}\,\mu\text{V/m} = 20\log[1 \times 10^{-6}]\,\text{V/m} \qquad \textbf{Equation 3-2}$$

Limits for spurious radiated emissions from intentional transmitters are usually specified as maximum output power (P*) levels at the antenna connector. The basic units of P* are Watts. However, again because the radiated emission limits are low, units of dB relative to 1 mW (dBm) are typically specified as follows:

$$\text{dBm} = 10\log[P^*/0.001],\ P^*\ \text{in Watts} \qquad \textbf{Equation 3-3}$$

It is possible to convert between field intensity and radiated power (P), if specific boundary conditions are specified. For example, if a "free space" environment is assumed (i.e., no reflections or electromagnetic variation in properties from nearby environment), Equation 3-4 can be used to compare E and P (see Figure 3.7).

$$P = [E^2 \times 4\pi R^2]/(120\pi D) \qquad \textbf{Equation 3-4}$$

where

P = Power radiated from antenna (W)
E = Maximum electric field intensity as specified in a plane at a distance R from the antenna (V/m)
R = Distance between point at which electric field intensity is measured/computed and point of antenna radiation (m)
D = Directivity

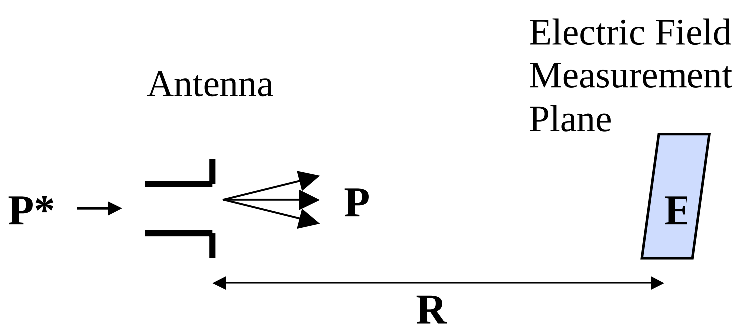


Figure 3.7: Diagram for relationship between applied power (P*) to an efficient antenna and the electric field intensity (E) at some distance (R) away.

Equation 3-4 addresses the E and P relationship, at some distance, for an antenna. It is important to note that the limits in Table 6 are specified for unintentional spurious radiated emissions, where the antenna is inadvertent, with unknown gain characteristics. It is, therefore, necessary to make assumptions about the directivity characteristics of various PEDs.

To estimate D for unintentional transmitters, a statistical theory developed to quantify uncertainties for radiated emission measurements performed in anechoic chambers can be applied. Assuming a device with a maximum overall dimension of 15 cm (typical wireless phone), the expected maximum measured directive gain for three relevant cases can be calculated [42]:

1. Intentional antenna with maximum possible directivity.

2. Directivity from unintentional radiator, sampling over 3 rotational planes.

3. Directivity from unintentional radiator, sampling over 1 rotational plane.

These calculations are shown in Figure 3.8. Case 1 provides an upper bound for an intentional, high-gain antenna that conforms to a maximum spherical diameter of 15 cm. Case 2 represents a thorough screening for characterization of directivity of an antenna. Case 3 represents standard practice for spurious radiated emission measurements according to IEEE/ANSI C63.4 and CISPR22. If the device maximum overall dimensions were to increase beyond 15 cm, the breakpoint for increasing directivity would occur at a lower frequency.

3.2.4 Commercial Product Standards Comparison to Airborne Equipment Test Limits

Applying the conversion equations and directivity estimates of Section 3.2.3 to the spurious radiated emission limits of Section 4.4.1, commercial product standards are directly compared to airborne equipment qualification standards in Figure 3.9.

In Figure 3.9, all limits were normalized to radiated power (P, in dBm) to allow direct application of aircraft path loss and receiver interference-level data. (Aircraft path loss is defined as the radiated field

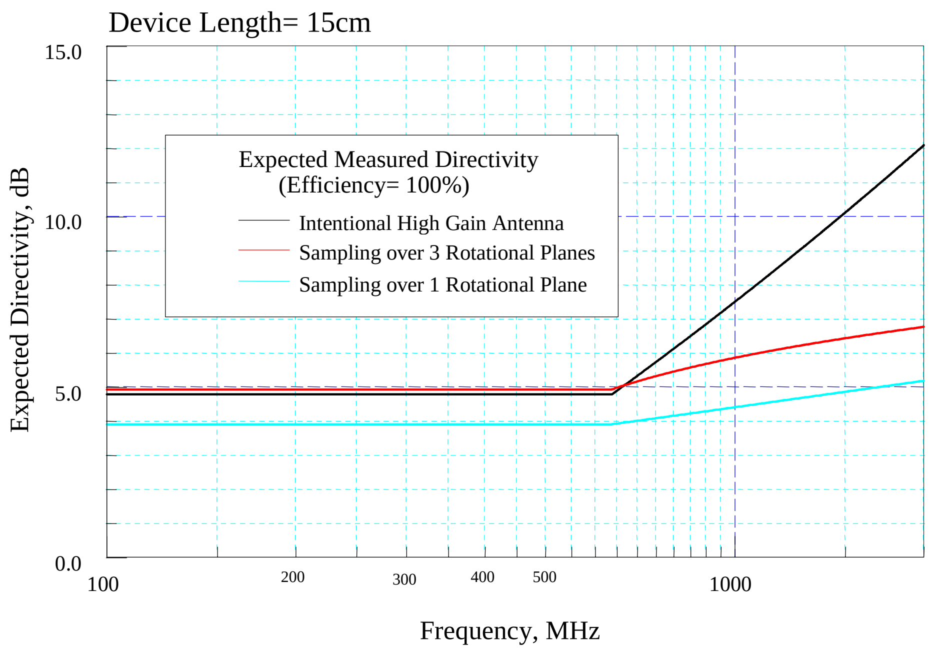


Figure 3.8 Comparison of expected directivity (referenced to isotropic radiator), using statistical estimates provided in [42].

attenuation between a PED, located in the passenger cabin of an aircraft, to the RF connection of a particular communication/navigation radio receiver.) RTCA/DO-233 [2] applied this approach for unintentional transmitters, which is equally applicable for intentional transmitters if their spurious radiated emissions are specified in units of E, at some distance.

Figure 3.9 clearly shows a large difference between allowable limits for spurious radiated emissions from consumer products versus airborne equipment. The difference is alarming when intentional

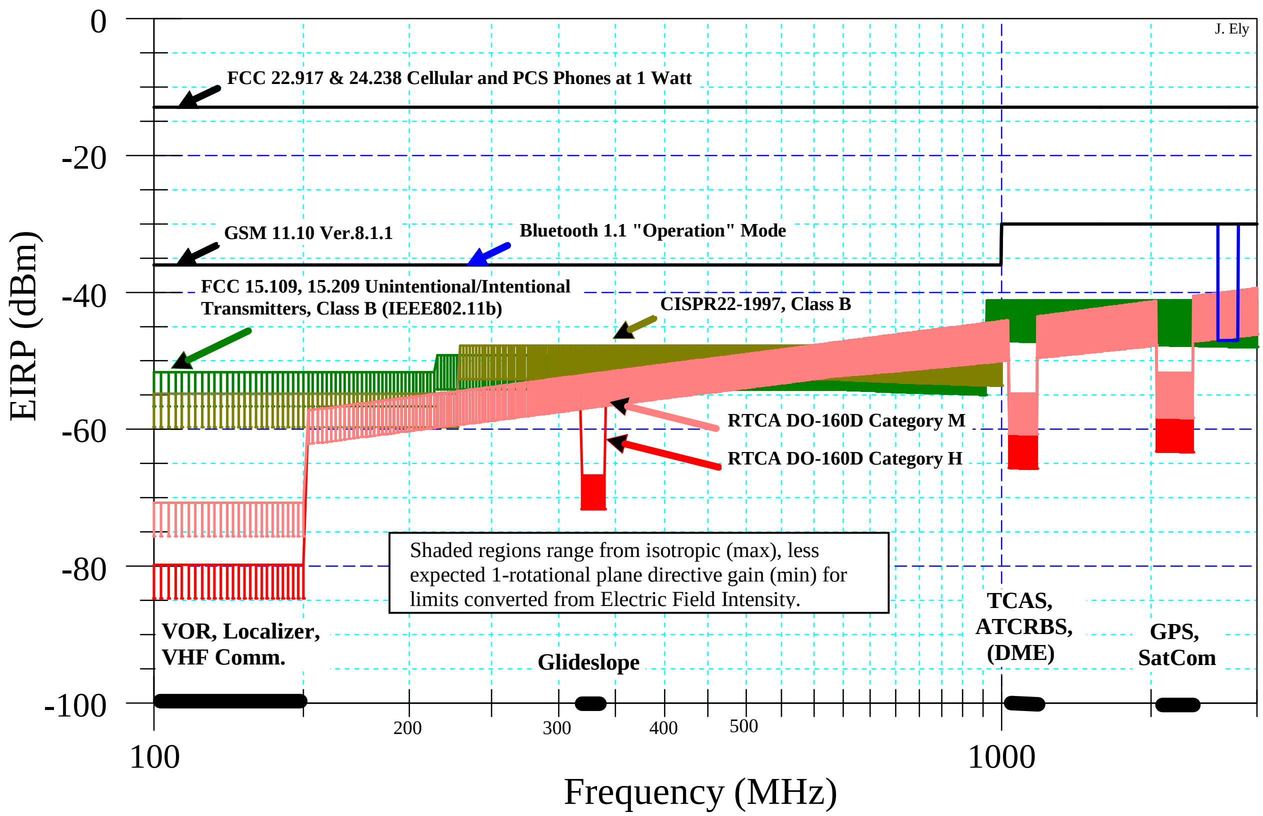


Figure 3.9: Comparison of spurious radiated-emission limits from consumer products versus RTCA/DO-160 qualification limits for airborne equipment. Aircraft radio frequency bands are shown along the bottom frequency scale.

transmitters such as cellular and PCS wireless phones are considered. In practice, however, wireless devices are rarely reported to cause EMI to aircraft systems. Device measurements at NASA LaRC have shown that typical wireless voice and data products radiate spurious signals in aircraft radio bands at levels far below commercial standards. While this is comforting, the best approach for PED usage policy must rely on “allowable”, rather than “typical” emissions levels.

The preceding analysis demonstrates that commercial spurious radiated-emission standards are not intended to provide protection to aircraft communication and navigation radio-frequency bands.

3.3 Ubiquitous Wireless and Unauthorized Use

3.3.1 Availability and Usage Trends

According to a survey by Dataquest, about 51% of domestic households owned a mobile phone in February 2000 [43]. According to the Cellular Telecommunications & Internet Association's (CTIA) Semi-Annual Wireless Industry Survey [44], wireless phone subscribers currently number over 137,000,000 in the U. S., and continue to increase at a rate of 17.3% annually. The same survey also indicates that the number of hours individual subscribers are talking on their phones has increased about 42% annually (from 2000 to 2001). Figure 3.10 shows estimated subscribers and minutes of use.

The Windows XP operating system now includes native support for IEEE802.1x and Bluetooth devices [45]. The Linux operating system also includes support for IEEE802.11, and Bluetooth support via BlueZ, the official Linux Bluetooth protocol stack [46]. PCWorld.com's "Top 15 Notebook PC's",on October 7, 2002 showed five units with built-in 802.11b functionality, and one with built-in Bluetooth functionality [47]. IEEE802.11 and Bluetooth PC card adapters have been available to fit any notebook computer (and most PDA's) for many months.

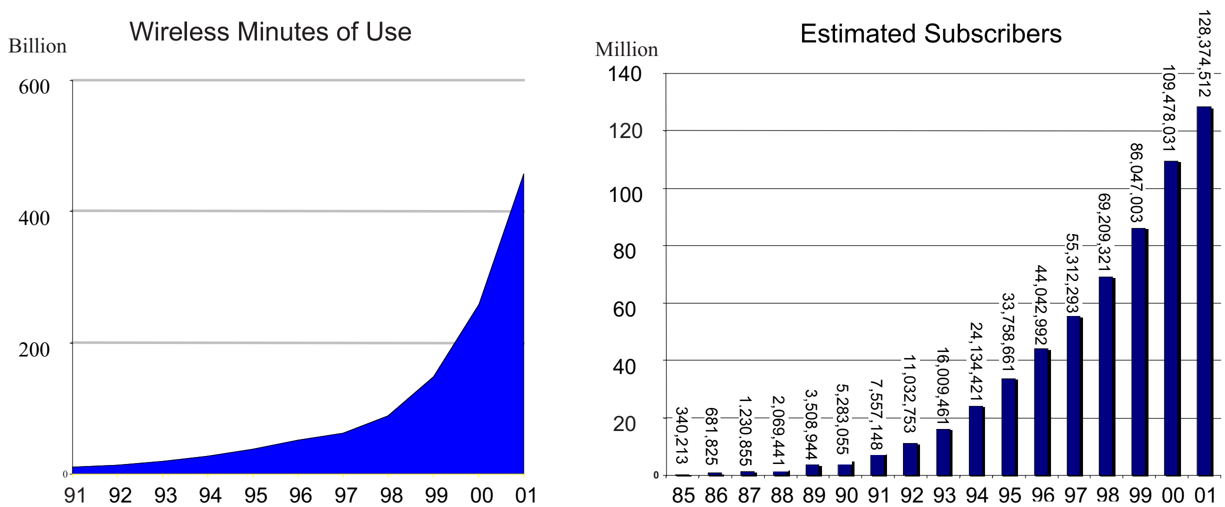


Figure 3.10: Estimated number of U. S. wireless phone service subscribers and total minutes of use, from the CTIA's Semi-Annual Wireless Industry Survey (used with permission from the CTIA, available at http://www.wow-com.com/pdf/CTIA2001Survey.pdf).

Clearly, the world is in the midst of explosive growth in wireless product availability, acceptance, and use. Today's wireless devices are beginning to reveal a convergence between the functions of wireless voice (i.e., telephone) versus wireless data (i.e., email and web-browsing). Wireless device manufacturers, research organizations and other technology leaders are rapidly developing technologies for location-based-services, ad-hoc networks, and broadband multimedia data capability. These wireless technologies form a powerful synergy with increasingly inexpensive and compact microprocessors, the enormous address space enabled by the IPV6 standard, and emerging technologies for compact energy storage (batteries, fuel cells, etc.). Emerging applications, such as multimedia entertainment and gaming, inventory-tracking, security and emergency location services will undoubtedly be followed by products that will entertain the imaginations of visionaries and entrepreneurs for many years to come.

Given the increasing omnipresence of portable wireless technology, the potential for passengers to operate intentionally transmitting PEDs (T-PEDs) onboard airplanes is inevitable. For U. S. airlines, cabin attendants are required to announce the airline's PED control policy prior to every flight. Airline PED control policies nearly always comply with the FAA recommendation that all T-PEDs be turned OFF for the entire flight. However, many passengers have heard these announcements many times, and do not pay very close attention. Sometimes, flight attendants simply refer to the PED policy announcement published in the airline magazine, which may (or may not) be in the passenger's seat-back pocket. To make matters even more confusing, commonly authorized devices, like notebook computers and PDAs, are now likely to conceal intentional transmitters. Many passengers and flight attendants do not realize that the subtle addition of wireless data network capability converts an authorized PED into an unauthorized T-PED. This misperception was clearly evidenced when the USA Today newspaper quoted an FAA spokesman mistakenly concluding that a PDA, with built-in transmitter, is acceptable for use onboard passenger airplanes [48]. Even more troubling, a belief has emerged among many passengers that T-PEDs do not present *any* EMI threat to aircraft systems.

Table 7 provides a sampling of testimony revealing a deliberate and reckless attitude among some passengers, regarding the potential for EMI from T-PEDs to adversely affect aircraft radios.

Some US airlines have recently started terminating their North American Terrestrial System (NATS)-based airplane telephone service. This development is likely to further increase passenger motivation to use wireless phones onboard airplanes. (See Figure 3.11.)

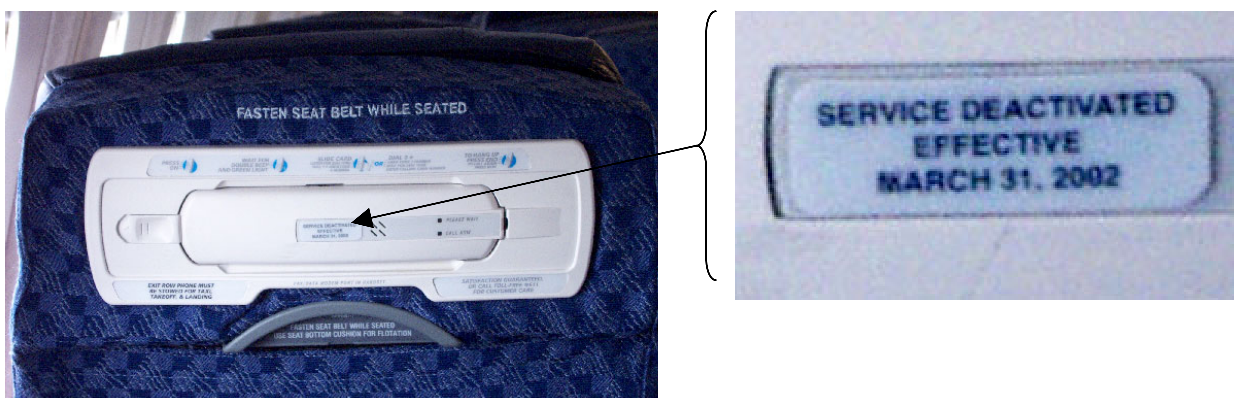


Figure 3.11: One US air carrier has terminated airplane telephone service on much of its fleet, effective March 31, 2002.

Table 7: A Sampling of Testimony Revealing a Deliberate and Reckless Attitude Regarding the Potential for EMI from T-PEDs to Adversely Affect Aircraft Radios

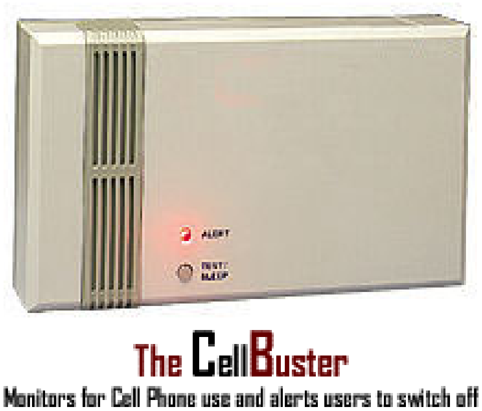
Quotes	Date	Source
"On a recent flight from Newark, N.J., to Orlando, Mike Corbo decided to check his e-mail. Instead of plugging into a $3.99-a-minute in-flight phone, he powered up his Palm VII and downloaded the messages wirelessly, at 35,000 feet.", "No one tried to stop Corbo because what he did is legal. The Federal Aviation Administration doesn't ban the onboard use of a personal digital assistant - even one that can connect to the Internet through a cellular network - according to FAA spokesman Paul Takemoto. "He isn't violating any rule," he says.", "That's a question Bob Johnson may have to ask himself soon. The Houston consultant uses his BlackBerry to connect to the Internet wirelessly all the time — including from a commercial airplane. 'It connects every time I pass over a served city and am in range of a transmitter,' he says."	8/19/2002	USA Today [48]
"The issue began heating up again in 1992, when Rep. Bob Carr, then a Michigan Congressman, and vice chairman of the Transportation Appropriations subcommittee, asked the FAA for a detailed look at alleged cellular interference. Rep. Carr had been reprimanded by a United flight attendant for using his cell phone while a flight to Chicago was delayed on the ground in Detroit. Mr. Carr, a pilot, says he regularly used his cell phone while flying on commercial planes in the late 1980s. He says he is convinced the airline ban was, and is, 'bogus' and not founded in science."	1999	Wall Street Journal [49]
"...air carriers have resisted allowing cell-phone use on the ground because it detracts from the revenue they get from the air phone.", "cell phones are regularly used on private and corporate planes 'thousands of times every day' without incident." Quotes of John Sheehan, chairman of RTCA SC 177.	1999	Wall Street Journal [49]
"It works on an airplane when you are within a few thousand feet of the ground, so it will download email messages when you are landing (I know, it should be turned off. There is even a menu item to turn off the 2-way)." (Regarding the RIM Blackberry Two Way Pager)	10/4/2002	Epinions.com [50]
"The same applies for messages sent to you while you are on the subway, in an airplane, or out of coverage - the messages will reach you once coverage is restored." (Regarding the RIM Blackberry Two Way Pager)	10/4/2002	Blackberry.net FAQs [51]
"Mr. Laermer has come up with an ingenious way to get his BlackBerry to work on airplanes. Devotees claim that if they hold the device up to the airplane window they can get messages until the plane climbs over about 10,000 feet. But Mr. Laermer soon tired of scoldings from flight attendants and weird looks from fellow passengers. 'Now I stick it between the window and the shade. It stays there and when it vibrates you can hear it,' he says. 'If you're going over an area that has coverage you'll get e-mail coast to coast for free.'"	4/26/2000	Wall Street Journal [52]

3.3.2 Detection and Mitigation

In August 1996, RTCA Special Committee-177 recommended "Government and industry should pursue research into the design and feasibility of using devices designed to detect emissions that produce electromagnetic interference from PEDs within aircraft cabins". Soon after publication of the RTCA/DO-233 report [2], the FAA entered into a Small Business Innovative Research (SBIR) contract with Megawave Corporation (Boylston, Massachusetts) and Embry Riddle Aeronautical University (ERAU, Daytona Beach, Florida) to design a system for the detection and localization of potentially harmful radiation from PEDs carried onboard aircraft. The system was designed to monitor the radio spectrum from 50 to 2000 MHz, with up to 64 sensors distributed throughout the passenger cabin of an airplane. Unfortunately, funding and sponsorship of the system dissolved before a prototype could be built. To date, the Megawave/ERAU design remains the most comprehensive approach for a PED detection system. Details of the design may be found in [53].

Aside from a system designed exclusively for installation on aircraft, other PED detection options have become available since the RTCA/DO-233 recommendation. Holaday Industries (now a part of ETS-Lindgren) markets a Cell Alert® system for detection and alerting of wireless phones that may be activated in the hospital environment, but are unauthorized. Details may be found at http://www.emctest.com/Holaday/pa3.htm. Cellbusters.com, in Phoenix, Arizona, manufactures the Cellbuster®, which appears similar to the Cell Alert®, and is marketed for use in power plants, airports, medical clinics, computer rooms, transportation operations, industrial plants, control rooms, laboratories, financial institutions, courthouses, government buildings, legal offices, embassies, and defense facilities. Details may be found at http://www.cellbusters.com, and a photograph is shown in Figure 3.12. Channel Business Services, of Hamburg Germany, markets the Mobifinder® mobile phone detector, for use in airplanes, airports, hospitals, doctor's offices, medical laboratories, near fuel depots and gas stations, and other security areas. A photograph of the portable Mobifinder® unit is shown in Figure 3.12. Further details may be found at http://www.mobifinder.de/english/products/index.html.

Alitalia Airlines has evaluated the Mobifinder® as a tool for the chief cabin attendant on some flights in 1998 [54], and found that it was often difficult to identify the exact location of the unauthorized transmitter. The Alitalia evaluation team recommended that multiple Mobifinder® units be used to increase the likelihood of threat localization, to heighten passenger awareness to the potential hazards of wireless phones, and to aid the flight crews in resolving suspected EMI events. Other PED detection products are also likely to be (or become) available.



The Mobifinder®
Mobile Phone Detector

Figure 3.12: Examples of two products designed to detect and alert unauthorized wireless phone usage. (Graphics obtained from websites noted above.)

Narda East (L3 Communications), in Hauppauge, New York has advertised the portable AirGuard PED sensor, for detecting PED emissions that may be present in aircraft communication/navigation frequency bands, and has demonstrated a prototype unit at NASA LaRC. The Narda approach is subtly different from the other approaches because it focuses on excessive PED emissions in aircraft frequency bands, rather than detecting specific T-PED frequencies that have been designated as unauthorized for use onboard airplanes. This significant difference was identified in the Megawave/ERAU study, and acknowledged to be of significant design concern for an operational system to provide a high probability of detecting potentially harmful PED signals, while not burdening flight crews with false alarms.

The most difficult issues relating to the detection of unauthorized PEDs are less technical than financial and operational. Any piece of electronic equipment an airline designates for use onboard their aircraft must be certified for flight worthiness according to FAA regulations. Certification may add significant cost over the base price of the equipment. Also, airplanes can only generate revenue when they are carrying passengers. Thus, an installed PED detection system is subject to the additional cost of lost revenues during its installation time. Once the technical issues and certification requirements for a PED detection system have been resolved, flight crew training and enforcement policies must be developed to address situations when potentially harmful PEDs are being used by passengers. These operational issues are largely unresolved, but are an integral part of ongoing research under a cooperative agreement between NASA and DAL.

In 1988, RTCA Special Committee 156 recommended, "the FCC specify a new classification for portable devices that may be operated on aircraft" [1]. Subject to this new FCC device classification, the committee further recommended: 1.) *Aircraft-authorized* devices meet lower limits for spurious radiated emissions than FCC requirements for unlicensed transmitters (FCC Part 15.109); 2.) Devices have a means for being turned off when requested by the aircraft operator; and 3.) Devices in the new class have a conspicuous permanent marking. Such an aircraft-authorized certification approach could be used for an emerging wireless industry standard; and could provide a novel way to minimize the duration of threat from unauthorized wireless phones. An onboard cellular base station (for the authorized network) could be designed to ring the unauthorized user's handset, and play a prerecorded message alerting them to turn their phone OFF. This approach requires modulation decoding and signal processing that is much more sophisticated than the simple amplitude detector approach in all existing PED detectors. The approach could also be extended to aircraft 802.1x WLAN access points and Bluetooth devices. Unfortunately, it is currently illegal for a cellular (or PCS) base station to transmit in a frequency band that is licensed to another wireless service provider. To date, the recommendation for creating a new aircraft-authorized device classification has not been pursued by the FCC.

A likely part of minimizing the risk of interference to aircraft radio communication/navigation signals will be to mitigate potentially harmful PED signals that will inevitably be radiated from within airplane passenger cabins. NASA has performed some measurements, in conjunction with EWI and UAL, to determine how much IPL (path loss between passenger cabin and aircraft-mounted antennas) may be increased by applying conductive gaskets to aircraft door and window exits, and conductive films to aircraft windows. (See Figure 3.13.) Measurement and analysis details relating to this work will be provided in a subsequent publication. Increasing the IPL improves the protection of aircraft radios from interference generated by PEDs within the passenger cabin.

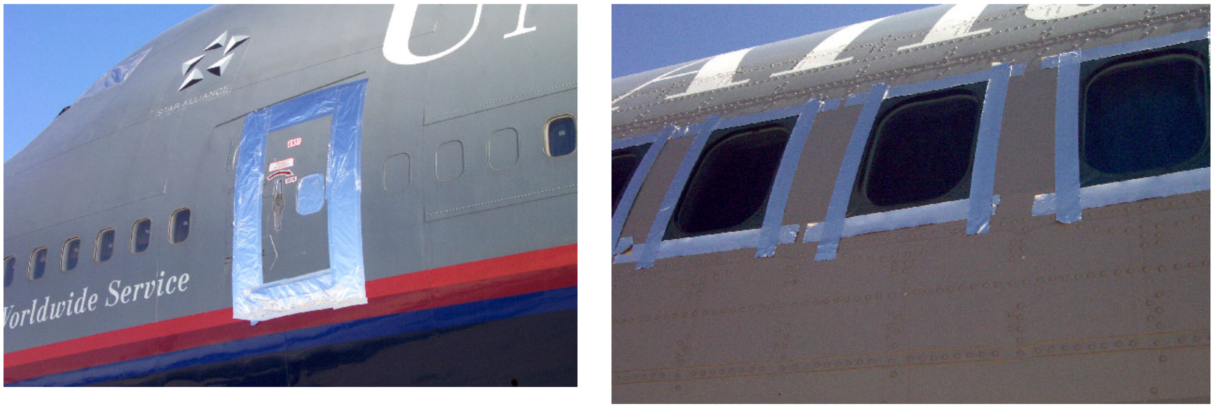


Figure 3.13: Left: Aluminum foil, secured with conductive aluminum tape, applied to the forward port door of a B-747 airplane. Right: Transparent conductive window film, secured with conductive aluminum tape, applied to several windows of a B-737 airplane. IPL measurements were performed with these treatments to assess the increase in IPL due to conductive gaskets in aircraft doors, and passenger cabin window treatments.

3.4 Ultrawideband

3.4.1 Background

UWB technology is typically characterized by the radiation and detection of base-band pulse signals, having duration of less than 1 nsec. A periodic sequence of these pulses can be shown in the frequency domain to appear as narrow-band signals at frequency spacing that is the inverse of the pulse repetition interval. Highly broadband antennas are required to transfer enough frequency content through the transmission medium to preserve the required degree of pulse-shape characteristics. The first patent for an UWB-type communication system was issued to Gerald Ross, in 1973 [55]; however, the technology was referred to as *baseband* at that time. According to Dr. Robert Fontana, President of Multispectral Solutions Inc., most UWB technology development prior to 1994 was performed under classified government programs [56]. Fontana provides an excellent history of UWB, with many downloadable references at the Multispectral Solutions website: http://www.multispectral.com/history.html.

In 1994, Thomas McEwan was issued a patent for an "Ultra-Wideband RADAR Motion Sensor" [57], and was credited with specifying numerous commercial applications for the technology in a Popular Science magazine article entitled "RADAR on a Chip, 101 Uses In Your Life" (June 1995), [58]. Because UWB technology is inherently a pulse-modulated radio-transmission scheme, blending of digital communications and radar sensor applications is greatly simplified. Some safety-related UWB applications address situational awareness needs in automobiles, like backup warning systems, intelligent cruise control and collision avoidance. Some security-related UWB applications include sensors that can see into (and even through) boxes, bags, crates and walls, allowing detection of unauthorized equipment or intruders. UWB ground penetrating radars have been demonstrated to provide extensive information about buried pipes, weapons and facilities for military, geological, archeological and architectural applications. UWB systems can be implemented with very inexpensive and compact electronic components. Perhaps these characteristics hold the greatest promise for driving a revolution in new applications for consumer products. Designers and developers of wireless technology are promoting UWB technology for addressing the needs of high data rates, interoperability and location awareness that will be required for emerging wireless applications.

3.4.2 Status of UWB Regulation

On February 14, 2002, the FCC adopted a FIRST REPORT AND ORDER, releasing it on April 22, 2002, and on May 16, 2002 published in the Federal Register a Final Rule, permitting marketing and operation of new products incorporating UWB technology [59]. The FCC, the NTIA, universities and industry have invested years of effort to develop a technical rationale for setting limits on allowable UWB signal levels. The FCC Final Rule provides detailed requirements for allowable UWB radiated-emission levels. These levels are based primarily on FCC Part 15.209 spurious radiated emission limits [60]. Additional limitations are specified depending upon the stated application: imaging systems, vehicular radar systems, indoor UWB systems, and handheld UWB systems. The technical requirements for handheld UWB systems, as addressed in FCC Final Rule Part 15.519, are of primary concern when considering UWB technology applications within PEDs, particularly as a threat to aircraft radios. Handheld UWB system emission-limit levels are specifically provided as effective isotropic radiated power (EIRP) from 960 MHz to above 10.6 GHz. Below 960 MHz, the standard FCC Part 15.209 limits apply. The field intensity levels specified in FCC Part 15.209 can easily be converted to EIRP levels at frequencies below 960 MHz. The final composite limits, from 100 MHz to 10.7 GHz are shown in Figure 3.14. While UWB operation is stated to be restricted to the 3.1-10.6-GHz frequency band in the FCC Final Rule, relatively high limits are also allowed for operation below 960 MHz.

The FCC FIRST REPORT AND ORDER states that the adopted standards “may be overprotective and could unnecessarily constrain the development of UWB technology”, and reveals the intention to issue further rulemaking to “explore more flexible technical standards and to address the operation of additional types of UWB operations and technology”. These statements appear to indicate that a relaxation of UWB-radiated emission limits is planned for the near future. On July 12, 2002, the FCC issued an additional Order [61], permitting the continued operation of UWB ground-penetrating radars (GPRs) and wall imaging systems that do not comply with the FCC FIRST REPORT AND ORDER [59]. Reference [61] applies to GPRs and wall imaging systems that had previously been operating without FCC licenses, authorized under FCC experimental rules under FCC Part 5, or by waivers. Reference [61] cites that several public-safety benefits result from the continued operation of existing GPRs and wall imaging systems currently in use, and that the FCC is not aware of any reports of harmful interference resulting from the long-term use of these systems in the past.

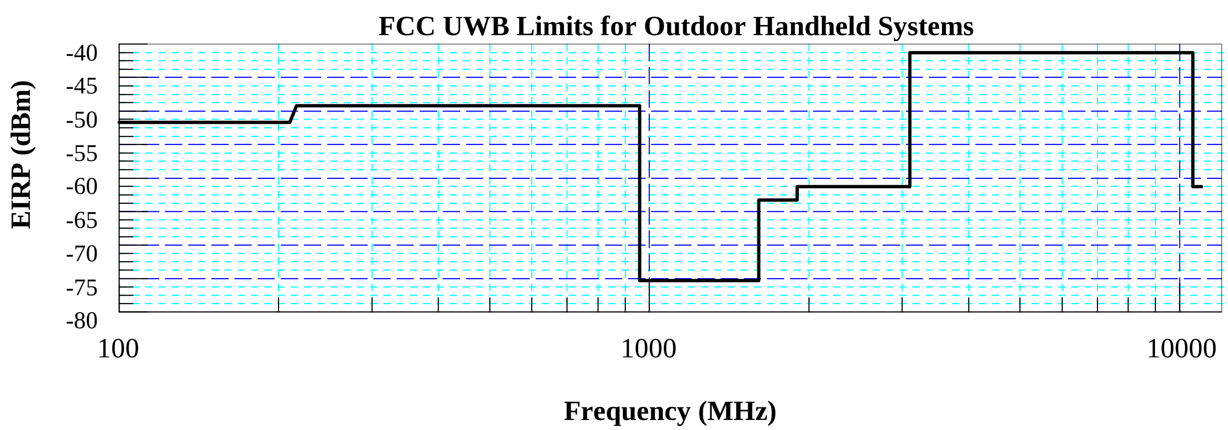


Figure 3.14: Composite graph of EIRP allowed by the FCC Final UWB Rule, Part 15.519, dated May 16, 2002.

3.4.3 Why is UWB EMI a Concern For Aircraft Radios?

Spurious radiated emission data from typical PEDs is available within the RTCA/DO-199 and /DO-233 publications. (See DO-190 Vol. 2 Section 4.0, and DO-233 Appendix A, [1-2].) The RTCA publications contain numerous charts, clearly showing that typical PEDs radiate spurious signal amplitudes that are thousands of times less, at most frequencies, than the FCC 15.209 limits require. In fact, the DO-233 analysis concluded that PEDs meeting FCC 15.209 limits could *exceed* interference limits for aircraft VOR and LOC radios by a factor of over 1000 times; even when their emissions are attenuated by traveling from the passenger cabin to aircraft radio receivers. However, as noted by the DO-233 authors, the probability of a typical device radiating at the FCC limit, on a particular aircraft radio channel, is extremely low. UWB transmitters, on the other hand, emit equal-amplitude, narrow-band signals at frequency spacing that is the inverse of the pulse repetition interval. When using pulse-position modulation and different clock frequencies, UWB transmitters emit narrow-band signals simultaneously at *any* frequency, even in safety-critical aircraft bands. There is clearly a very big difference between typical consumer devices that radiate spurious signals which are nearly always far below FCC 15.209 limits, and UWB devices, that may be intentionally designed to radiate at or near FCC 15.209 limits.

The final FCC rule explicitly states, “The operation of UWB devices is not permitted onboard aircraft, ships, or satellites…” This statement indicates that the FCC has documented EMI concerns for UWB operation onboard these vehicles. The FCC rule provides no guidance on how UWB devices can be restricted from operating in these vehicles, or who is responsible for enforcing the restrictions, and appropriate penalties.

3.5 Results and Conclusions: Technology Assessment

1. Technologies for versatile and inexpensive wireless voice and data devices are rapidly expanding. Air-travel passengers continue to become increasingly comfortable with existing and emerging wireless transmitters. Most intentional transmitters are not required to meet the more rigorous FCC standards applicable to non-intentional transmitters. While limited data indicate that many wireless voice and data transmitters do not emit excessive signals in aircraft radio-frequency bands, there is no guarantee that this situation will continue. Reports of unauthorized use of wireless transmitters onboard aircraft have become increasingly common.

2. Deficiencies were identified in available data for performing a detailed statistical risk assessment for wireless transmitters in aircraft.

    a. Spurious radiated-emission data are not available for typical and emerging wireless transmitters. While FCC and CISPR emissions standards must be met for products sold in the US and Europe, they are not intended, and are, therefore, inadequate for protecting aircraft spectrum from passenger-generated EMI.

    b. Available aircraft IPL data are insufficient for estimating the minimum possible IPL in US airline passenger-airplane fleets. IPL data need to be collected on additional airplane types, and incorporated into a statistical assessment of expected IPL, based upon aircraft type and passenger location.

    c. Inadequate aircraft navigation radio receiver susceptibility data are available for estimating signal-to-interference radios required to thoroughly assess the threat from PED-type EMI.

3. Past studies of EMI to aircraft systems from passenger-carried PEDs have recommended the evaluation of detection devices for unauthorized PED use onboard aircraft. While the threat has increased and product standards have remained stagnant, little work has been performed in the design, implementation and demonstration of PED-detection devices for use on passenger aircraft. It is becoming increasingly difficult for flight attendants and passengers to discern whether today's highly integrated and multi-function devices are designed to transmit, or not. Observations suggest that passengers are increasingly likely to knowingly operate unauthorized transmitters while onboard aircraft. There are numerous political and operational issues to resolve before PED detection systems can be integrated into a viable airline PED policy plan.

4. More detailed analysis and testing of UWB device impact upon flight-essential aircraft navigation and communication systems and ground-based air traffic control is strongly recommended, particularly before unlicensed devices are widely available.

4 CDMA/GSM Mobile Unit Threat Assessments

4.1 Approach

The most effective way to assess the potential for electronic equipment to interfere with aircraft systems is to exercise a representative unit in all modes of operation, at the location of installation, and monitor all critical and essential aircraft systems for unwanted effects during its operation. A good reference for an aircraft EMI evaluation is provided in [10]. Such in-situ testing is routinely performed for aircraft equipment before regulatory approval for installation on commercial transport aircraft.

In the case of wireless phones carried onboard aircraft by passengers, this process becomes impractical. Passengers routinely carry wireless handsets ranging from brand-new to over a decade old. The product design cycle for consumer electronics products is measured in periods of months. It is simply not possible to test every device, or even representative models of every device for potential EMI to aircraft systems. In addition, wireless handsets can potentially be present in any passenger cabin or cargo bay location. It is well established that coupling loss between aircraft radios and passenger cabin locations can vary by a factor of 10^6 depending upon location of operation. To assess the potential for

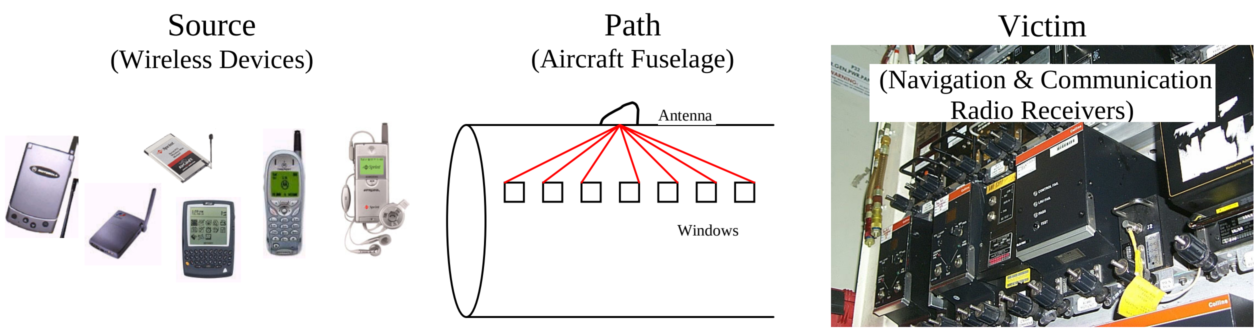


Figure 4.1: Elemental approach for assessing the potential for wireless phone electromagnetic interference to aircraft radio receivers.

wireless handsets to interfere with aircraft systems, it is necessary to separate the analysis into an elemental, rather than in-situ, approach. Figure 4.1 graphically illustrates the three required elements of any EMI problem, as they pertain to evaluating the wireless phone threat to aircraft radios. This section will address each of the three elements of the EMI threat assessment from GSM and CDMA wireless handsets. As noted in the introduction, the analysis focuses upon flight-essential aircraft navigation radio receivers (LOC, GS, VOR, and GPS). The potential for interference with flight-essential VHF and satellite communications, DME, TCAS and Air Traffic Control Radar Beacon System (ATCRBS) transponder systems, or flight critical propulsion, flight controls and display systems is not addressed because it is outside the scope of this task.

Section 4.2 of this report provides a summary of available data describing the radiated field attenuation between a PED, located at various locations within the passenger cabin of an aircraft, to the RF connection of a particular navigation radio receiver (aircraft "interference path loss", or IPL). The section includes a graphical and analytical description of aircraft path loss, and establishes values in terms of radiated power attenuation (dB).

Section 4.3 of this report provides a detailed analysis of aircraft ILS, VOR and GPS interference thresholds based upon ICAO and RTCA reference documents [1, 2, 11-20] and manufacturer's data. Threshold limits are derived in terms of interference power (dBm) required at the receiver to cause interference.

Section 4.4 of this report provides an overview of the FCC regulatory limits for wireless phone spurious radiated emissions, and a detailed description of the extensive measurement process developed and utilized for thoroughly characterizing emissions from GSM and CDMA handsets. Spurious radiated emissions were measured while operating the handsets in numerous modes during a three-week measurement program (by NASA LaRC in collaboration with the UOK Center for Wireless EMC) in August 2001. A detailed analysis of measurement data is provided in Section 4.4, with additional graphical charts provided in Appendix C.

4.2 Aircraft Interference Path Loss

4.2.1 What is Interference Path Loss?

The goal of this section is to describe the radiated field attenuation between a PED, located in the passenger cabin of an in-flight aircraft, to the RF connection of a particular navigation radio receiver. Because radio frequency spectrum is managed by government regulations, publicly available transmitters do not transmit intentionally into aircraft RF bands. However, they often do transmit unintentionally into aircraft RF bands. It is this unintentional transmission of RF signals into specific aircraft frequencies that are the focus of IPL, as defined in this report. Using the World Jet Inventory [62] as a guide, there are about 35 different types of operational, commercial jet airplanes built in the US and Western Europe with a capacity of 30 seats or more. Each aircraft type has a unique configuration of antenna placements and radio receiver installations. In fact, different series of the same aircraft type may have different antenna placement and cable routing variations. These variations may result in widely different IPL values for different airplanes. The analysis considered herein covers VOR, LOC, GS and GPS navigation radio signal paths. Figure 4.2 shows a diagram of IPL, as defined as the attenuation between a portable transmitter to an aircraft radio receiver via coupling through its aircraft-mounted antenna, as the signal penetrates the aircraft through window and door apertures.

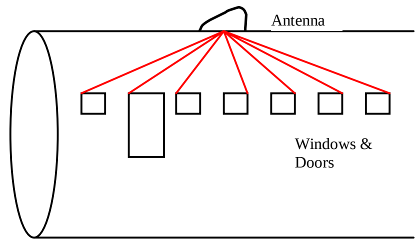


Figure 4.2: Diagram of section of aircraft illustrating IPL. The primary path for PED signals to aircraft radios is through window and door apertures and then to fuselage-mounted antenna systems.

In order to approximate a PED radiating spurious signals in a particular aircraft RF band, the test setup shown schematically in Figure 4.3 was described in RTCA/DO-233 as a standard technique for assessing the threat to communication and navigation radio receivers.

In Figure 4.3, IPL is defined as the loss between a reference antenna (approximating the PED) and a particular aircraft radio receiver terminal connector. (The aircraft radio needs to be removed to allow connection of the measurement receiver to the aircraft antenna.) The IPL can alternately be described as the loss between a calibrated signal source and measurement receiver, less any test cable losses. In

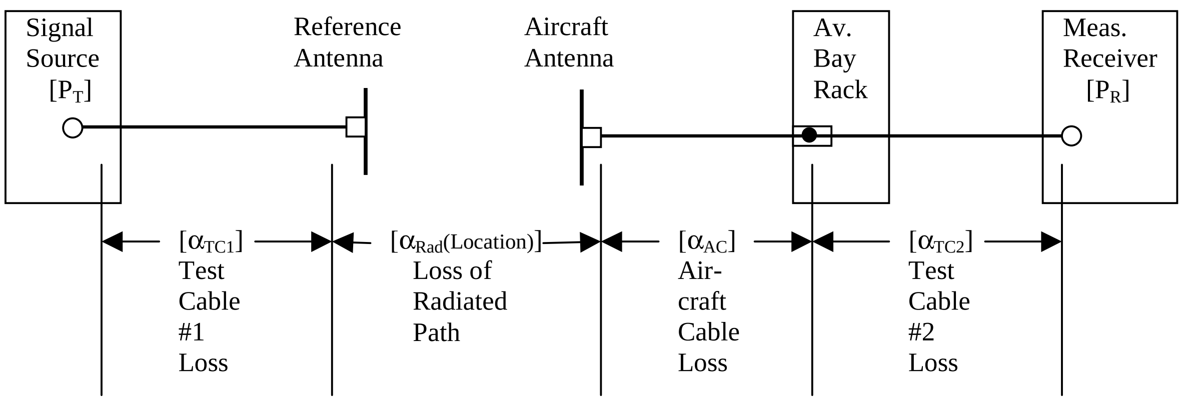


Figure 4.3: Schematic diagram of IPL, showing RF pathways and their respective attenuation (loss) as discrete variables.

equation form:

$$\mathrm{IPL} = \alpha_{\mathrm{Rad(Location)}} + \alpha_{\mathrm{AC}} = \mathrm{P_T} - \alpha_{\mathrm{TC1}} - \alpha_{\mathrm{TC2}} - \mathrm{P_R}$$ **Equation 4-1**

where

P_T (dBm) is the root-mean-square (RMS) power amplitude transmitted by the Continuous Wave (CW) signal source.

P_R (dBm) is the RMS power amplitude measured at the test receiver (spectrum analyzer).

$\alpha_{Rad(Location)}$ (dB) is the radiated path loss between the test antenna connector and the aircraft antenna connector. This term includes the characteristic antenna gains and any associated path factors (i.e., multipath, separation distance and electric/magnetic field coupling to, conduction upon, and re-radiation from the surrounding environment nearby).

α_{AC} (dB) is the aircraft cable loss.

α_{TC1} (dB) is the loss of Test Cable #1, between the signal source and reference antenna connector. If an active device such as a RF amplifier is present, this factor may be negative.

α_{TC2} (dB) is the loss of Test Cable #2, between the aircraft radio receiver rack location and the measurement receiver. If an active device such as a RF pre-amplifier is present, this factor may be negative.

Figure 4.4 shows photographs where IPL measurements have been performed (with participation by NASA-LaRC personnel). The reference antenna is placed at multiple locations within the aircraft passenger cabin to approximate the operation of a PED. A known reference signal is applied to the reference antenna, and a calibrated radio receiver (spectrum analyzer) is connected in place of the aircraft radio receiver.

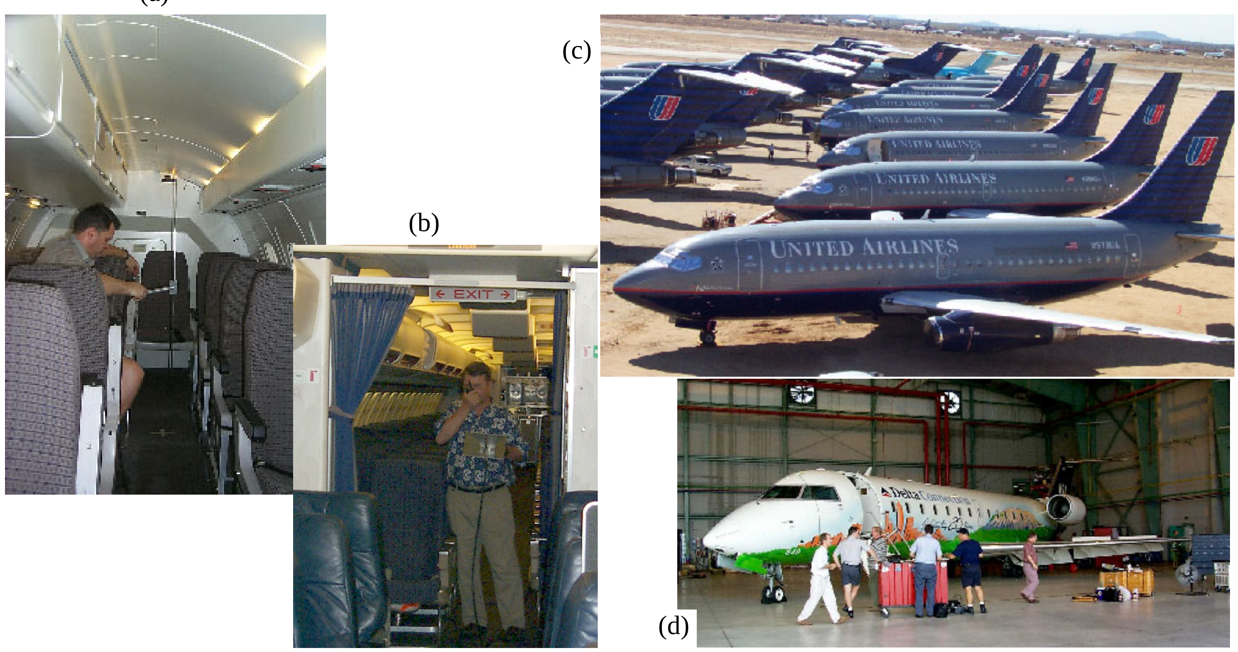


Figure 4.4: Photographs of IPL measurement locations. (a) VHF measurements inside Embraer 120, (b) L-band measurements inside B-757, (c) B-737 IPL measurements in outdoor location, (d) Canadair Regional Jet IPL measurements inside a hangar. (See [30]).

It is important to note that α_{Rad}(Location) varies with position of the reference antenna. The goal for IPL measurements is to quantify α_{Rad}(Location) for different aircraft passenger cabin locations, while eliminating variations due to directivity, efficiency and near-field coupling to aircraft surroundings by the reference antenna. In practice, reference antennas that are tuned to the measurement frequency band can be used, thus minimizing uncertainties due to antenna efficiency. It is preferable to use a spectrum analyzer/tracking source instrumentation configuration, to obtain minimum loss (maximum coupling) from numerous samples over the entire frequency band of interest, for each measurement location. This de-emphasizes spectral "drop outs", and minimizes measurement variations due to near-field coupling to aircraft surroundings by the reference antenna. Using reference antennas with low directivity tends to best approximate the PED threat, because PEDs are not designed to radiate spurious signals.

The photographs in Figure 4.4 emphasize several factors imposing varying degrees of uncertainty upon past IPL measurements. First, it can be seen that there is no direct path from the reference antenna to the aircraft antenna. Signals radiated by the reference antenna will generate currents on the inside and outside of the metal aircraft fuselage, and may radiate directly through windows and non-conductive panels if their wavelength is smaller than the fuselage aperture. The distribution of electromagnetic fields and currents within the passenger cabin will vary according to source location, as well as the presence of other nearby objects (like people and cabling). Electric currents present on the exterior of the aircraft will mostly re-radiate to the surrounding area, but can also couple reactively to communication and navigation radio antennas. Figure 4.4(c) and (d) clearly show numerous opportunities for reflection and scattering of reference signals outside the aircraft, including the ground and other surrounding aircraft. This fact is significant because the goal is to assess the magnitude of coupling from PEDs to aircraft radios *during flight*. Reflection and scattering while measuring IPL will present a factor of uncertainty when applying the data to an in-flight PED threat assessment.

4.2.2 Previous Reports

4.2.2.1 RTCA/DO-199

RTCA/DO-199, "Potential Interference to Aircraft Electronic Equipment from Devices Carried Aboard" was prepared by Special Committee (SC) 156 of the Radio Technical Commission for Aeronautics, and was published on September 16, 1988 [1]. The report was issued in two volumes. Appendix A of the first volume summarized IPL data from a wide range of tests performed on different aircraft and using different techniques, and included data for Optimized Method for Estimated Guidance Accuracy (OMEGA) Very Low Frequency (VLF) Navigation System, VLF, Long Range Navigation (LORAN) C, Automatic Direction Finder (ADF), ILS LOC, VOR, VHF COM, ILS GS, DME/Tactical Air Navigation (TACAN), GPS and Microwave Landing System (MLS). Data for Volume 1, Appendix A was obtained from numerous SC156 papers, which were published in chronological sequence in RTCA/DO-199 Volume 2, Section 3.0.

The RTCA/DO-199 contributors used several different approaches to measure aircraft IPL. Approaches included measurements of electric field strength at various distances, “hull loss” measurements through windows and doors, “1-meter” measurements of the aircraft radio antennas (outside the airplane), and interference testing using the actual aircraft radios with criteria of flag extensions and audible noise. No guidance was provided for using a particular type of reference antenna, therefore, reference antennas with different directivities and efficiencies were used. The different approaches were often innovative, and provided great insight into specific and general characteristics of aircraft IPL. RTCA/DO-199 Section 5.3.1, and several papers in RTCA/DO-199 Volume 2 were dedicated to conversion and scaling of reported IPL values for comparison in terms of power attenuation of radiated signals from a PED to an aircraft radio RF connector. Section 2 of RTCA/DO-199 Section A provides a summary table compiling all reported data.

The RTCA/DO-199 IPL measurements were all obtained at a very limited number of locations, at discrete frequencies (not swept over the entire frequency band). When values were compared using conversion and scaling formulas, variations between minimum values often exceeded 50 dB. Tables and graphs clearly showed that minimum (and often average) IPL values allowed signal levels in excess of aircraft radio sensitivity limits, from consumer products meeting FCC Part 15 and Verband Deutscher Elektringenieure (VDE) (German Equivalent of IEEE) limits.

The RTCA/DO-199 report contained unique IPL comparisons between aircraft sitting on the ground versus in-flight for VOR frequencies. This testing was performed by the FAA Technical Center, on FAA aircraft N-40 (Boeing 727). Estimated IPL variations of +/- 10 dB between on-ground and in-flight were measured for particular locations, but not enough measurements were acquired to determine if minimum values were simply shifting positions.

While the RTCA/DO-199 IPL measurements met the objectives for demonstrating the potential for PEDs to interfere with aircraft radios, the number of measurements was inadequate and the methodology was inconsistent between contributors to establish a viable aircraft IPL database.

4.2.2.2 RTCA/DO-233

RTCA/DO-233, "Portable Electronic Devices Carried on Board Aircraft" was prepared by SC 177 of the Radio Technical Commission for Aeronautics, and was published on August 20, 1996 [2]. RTCA/DO-233 Section 2.4 compared the direct functional approach (interference testing using the actual aircraft radios with criteria of flag extensions and audible noise) with a swept-frequency approach for measuring IPL data. It was concluded that a closed-loop swept-frequency approach was the most accurate and operationally efficient way to measure aircraft IPL. (The swept-frequency approach uses a spectrum analyzer/tracking source configuration recommended for reasons stated in 4.2.1.) RTCA/DO-233 included an Aircraft IPL Test Plan (Appendix B), and Aircraft IPL Test Procedures (Appendix C). These documents provided detailed guidance for consistency among IPL measurements obtained by different personnel at different locations. RTCA/DO-233 avoided the difficulty of interpreting data obtained using numerous measurement approaches by establishing the test methodology up-front. IPL data were summarized (RTCA/DO-233 Table 3.2) for seven different aircraft, representing large, medium and small commercial transports, and included data for ILS Localizer, VOR, VHF COM, ILS GS, DME, ATC, TCAS, GPS, SATCOM and Marker Beacon systems.

The RTCA/DO-233 Appendix C procedure recommended a SETH SRS-2100 E-field antenna system. However, the alternate dipole reference antenna was used for most measurements due to unavailability of the SETH Antenna. Because of their low radiation efficiency, it is likely that electrically small reference antennas would have difficulty radiating enough power to provide adequate signal at the spectrum analyzer during aircraft IPL measurements.

RTCA/DO-233 Table 3.2 provided IPL minimums, 90% minima, averages, and standard deviations for each system of each airplane, but did not provide measurement locations or numbers of samples. This omission is a serious limitation because it cannot be determined whether adequate data samples were obtained, or whether the data were biased from focusing too heavily on one part of the airplane. Unlike RTCA/DO-199, RTCA/DO-233 did not provide a second volume containing IPL data from individual contributors, for cross comparison and supplementation of the summary table. Also, it is unclear whether the IPL values reported as "average" are averages of averages (i.e., average IPL over frequency for each particular location, with all locations averaged) or averages of minimums (i.e., minimum IPL at a given frequency for a particular location, with all locations averaged).

4.2.2.3 CV-580 RF Coupling Validation Experiment

Veda Report #79689-96U/P30041, "CV-580 RF Coupling Validation Experiment Report" was prepared by Veda Incorporated, Lexington Park, Maryland, and was published on November 15, 1996, under contract for the FAA Aviation Security R&D Division [22]. A goal for the effort was to research potential terrorist electromagnetic environmental effects (E^3) threats to commercial aircraft and avionics systems. IPL measurement procedures and equipment were compliant with guidelines documented in RTCA/DO-233, with added attention to quantify the effect of reverberation and mode-stirring effects upon IPL measurements. The effort also included assessment of shielding techniques for improving avionics immunity to EMI threats. IPL data were obtained and published for the VOR, VHF COM, ILS GS, DME and GPS systems.

The Veda reports stated that signal paths from inside the aircraft to the communication and navigation antennas were found to be dominated by currents induced on the aircraft skin at window apertures, rather than reflections from wing and engine.

4.2.2.4 B-747-222 Path Loss Test, Las Vegas

EWI provided a report "747-222 Path Loss Test, Las Vegas, Nevada, Fall 1999", authored by Gerald Fuller, under NASA contract PO#L-10005 [23]. IPL data were obtained and published for the ILS LOC, VOR, VHF COM, ILS GS, ATC and TCAS systems.

4.2.2.5 NASA/Delta Airlines NCC-1-381

Delta Air Lines Report 10-76052-20, "Engineering Report, Delta/NASA Cooperative Agreement NCC-1-381 Deliverable Reports" was provided to NASA Langley Research Center on November 12, 2001 [21]. The cooperative agreement between NASA and DAL was initiated July 5, 2000, and extends for three years. The objective was to compile sound technical data and develop operational policies and design tools for assuring availability of essential aircraft systems, while allowing passengers freedom to operate PEDs that will not interfere with aircraft communication and navigation radios. Attachment 2 of the report (completed December 8, 2000) included a detailed IPL assessment for Boeing 757, Embraer 120, ATR-72, and Canadair Regional Jet aircraft. IPL data were obtained and published for the VOR, VHF COM, ILS LOC, ILS GS, DME, ATCRBS, TCAS, Radio Altimeter, and GPS systems (as installed). As part of the cooperative agreement, NASA personnel participated in many of the IPL measurements, and have contributed resources to evaluating the raw data.

IPL data reported in 10-76052-20 were referenced to 1-m IPL measurements. Such measurements are useful because they can reveal excessive loss in aircraft RF cabling and aircraft antenna anomalies, which may vary between airplanes of the same type and can present errors in aircraft IPL measurements. Referencing IPL data to 1-m measurements also calibrates out test-cable losses and in-line amplifier gains. However, referencing IPL data to 1-m IPL measurements provides the disadvantage of comparability to measurements performed to the standard procedure established in RTCA/DO-233, unless the data are accompanied by test-cable losses and in-line amplifier gains. Fortunately, all applicable data were available for analysis by NASA, allowing comparison to other reference data.

4.2.2.6 Observations and conclusions from previous analyses

1. Larger aircraft generally have higher IPL, except for special situations such as multiple floor levels and exit/door seams close to antennas. (RTCA/DO-199 App. A, 1.0a; EWI 747-222, Delta 10-76052-20) [1, 23, 30]

2. VHF signals (below 300 MHz) do not propagate well through windows, but propagate freely through window exits and door exits on typical aircraft, presumably because of larger electrical apertures. UHF and L-Band frequencies (300MHz and up) propagate well through aircraft windows, window exits, and door apertures. (Delta 10-76052-20) [30]

3. Close proximity of PED to aircraft radio antennas tends to be a primary factor for minimum IPL. (RTCA/DO-199 App. A, 1.0b; Delta 10-76052-20) [1, 30]

4. Window seat locations provide much higher coupling than aisle seat locations (RTCA/DO-199 RTCA Paper No. 238-84/SC156-26, Delta 10-76052-20) [1, 30].

5. Ground versus in-flight IPL measurements can vary by up to 10 dB at a specific measurement location. (RTCA/DO-199 App. A) [1]

6. At VHF frequencies, opening one of the front aircraft doors was observed to decrease IPL values by about 10 to 20 dB. (RTCA/DO-233 Sec. 2.4.4.1) [2]

7. Stirring (reverberation) has little effect when compared to direct path (VEDA #79689-96U/P30041 [22])

4.2.3 Summary of Data to date

Data published in the previous reports were compiled and are summarized in Table 8. To perform a statistical risk assessment, it would be best to generate a probability distribution for the IPL to be below a certain value for a particular percentage of seat locations in various classes of airplanes. Many references do not report any statistical information regarding IPL data, such as standard deviation and number of samples. Minimum IPL values for each system are highlighted in Table 8 using **gray with bold type**. It is suspected that the minimum values set by RTCA/DO-199 studies are biased low due to the technique of computing isotropic radiated power from field-strength measurements acquired in airplanes. For these measurements, the high multi-path environment likely resulted in better coupling than the free-space isotropic approximation would indicate. The minimum IPL values would clearly be set by smaller, regional aircraft (which is more reasonable) if not for these cases. On the other hand, some minimum IPL values are unrealistically high. For example, the variation between minimums for B-727 VOR systems is 45 dB.

A column average of minimum values is highlighted in Table 8 using gray with white type. In the absence of adequate data for a probabilistic description of IPL, it was decided to perform an average of minimum IPL values for the risk assessment described in this report. It was decided to compile and compare existing data, while supplementing the database in subsequent efforts.

Table 8: A Summary Compilation of Published IPL Data for VOR, LOC, GS and GPS Aircraft Navigation Systems.

Measured Airplane	VOR					LOC					GS					GPS					Ref.
	Min.	Avg.	Std. Dev.	# of Pts	1 m Loss	Min.	Avg.	Std. Dev.	# of Pts	1 m Loss	Min.	Avg.	Std. Dev.	# of Pts	1 m Loss	Min.	Avg.	Std. Dev.	# of Pts	1 m Loss	
B-747 (DO-233)	85	105	5			65	94	13			55	86	14								[2]
B-747 (EWI/UAL)	76	80	3	8	21	55	61	2	38	28	53	71	8	36	35						[23]
L-1011 (DO-233)	70	79	2			61	85	9			64	83	8								[2]
B-737 (DO-233)	76	90	5			73	91	9			69	83	5								[2]
MD-80 (DO-233)	66	88	9								64	85	11								[2]
DC-10 (DO-199)	89	89		20		82	91		10		77	91		24							[1]
B-757 (DO-199)	42	49		20		**23**	45		30		**22**	38		28							[1]
B-757 (DO-233)	50	91	10			52	86	11			58	83	10								[2]
B-757 (Delta)	46	66	7	113	16	56	75	10	104	16	59	72	6	106	32						[21]
A-320 (DO-233)	65	92	9			49	86	15			65	84	10								[2]
A-320 (Aerospatiale)	59	84				54	75				56	70									[2]
B-727 (DO-199a)	70	74		6		63	67		6		68	76		12		71	77		12		[1]
B-727 (DO-199b)	**30**	56		86		35	53		86												[1]
B-727 (DO-199c)	71	76		6																	[1]
B-727 (RTCA SC177)	75	90					72	90			68	83									[2]
CV-580 (Veda/FAA)	45										64					**41**					[22]
Gulf G4 (DO-233)																82	91	6			[2]
Canadair RJ (Delta/ASA)	58	72	7	28	28	58	72	7	28	28	52	60	3	28	30	43	54	6	28	18	[21]
EMB-120 (Delta/ASA)	42	56	5	22	28	42	56	5	22	28	46	52	2	20	28						[21]
ATR-72 (Delta/ASA)	64	72	4	50	24	64	72	4	50	24	58	68	5	53	38						[21]
Column Average	62					55					59					59					

[1] RTCA/DO-199, "Potential Interference to Aircraft Electronic Equipment from Devices Carried Aboard", 7/16/1998
[2] RTCA/DO-233, "Portable Electronic Devices Carried on Board Aircraft", 8/20/1996
[21] Delta Airlines/NASA Data, Provided to NASA in support of Cooperative Agreement NCC-1-381
[22] Veda Inc. Report #79689-96U/P30041, "CV-580 RF Coupling Validation Experiment Report", 11/15/1996
[23] Gerald Fuller, "747-222 Path Loss Test, Las Vegasa, Nevada Fall 1999", prepared under NASA PO #L-10005

4.3 Aircraft Radio Receiver Interference Threshold

The effort presented in this section is an attempt to gain a better understanding about susceptibilities of aircraft receivers, or the victim systems. The receiver systems under consideration include ILS LOC, ILS GS, VOR, and GPS. For LOC, GS and VOR, the section first describes the desired signal strength in the coverage airspace. The desired signal strengths at the receivers are then shown based on the computed values reported in various standards and in receiver Minimum Operational Performance Standards (MOPS). The desired signal strength data are then compared with the results from a survey of receiver sensitivities. These receiver sensitivities are related to receiver interference thresholds for certain types of modulated interference signals according to RTCA/DO-233. A summary of receiver susceptibility data from RTCA/DO-199 and RTCA/DO-233 is also presented. Deficiencies in the currently-available data are highlighted for possible future research efforts.

For GPS, receiver susceptibilities are well defined, as reported in various International Telecommunications Union (ITU) and receiver MOPS. This section summarizes the elements relevant to PED problems.

4.3.1 LOC, GS and VOR Interference thresholds

In this section, the minimum field environments assumed in various specifications are summarized and compared, and the desired signal strengths at the receivers are reported. The desired signal strengths are compared with results from a survey of receiver sensitivities provided by manufacturers. The interference thresholds, in relation to desired signal strength at the receiver, are summarized from the previous works documented in RTCA/DO-199 and RTCA/DO-233. The results, together with limitations on their usefulness, are discussed.

4.3.1.1 LOC, GS and VOR minimum field environment

The minimum field environments within the airspace coverage volume are used to estimate the desired signal field strength at the receiver. The interference thresholds can be calculated if the ratio of desired-to-undesired signal is known.

The minimum field environments were derived from many documents, including the International Civil Aviation Organization (ICAO) Annex 10 [11], receiver MOPS RTCA/DO-192, -195, -196 [12-14], and RTCA/DO-199 [1], RTCA/DO-233 [2] for aircraft interference by PEDs. The results are tabulated in Table 9.

As seen in Table 9, the minimum LOC environment is the same in all listed documents. However, for GS and VOR, the environments are different depending on the documents used.

Of all the sources listed, the field environment data documented in RTCA/DO-192, -195 and -196 were most credible for the US airspace, as these documents are specified in FAA's Technical Standards Orders (TSOs) C36, C34 and C40 for LOC, GS and VOR instruments, respectively.

Table 9: Minimum Field Environment Within Coverage Airspace

	LOC (µV/m)	**GS (µV/m)**	**VOR (µV/m)**
ICAO*	40	400	90
RTCA/DO-192, -195, -196	40	350	20
RTCA/DO-199	40	400	20**
RTCA/DO-233	40	200	90

* ICAO Annex 10, Vol. I [11], Part I, par. 3.1.3.3.2 (LOC) 3.1.4.3.2 (GS), and 3.3.4.2 (VOR)

** FAA National Standard Document Order No. 9840.1, Sept. 2, 1982 "US National Aviation Handbook for the VOR/DME/TACAN Systems

4.3.1.2 Desired Signals at Receivers

Minimum desired signal strengths at the receiver inputs are documented in various documents such as receiver RTCA/DO-192, -195, -196 and in RTCA/DO-199 [1], and RTCA/DO-233 [2]. The results are summarized in Table 10.

Table 10: Calculated Minimum Desired Signal Strength at Receiver Antenna Input and Comparison with Receiver Sensitivity

	LOC (dBm)	**GS (dBm)**	**VOR (dBm)**
RTCA/DO-192, -195, -196	-86	-76	-93
RTCA/DO-199	-86 to -88	-76 to -78	-92 to -97
RTCA/DO-233*	-90	-86	-90
Min/Max Receiver Sensitivity**	-113/-93	-99/-87	-113/-99

* from Table 11, ** from Table 12

From Table 10, the calculated minimum signal strength at the receivers specified in RTCA/DO-192, -195, -196, -199 and -233 vary from -86 to -90 dBm for LOC, from -76 to -86 dBm for GS and between -90 to -97 dBm for VOR.

RTCA/DO-192, -195, and -196 provided the data shown in Table 10 without clarifications. It is understood that they were computed assuming field incident upon an isotropic, lossless antenna, and that there was no additional cable loss. The same assumptions were made in RTCA/DO-199 as the initial estimations, and the results were similar.

RTCA/DO-199 also provided a range for minimum signal strength at receivers for each receiver system. For LOC, the range at the output of a lossless isotropic antenna is from –86 dBm to –88 dBm, which includes a 2-dB cable loss. For GS, the range at the output of an isotropic lossless antenna is from –76 dBm to –78 dBm with the additional 2-dB cable loss. For VOR, the range at the output of the antenna is from –92 to –97 dBm, which accounts for the additional 2-dB cable loss and 3-dB splitter loss.

RTCA/DO-233, on the other hand, estimated signal strength based on a number of corrections. These corrections included shadow loss; dipole antenna factor and aircraft cable loss. For shadow loss, RTCA/DO-233 assumed 3 dB for antennas at the bottom of an aircraft and 10 dB for antennas atop the aircraft. Aircraft antennas were assumed to behave like a monopole on a ground plane, thus having a dipole antenna factor. The cable loss was assumed to be 3 dB. A sample calculation used in RTCA/DO-233 is tabulated in Table 11.

Table 11: RTCA/DO-233 Sample Desired Signal Strength Calculation

	LOC	**GS**	**VOR**
External Signal Strength (dBμV/m)	32	46	39
Shadow Loss (dB)	3	3	10
Dipole Antenna Factor (dB)	9	19	9
Aircraft Cable Loss (dB)	3	3	3
Desired Signal at Receiver (dBμV)	17	21	17
Desired Signal at Receiver (dBm)	**-90**	**-86**	**-90**

For comparison, the last row of Table 10 also shows the range of receiver sensitivities according to manufacturers' published specifications. These specifications were compiled from manufacturers' web sites and by communication with manufacturers. More details are described in the next section.

The range of receiver sensitivity is from -113 to -93 dBm for LOC, -99 to -87 dBm for GS, and -113 to -99 dBm for VOR. Compared to the calculated minimum desired signal strengths, the receiver sensitivities are lower (more sensitive) in all cases, regardless of whether the desired signal strengths were from receiver MOPS (such as RTCA/DO-195, -196, -192), or from RTCA/DO-199 and RTCA/DO-233. Thus, most receivers are sufficiently sensitive in most installations.

4.3.1.3 Manufacturer Receiver Sensitivity Specifications

Based on test results in RTCA/DO-199 and RTCA/DO-233, the receiver interference thresholds bear a relationship with receiver sensitivity for certain modulated interference signals. Thus, it is desirable to characterize the receiver sensitivity, as this characterization may provide additional insight regarding the range of receiver interference thresholds.

A survey of receiver sensitivity was conducted for many commercially available models from manufacturers of aircraft receivers, including Bendix King, Allied Signal, Honeywell, and Rockwell Collins. A summary of the results is shown in Table 12. The highest and the lowest values for each receiver are **highlighted in bold and underlined in the table**.

Table 12: Receiver Sensitivity Derived from Equipment Specifications. The Highest and the Lowest Values are Highlighted.

GS		LOC	
Model	**Level (dBm)**	**Model**	**Level (dBm) * typical/max**
Rockwell Collins		**Rockwell Collins**	
ILS-700**	-99	ILS-700**	**-113/-113**
ILS-700A	**-99**	ILS-700A	-99/-99
ILS-720	-89	ILS-720	-99/-99
ILS-900	-96	ILS-900	-96/-96
GLU-9xx	-89	GLU-9xx	-96/-96
GNLU-9xx	-89	GNLU-9xx	-96/-96
Honeywell/Allied/Bendix King		**Honeywell/Allied/Bendix King**	
RNA-34A	-87	RNA-34A	-93/-99
KNR-6030	-93	KNR-6030	-109.5/-109.5
RIA-35A	-87	RIA-35A	-103.5/-103.5
RIA-35B	**-87**	RIA-35B	-103.5/-103.5
KN 35	-91.4 (typ), -87 (max)	KX155	**-113/-107**
		KN 35	**-113/-107**

VOR			
Rockwell Collins Avionics		**Honeywell/Allied Signal/Bendix King**	
Model	**Level (dBm)**	**Model**	**Level (dBm)**
VOR-700	-107/-107	RNA-34A	-101/-99
VOR-700A	-107/-107	KNR-6030	-109.5/-109.5

* For ILS-LOC and VOR, receiver sensitivity levels are given for flag condition and for 6 dB (S+N)/N audio

** ILS-700 and VOR-700 do not meet the ICAO frequency modulation (FM) interference immunity requirements

As stated previously, there were wide ranges of sensitivity for each of the receivers. The difference in sensitivity between the most and the least sensitive models is 20 dB for LOC, 12 dB for GS and 14 dB for VOR. This large range of sensitivity may be cause for concern. It is possible that many receivers are too sensitive, which may lead to undesired valid signals being received far outside of the intended coverage airspace. The lower sensitivity threshold tends to imply lower interference thresholds, as the desired-to-undesired signal ratio tends to stay fixed according to RTCA/DO-199 and RTCA/DO-233. As a result, lower sensitivity threshold may lead to higher occurrences of false interference outside the intended coverage airspace.

4.3.1.4 Receiver Interference Threshold Determination

To address the in-band, on-channel type of interference, several information sources on receiver interference thresholds were considered in this study. These sources included ICAO, RTCA/DO-199, and RTCA/DO-233. Relevant data from these documents were extracted and summarized in this section. In addition, deficiencies in these documents are discussed and suggestions are made concerning future investigation on this topic.

Type of interference considered in MOPS

Receiver MOPS RTCA/DO-192, -195 and -196 provided specifications on tolerance to various types of front-end interference, or the interference caused by signals entering through the receiving antenna port. These interferences include, but are not limited to, in-band adjacent channel signal, cross modulation, intermodulation with FM broadcasts, desensitization due to high input power and out-of-band, out-of-channel spurious interference. Due to low power output from PEDs (even intentional transmitters) and the high path loss between the passenger cabin and external aircraft antennas in aircraft frequency bands, the out-of-band, out-of-channel interference threats are either not relevant, or become insignificant.

The receiver MOPS, however, failed to address the most severe type of interference: the in-band on-channel type. This type of interference is important as receivers are designed to deal with very low desired signal levels (approximately -90 dBm range or lower). The extreme receiver sensitivity now makes those weak in-band emissions from PEDs a concern that had to be properly addressed.

In-band on-channel interference is briefly mentioned in ICAO, and more extensively in RTCA/DO-199 and RTCA/DO-233. RTCA/DO-199 and RTCA/DO-233, however, are not performance standards for receivers.

ICAO's in-band on-channel interference specifications

The ICAO documents provided a few guidelines for receivers regarding in-band on-channel interference signal. The ICAO documents call for desired signal to undesired co-channel signal ratio to be at least 20 dB (ICAO Annex 10, Attachment C. Section 2.6.2.1 for LOC, 2.5.2.2 for GS and Section 3.4.6.2 for VOR). The interference signals in this case are of the same type as the desired signals, i.e., LOC, GS and VOR. However, the ICAO attachment C, where these guidelines were specified, was only intended for guidance and clarification purposes. It was not intended to be a part of the official ICAO document. Therefore, it is unlikely that these specifications were taken seriously.

RTCA/DO-199 Investigation

RTCA/DO-199 and RTCA/DO-233 provided the most information about receiver interference thresholds with respect to PEDs. In RTCA/DO-199, many tests were conducted to determine the receiver interference thresholds for various systems. LOC, GS and VOR were among the systems tested. Interference-to-desired signal ratio could easily be determined from the test signal strength and the measured susceptibility level.

The results of the testing reported in RTCA/DO-199 were provided in the form of tables and charts, from which relevant data for LOC, GS and VOR were extracted and shown in Table 13.

In RTCA/DO-199, the official desired-to-undesired signal ratios were provided as a typical value, which is valid across most of the channel bandwidth. However, when the interfering signal is such that it mixes with the local carrier to produce a frequency close to the receiver's side band, susceptibility notches can occur. The desired-to-undesired signal ratio can then be as high as 38 dB for LOC, 35 dB for

GS and 46 dB for VOR. Theoretical analysis was also conducted and presented in RTCA/DO-199, and the results are shown in the same table for comparison.

Table 13: Receiver Iinterference Thresholds Reported in RTCA/DO-199.

	Test Signal Level (dBm)	Disruption Threshold (dBm)	Official Desired-to-Undesired ratio (dB)	Unofficial* Disruption Threshold (dBm)	Unofficial* Desired-to-Undesired Ratio
LOC	-88	-104	**16**	-127	38 (meas.) 42 (theo.)
GS	-78	-93	**15**	-113	35 (meas)
VOR	-97	-110	**13**	-143	46 (meas) 51 (theo)

* The unofficial data were characterized at the receiver susceptibility notches. Data on desired/undesired signal ratio were based on both measurement and theoretical analysis.

According to RTCA/DO-199, it is very difficult to maintain signal lock at the susceptibility notches, even if intended. The official values were, therefore, selected by ignoring narrowband notches. RTCA/DO-199 also provided probability analysis for VOR systems to support the above observations.

A major limitation with the analysis and the interference thresholds reported in RTCA/DO-199 was that they were based on measurements on a single system. There were actually more than one LOC and VOR system characterized and documented in Volume II. However, the measurements conducted on other systems were not as thorough, and, therefore, not used as official data. Regardless, test results from a very limited set of equipment are a concern when extrapolating or generalizing to all products.

RTCA/DO-233 Investigation

RTCA/DO-233 (Section 4.2.2.2) discusses antenna-coupled interference and the susceptibility requirements. Tests conducted have identified four interference mechanisms for ILS systems (both for LOC and GS receivers). These four mechanisms are summarized below.

Mechanism 1: Out-of-Band Interference

This mechanism is defined as an undesired signal falling outside the frequency range of the ILS receiver. Out-of-band interference requires too high a level of the undesired signal to be produced by non-intentionally transmitting PEDs.

This statement was made specifically for unintentionally transmitting devices, or for out-of-channel emissions from intentional transmitters. For in-band intentional transmission, such as cellular phone carrier frequency, FCC spectrum management policy is designed to provide protection; in this case, according to RTCA/DO-233.

Mechanism 2: *In-Band On-Channel CW Interference*

This mechanism is defined as an undesired, low-level CW signal falling inside the bandwidth of a selected ILS channel, but outside the sidebands of the ILS signal (susceptibility notches). In this case, interference takes place when undesired signal level is increased to 6 dB below the desired signal.

<u>Mechanism 3:</u> *In-Band On-Channel Amplitude Modulation (AM) Interference*

This mechanism is defined as an undesired signal, modulated with very low frequency of any shape, falling inside the bandwidth of a selected ILS channel, but outside the sidebands of the ILS signal (susceptibility notches). In this case, the susceptibility is roughly equal to the sensitivity of the receiver, and is independent of the desired signal level. The consequence of the disturbance is a deviation of the ILS indicator that can lead to autopilot disconnect.

<u>Mechanism 4:</u> *Undesired signals inside the susceptibility notches*

This mechanism is defined as an undesired, very low-level CW or AM signal that falls inside the sidebands of the ILS signal (susceptibility notches). This phenomenon is most unlikely to occur, according to RTCA/DO-233. In this case, the interference level can be as low as 40 dB below the desired signal level, and it can result in a stable deviation of the ILS indication (i.e., introducing a stable and erroneous offset in either the LOC bar or GS pointer of the flight deck indicators).

Concerning interference Mechanism 1 for intentionally transmitting PEDs, protection against desensitization also depends on aircraft pathloss and PEDs carrier signal strength. According to receiver MOPS, out-of-band interference levels (desensitization) are -13 dBm for ILS LOC and VOR, and -16 dBm for ILS GS (spurious response). Thus, for cellular phones transmitting 1 W of power (30 dBm), a minimum pathloss of approximately 45 dB or lower (measured at cellular phone carrier frequency), may run the risk of interference. Realistically, cellular phones typically radiate at a much lower level than 1 W to conserve power and increase battery life. In addition, aircraft antennas are not designed to be efficient out of band. It is, therefore, expected that pathloss is significantly higher than 45 dB at cellular phone carrier frequencies, and the risk of interference through the antennas is low.

For ILS LOC receivers, RTCA/DO-233 sets four different interference thresholds for in-band interference. The first three deal with interference from unmodulated carrier signals, and the fourth deals with interference from a modulated carrier signal. A brief summary of the four types is shown below:

- <u>Type I:</u> Unwanted CW signal mixes with the LOC carrier to produce a frequency within about 0.5 Hz of 90-Hz or 150-Hz ILS sidebands. The unwanted RF signal must be as low as 46 dB below the LOC carrier level.

- <u>Type II:</u> Unwanted CW signal mixes with the LOC carrier to produce a frequency within about 10 Hz of 90-Hz or 150-Hz ILS sidebands. The unwanted RF signal must be as low as 26 dB below the LOC carrier level.

- <u>Type III:</u> Unwanted CW within the ILS LOC receiver pass band. Unwanted signal must be as low as 7 dB below the LOC carrier level

- <u>Type IV:</u> Unwanted “AM” modulated with 90 Hz or 150 Hz. Unwanted signal must be as low as 13 dB below the LOC carrier level.

While the above statements were stated explicitly for the ILS LOC, similar statements can be made for GS as well, due to similarity between the two systems. RTCA/DO-233 did not provide data or analysis pertaining to VOR systems’ receiver interference thresholds.

RTCA/DO-233, however, did not provide much data to substantiate the above statements. In addition, while there were tests conducted, the number of systems tested appeared to be limited.

RTCA/DO-233 is also not consistent even within itself. The statements made concerning the four interference *mechanisms* and the four *types* of interference thresholds are somewhat inconsistent with each other. An example is *Type IV* interference threshold versus *mechanism 3* threshold for "AM" modulated interference. Type IV threshold can be as high as 13 dB below the LOC carrier, while mechanism 3 threshold should be independent from the desired signal level. Also, for undesired signals inside the susceptibility notches, *Type I* states that the interference-to-signal ratio is as low as -46 dB at the susceptibility notches, while interference *mechanism 4* shows the same ratio as -40 dB.

There appear to be inconsistencies between RTCA/DO-199 and RTCA/DO-233. Measured data in RTCA/DO-199 show signal-to-interference (CW) of approximately 16 dB across the channel except near the susceptibility notches. RTCA/DO-233 shows signal-to-interference of 6 dB to 7 dB for in-band on-channel "CW" interference.

It is, therefore, desirable that further testing and more rigorous analysis be conducted to provide a more substantiated set of conclusions. This testing requires the participation of equipment manufacturers, as they have the proper experience and interface equipment to deal with the issue properly.

4.3.2 GPS Receiver Interference Thresholds

Of the four systems considered (LOC, GS, VOR and GPS), the interference thresholds for GPS systems are the most well defined and consistent between various standards and regulations. A representative set of data, taken from ITU-R M.1477 [15], is summarized below:

There are three types of GPS air navigation systems in which receivers are relatively well developed:

Satellite Based Augmentation System (SBAS): This system is designed for Category I precision approach. GPS/WAAS and European Geostationary Navigation Overlay Service (EGNOS) are examples of this system.

Ground Based Augmentation System (GBAS): This system uses ground-based pseudolite emitting signal having similar characteristics of GPS. An example is GPS/Local Area Augmentation System (LAAS), designed for Category II/III precision approach.

Semi-Codeless Receiver: Receivers of this type are typically ground based and are more sensitive to interference.

Receiver interference thresholds defined in ITU-R M.1477 are summarized in Table 14. Data for semi-codeless ground receivers are also provided for comparison. Even though semi-codeless receivers have lower interference threshold (in track mode), this type of receiver is to be used only on the ground and, therefore, not considered in this analysis.

Table 14: GPS Interference Thresholds

	SBAS Receiver	**GBAS Receiver**	**Semi-codeless Receiver**
Narrow-band Track mode	-120.5 dBm	-120.5 dBm	-124.5 dBm
Narrow-band Acquisition mode	-126.5 dBm	-126.5 dBm	-126.5 dBm
Wide-band Track mode	-110.5 dBm/MHz	-110.5 dBm/MHz	-116.5 dBm/MHz
Wide-band Acquisition mode	-116.5 dBm/MHz	-116.5 dBm/MHz	-116.5 dBm/MHz

ITU-R M.1477 also provided additional data concerning the behavior of the interference threshold as a function of interference signal bandwidth. The narrow-band acquisition mode data show that CW, and for signal with bandwidth up to 700 Hz, are the most severe threats with the lowest thresholds of -126.5 dBm. The same threshold holds for both SBAS and GBAS air navigation receivers.

The interference threshold is monotonically higher with larger interference bandwidth. Interference threshold versus bandwidth for SBAS and GBAS air navigation receivers in track mode is similar to the data presented in Table 15. The same trend is also used for receivers in acquisition mode, with the interference threshold 6 dB lower. In Table 15, narrow-band signal is defined as having bandwidth less than or equal to 700 Hz, and wide-band signal as having interference bandwidth in the range 100 kHz to 1 MHz.

In addition to the previously referenced ITU document, the following MOPS and TSO references also provide similar data for various GPS receiver systems:

- RTCA/DO-208 [16] and TSO-C129a: Airborne Supplemental Navigation Equipment using GPS
- RTCA/DO-229B [17] and TSO-C146: Stand-Alone Airborne Navigation Equipment using the GPS/WAAS
- RTCA/DO-229A: Airborne Navigation Sensors using the GPS/WAAS
- RTCA/DO-253A [18]: GPS/LAAS Airborne Equipment
- RTCA/DO-228 [19]**:** Global Navigation Satellite System (GNSS) Airborne Antenna Equipment
- RTCA/DO-235 [20]: Frequency Interference Relevant to the GNSS

Table 15: Interference Threshold Versus Interference Bandwidth (BW_i) For GPS Receivers And For SBAS And GBAS Air Navigation Receivers In Track Mode.

Bandwidth (MHz)	**Receiver Interference Threshold**
$0 \le BW_i \le 700$ Hz	-120.5 dBm
$700 \le BW_i \le 10$ kHz	Linearly increasing from –120 dBm to –113.5 dBm
10 kHz $\le BW_i \le$ 100 kHz	Linearly increasing from –113.5 dBm to –110.5 dBm
100 kHz $\le BW_i \le$ 1 MHz	-110.5 dBm
1 MHz $\le BW_i \le$ 20 MHz	Linearly increasing from –110.5 dBm to –97.5 dBm
20 MHz $\le BW_i \le$ 30 MHz	Linearly increasing from –97.5 dBm to –91.1 dBm
30 MHz $\le BW_i \le$ 40 MHz	Linearly increasing from –91.1 dBm to –89.5 dBm
40 MHz $\le BW_i$	-89.5 dBm

4.3.2.1 General conclusions on GPS receiver susceptibility

The lowest interference threshold is -126.5 dBm for CW interfering signal and for signals having bandwidth up to 700 Hz. The wideband interference threshold is higher. These data are consistent between many RTCA MOPS and with the ITU-R M.1477.

RTCA/DO-199 also provided GPS receiver susceptibility at -130 dBm at the receiver. Since the receiver MOPS specified -126.5 dBm at the output of the antenna, the difference of 3.5 dB can be easily accounted for by cable loss.

It is also important to note that the interference thresholds specified were given at the output of a *passive* GPS antenna. Thus, additional cable losses had to be considered to determine the threshold at the receiver input. If the GPS antenna is active, the GPS threshold is given at the output of the antenna, but before the pre-amplifier. Thus, the receiver interference threshold and the pathloss measurement should account for the pre-amplifier gain appropriately.

4.3.3 Estimation of Reasonable and Worst Case Minimum Receiver Interference Thresholds

It is easy to select the worst case, or “absolute minimum” receiver interference threshold for the PED threat risk assessments. However, the probability analysis shown in RTCA/DO-199 for VOR receiver (Section 4.3.1.4) is very convincing by showing that the chance of a computer clock, or any signal, being exactly equal to 30 Hz VOR offset for a period long enough to cause undetectable interference is extremely unlikely (the susceptibility notches for VOR, at which the worst-case interference occurs, is where the interference signal is exactly 30 Hz from the VOR signal). Thus, the official interference threshold for VOR used in RTCA/DO-199 is 13 dB below the desired signal, rather than the 46 dB worst case. This 13 dB signal-to-interference ratio is valid across the band, except at the susceptibility notches. This value is, therefore, termed as a “reasonable” estimate of the ratio.

Both RTCA/DO-199 and RTCA/DO-233 failed to provide a similar probability analysis for LOC and GS systems. However, the same arguments are still valid, because the probability of having any signal lock on to the susceptibility-notches frequencies (90-Hz or 150-Hz ILS sidebands) long enough to cause undetectable interference is very small. According to RTCA/DO-233, the next worst case (Type II) for LOC is when the signal mixes with the LOC carrier signal to produce a frequency within about 10 Hz of the 90-Hz or 150-Hz sidebands. In this case, RTCA/DO-233 states that the unwanted RF signal must be as low as 26 dB below the LOC carrier level. This statement can be generalized to include GS systems as well, due to their similarity with the LOC system. This 26-dB signal-to-interference ratio is, therefore, considered a "reasonable" estimate for both LOC and GS systems. The "worst case", defined as Type I in RTCA/DO-233, has a signal-to-interference ratio of 46 dB for LOC systems, and is generalized to include GS systems due to similarities.

Table 16: Navigation Radio "Reasonable Minimum" and "Absolute Minimum" Interference Thresholds.

	VOR	**LOC**	**GS**	**GPS**
Desired Signal Strength (dBm) ("Reasonable min."/ "Absolute min.")	-93 /-113	-86 / -113	-76 /-99	
Signal-to-Interference ratio (dB) ("Reasonable "/ "Worst case")	13 /46	26 / 46	26 / 46	
Nav. Radio Minimum Interference Threshold (dBm) (row 1 – row 2) ("Reasonable min."/ "Absolute min.")	-106/-159	-112 / -159	-102/-145	-126.5

Table 16 summarizes the "*reasonable minimum*" and the "*absolute minimum*" receiver interference thresholds to be used for the wireless handset threat assessment reported in [3]. In this table, the "reasonable minimum" desired signal strength is chosen to be the minimum required sensitivity as specified in receiver MOPS such as RTCA /DO-192, DO-195, and DO-196. This value is the minimum receiver signal strength within the airspace coverage area, and is shown in Table 10 to be -93 dBm, -86 dBm and -76 dBm for VOR, LOC and GS, respectively. The "*absolute minimum*" desired signal strength is taken to be the lowest receiver sensitivity based on a survey of known commercial receivers shown in Table 12. Data for GPS were consistent between various RTCA and ITU documents. The lowest interference threshold is -126.5 dBm.

4.4 Spurious Radiated Emissions

4.4.1 Regulatory Limits

In the US, the FCC provides guidance for allowable signal emissions from consumer devices. This guidance is published and available on the Internet, in the US CFR, Title 47 "Telecommunication". Within Title 47, there are numerous "Parts" and "Sections" that address the full range of available product types.

4.4.1.1 Cellular Radiotelephone Service

FCC Part 22 contains the regulations for public mobile services, and Subpart H provides guidance for cellular radiotelephone service. 47CFR22.917 provides the emission limitations for cellular handsets, with graduated emissions masks depending upon the frequency offset from the unmodulated carrier frequency. In summary, on any frequency removed from the carrier frequency more than 90 kHz, the mean power of emissions must be attenuated below the mean power of the unmodulated carrier (P) by at least 43 + 10logP dB. Thus, for a 1-W unmodulated carrier frequency, a 47CFR22.917 compliant cellular handset could radiate 0.05 mW (or -13dBm) of power in any aircraft communication or navigation radio frequency band. Figure 4.5 shows these levels graphically.

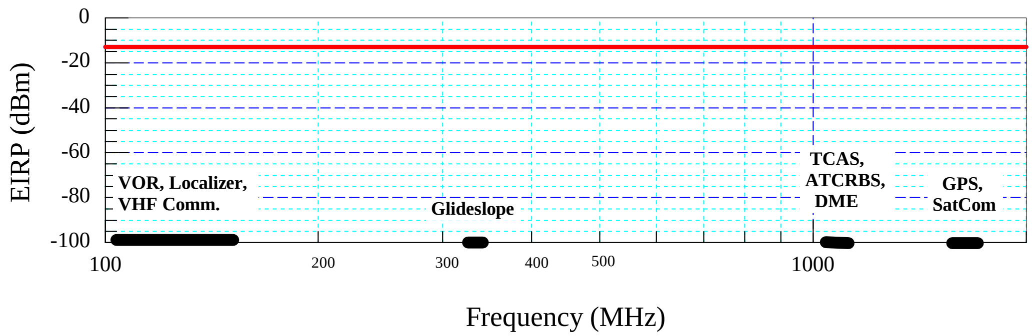


Figure 4.5: 47CFR22.917 and 47CFR24.328 limits for spurious radiated emissions from Cellular and PCS handsets, respectively. Aircraft radio frequency bands are shown along the bottom frequency scale.

It should be noted that 47CFR22.925 specifically prohibits airborne operation of cellular telephones. This regulation applies as soon as the aircraft is no longer touching the ground, and is intended to prevent interaction with multiple cell base stations and possible interference with other calls.

4.4.1.2 Personal Communications Services

FCC Part 24 contains the regulations for PCS. The 47CFR24.238 provides the simple emission limit statement in paragraph (a) “On any frequency outside a licensee's frequency block, the power of any emission shall be attenuated below the transmitter power (P) by at least 43+10log(P) dB.” Thus again, for a 1-W unmodulated carrier frequency, a 47CFR22.238 compliant cellular handset could radiate 0.05 mW (or -13dBm) of power in any aircraft communication or navigation radio frequency band.

It should be noted that 47CFR22.925 does NOT apply. The 47CFR24.2 lists the other FCC rule parts that are applicable to licensees in PCS, but specifically excludes any reference to Part 22. Thus, there is no FCC prohibition from airborne operation of PCS telephones.

4.4.2 Measurement Process for Spurious Radiated Emissions

4.4.2.1 NASA-LaRC Facility and Chambers

NASA-LaRC has a unique facility arrangement whereby three reverberation chambers are co-located in the same building with a semi-anechoic chamber. The facilities are well equipped with instrumentation, cables, antennas, and assorted passive and active devices appropriate for radiated emission measurement. A diagram of the reverberation and semi-anechoic chamber floor plan is shown in Figure 4.6.

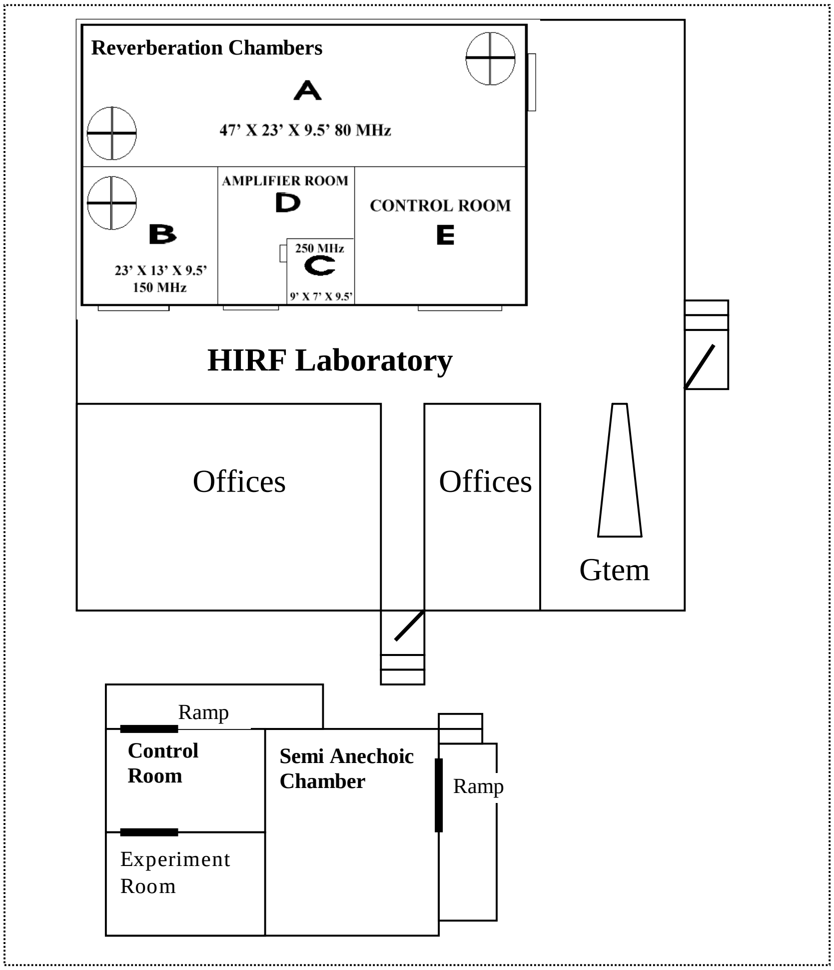


Figure 4.6: A floor plan diagram of NASA LaRC EMI measurement facilities, located in Building 1220, ground floor.

4.4.2.2 Semi-Anechoic Chamber Measurement Process

The measurement process described herein is based directly upon the RTCA/DO-233 [2] procedure, except the RTCA/DO-233 procedure did not require absorber lining for the shielded enclosure. NASA-LaRC's semi-anechoic chamber meets normalized site attenuation (NSA) requirements as specified in ANSI C63.4-1992, EN 50147-2, and CISPR16-1993, as well as field uniformity requirements as specified in IEC 61000-4-3. As with the RTCA/DO-233 procedure, a non-conductive table support was used, 0.8 m from the conductive floor, with a 1-m antenna-to-device separation distance. All antenna factor data were verified to be current, and within 1-m calibration standards specified by Society of Automotive Engineers (SAE) (Aerospace Recommend Practice-ARP) ARP-958-1997. A diagram of the SAC measurement setup is shown in Figure 4.7.

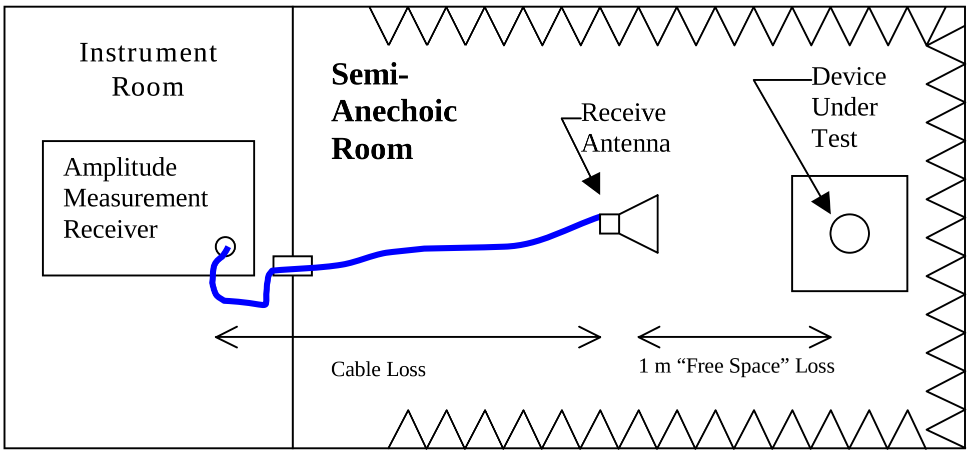


Figure 4.7: A diagram of Semi-Anechoic Chamber radiated emission measurement setup.

Standard radiated-emission measurements collected in open-area test sites, shielded rooms, and semi-anechoic chambers produce data in terms of dBμV/meter. This factor is of significant concern when applying the data to devices that are not typically used in such controlled environments. The authors of RTCA/DO-233 recognized this fact, and proposed that measured field intensity be converted to units of power, by approximating the PED as an isotropic radiator. This approximation was considered conservative, because an electrically-large PED could focus more power toward the measurement antenna than elsewhere, thus producing an artificially high measurement result. Ideally, the device should be oriented so as to provide maximum power transfer to the measurement antenna at all frequencies. The approximation is certainly more valid in a semi-anechoic room than in the passenger cabin of an airplane, and allows radiated-emission data to be more accurately applied to the measured pathloss data between passenger cabin and aircraft radio receiver antenna.

The RTCA/DO-233 formula for conversion of transmitted power to field strength of an isotropic radiator is:

$$\mathrm{EIRP} = \frac{E^2 \cdot 4\pi R^2}{120\pi} \qquad \textbf{Equation 4-2}$$

where

EIRP = Equivalent Isotropic Radiated Power of PED (wireless phone, in this case.)

E = Electric Field Intensity

R = Distance

The standard formula for converting measured voltage to radiated electric field intensity from a device, using a calibrated antenna in an Open Area Test Site (OATS) or semi-anechoic chamber is:

$$\mathrm{E}_{(\mathrm{dB}\mu\mathrm{V}/\mathrm{m})} = \mathrm{V}_{(\mathrm{dB}\mu\mathrm{V})} + \mathrm{AF}_{(\mathrm{dB})} + \alpha_{\mathrm{RcvCbl}\ (\mathrm{dB})} \qquad \textbf{Equation 4-3}$$

where

$\mathrm{E}\left(\mathrm{dB}\mu\,\mathrm{V}/\mathrm{m}\right)$ = electric field intensity (relative to $1\,\mu\,\mathrm{V}/\mathrm{meter}$)

$\mathrm{V}_{(\mathrm{dB}\mu\mathrm{V})}$ = measured voltage at amplitude measurement receiver (relative to 1 μV)

$\mathrm{AF}_{(\mathrm{dB})}$ = antenna factor from manufacturer relating field intensity at antenna to voltage measured at antenna connector (free-space input relative to 50 Ω output at 1 m)

$\alpha_{\mathrm{RcvCbl}\ (\mathrm{dB})}$ = cable loss from antenna connector to amplitude measurement receiver (input relative to output)

Equation 4-2 can be simplified for a 1-m measurement distance,

$$\mathrm{EIRP} = \frac{\mathrm{E}^2 \cdot 4\pi \mathrm{R}^2}{120\pi} = \frac{E^2(1)^2}{30} = \frac{\left[10^{-6} E_{\mu V/m}\right]^2}{30} \qquad \textbf{Equation 4-4}$$

Converting Equation 4-4 to dBm (relative to 1 mW), and accounting for E specified in μV/m at 1 m, the following relation can be obtained:

$$\begin{aligned}
\mathrm{EIRP}_{(\mathrm{dBm})} &= 10\mathrm{Log}\left[\frac{\mathrm{EIRP}}{0.001}\right] \\
&= 10\left\{\mathrm{Log}\left[\frac{1}{0.001}\right] + \mathrm{Log}\left[10^{-12}\right] + \mathrm{Log}\left[\frac{1}{30}\right] + 2\mathrm{Log}\left[\mathrm{E}_{\mu\ \mathrm{V/m}}\right]\right\} \\
&= 30 - 120 - 14.77 + 20\mathrm{Log}\left[\mathrm{E}_{\mu\ \mathrm{V/m}}\right] \\
&= -104.77 + \mathrm{E}(\mathrm{dB}\mu\mathrm{V}/\mathrm{m}) \\
&= \mathrm{V}_{(\mathrm{dB}\mu\mathrm{V})} + (\mathrm{AF}_{(\mathrm{dB})} - 104.77) + \alpha_{\mathrm{RcvCbl}\ (\mathrm{dB})}
\end{aligned} \qquad \textbf{Equation 4-5}$$

It is desirable to have the amplitude measurement receiver output in terms of power ($\mathrm{P}_{\mathrm{Meas(dBm)}}$), instead of voltage ($\mathrm{V}_{(\mathrm{dB}\mu V)}$). For a matched 50-**Ω** system, converting from dBμV to dBm:

$$\mathrm{P}_{\mathrm{Meas}\ (\mathrm{dBm})} = 10\mathrm{Log}\left\{\left(\frac{1}{10^{-3}}\right)\left(\frac{\mathrm{Volts}^2}{\mathrm{Ohms}}\right)\right\} \qquad \mathrm{Volts} = \left[\left(10^{-6}\right)\left(10^{\left(\mathrm{V}_{(\mathrm{dB}\mu\mathrm{B})}/20\right)}\right)\right]$$

$$= 10\mathrm{Log}\left\{\left(\frac{1}{10^{-3}}\right)\left(\frac{\left[\left(10^{-6}\right)\left(10^{\left(V_{(dB\mu V)}/20\right)}\right)\right]^2}{50}\right)\right\}$$

$$= 10\mathrm{Log}\left\{\left(\frac{1}{5 \bullet 10^{10}}\right)\left(10^{\left(V_{(dB\mu V)}/20\right)}\right)^2\right\}$$

$$= 10\left\{-10.7 + 2\left(V_{(dB\mu V)}/20\right)\right\}$$

$$= V_{(dB\mu V)} - 107$$

Equation 4-6

Combining terms, we obtain the following relationship between wireless phone radiated power and power at the amplitude measurement receiver:

$$\begin{aligned} EIRP_{(dBm)} &= (P_{Meas\ (dBm)} + 107) + (AF_{(dB)} - 104.77) + \alpha_{RcvCbl\ (dB)} \\ &= P_{Meas\ (dBm)} + \alpha_{RcvCbl\ (dB)} + AF_{(dB)} + 2.23 \end{aligned}$$

Equation 4-7

To obtain a reduced noise floor, and/or eliminate unwanted effects of wireless phone in-band transmissions, it was desirable to attach pre-amplifiers/filters/bias-tee/etc. in-line, before the amplitude measurement receiver. These data were incorporated as a modified factor in Equation 4-7:

$$\alpha_{RcvPath\ (dB)} = \alpha_{RcvCbl\ (dB)} + \alpha_{Other\ (dB)}$$

Equation 4-8

It must be noted that α is an *attenuation* factor. Therefore, any active elements (i.e. amplifiers) that provide positive gain will result in a *negative* value in $\alpha_{Other\ (dB)}$. Incorporating Equation 4-5 into Equation 4-4, we have:

$$\boxed{EIRP_{(dBm)} = P_{Meas\ (dBm)} + \alpha_{RcvPath\ (dB)} + (AF_{(dB)} + 2.23)}$$

Equation 4-9

Equation 4-9 is very useful for a simple five-step laboratory measurement process:

Step 1). Calculate $AF_{(dB)}$ + 2.23, and interpolate values for each required measurement frequency using antenna factor data provided by the manufacturer;

Step 2). Measure $\alpha_{RcvPath\ (dB)}$ at each required frequency;

Step 3). Measure $P_{Meas(dBm)}$ with wireless phone powered OFF, to obtain a noise floor baseline;

Step 4). Measure $P_{Meas(dBm)}$ with wireless phone powered ON, in each desired operational mode;

Step 5). Use Equation 4-9 to calculated wireless phone EIRP in each desired operational mode, as well as the associated noise floor.

Determination of Antenna Factor Using Reference Antenna (Micropulse GPS Antenna Calibration)

If calibrated AF data are unavailable for a test antenna, or to check measurement chamber configuration, a standard (or calibrated) reference antenna may be utilized. Assuming an isotropic radiation pattern for the reference antenna, the following expression is based upon Equation 4-9:

$$AF_{(dB)} + 2.23 = \left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CbrRef} - \left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CblThru}$$ **Equation 4-10**

where

$AF_{(dB)} + 2.23$ = Relationship between isotropic antenna transmitted power, and power received at test antenna terminals

$\left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CbrRef}$ = Thru-Loss when transmitting from isotropic antenna to test antenna, including all cable losses

$\left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CblThru}$ = Thru-Loss with isotropic antenna cable mated directly to test antenna cable (i.e., cable loss only.)

In practice, the reference antenna may not be isotropic, and will have some gain. This gain will cause improved coupling between the reference and test antennas, thus lowering the value of $\left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CbrRef}$. Fortunately, standard (or calibrated) reference antennas are accompanied by data describing their gain relative to an isotropic radiator (i.e., $G_{Ref\,(dBi)}$). This value should be added to Equation 4-10.

Equation 4-11

$$AF_{(dB)} + 2.23 = \left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CbrRef} - \left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CblThru} + G_{Ref\,(dBi)}$$

4.4.2.3 Reverberation Chamber Measurement Process

Radiated emission measurements in reverberation chambers produce data in terms of EIRP, so the isotropic radiator approximation of Equation 4-9 is not required. An EIRP measurement is particularly useful when evaluating the EMI potential of devices that may be used in multiple locations that are electromagnetically complex. This situation is certainly applicable to wireless phones used in aircraft passenger cabins. The measurement process utilized the same amplitude measurement receiver and antennas as those used in the semi-anechoic chamber. The National Institute of Standards and Technology (NIST) have characterized NASA-LaRC's reverberation chambers for field uniformity. Details regarding their performance may be found in [24].

The standard formula for measuring EIRP in a reverberation chamber is:

$$EIRP_{(dBm)} = P_{Meas\,(dBm)} + \alpha_{Cbr\,(dB)} + \alpha_{RcvCbl\,(dB)}$$ **Equation 4-12**

where

$P_{Meas\,(dBm)}$ = power measured at amplitude measurement receiver

α_{RcvCbl} (dB) = cable loss from antenna terminals to amplitude measurement receiver (input relative to output)

α_{Cbr} (dB) = chamber loss, described below.

The relationship between the power transmitted into the reverberation chamber and the power coupled out through the receive antenna connector is given by α_{Cbr} (dB) . This definition includes the power lost as the signal travels through the chamber, reflecting off the walls and paddle wheel, coupling to, and re-radiating from anything else contained within the chamber. It also includes reflection and resistive loss contributed by the receive antenna. It is important to note that α_{Cbr} (dB) varies with paddle wheel position. For the testing described herein, all measurements were obtained with the paddle wheel rotating continuously. This technique is often referred to as “mode-stirred” testing. From this point on, it will be assumed that all values in Equation 4-12 are maximum values obtained over at least one entire paddle wheel rotation. The paddle wheel should be rotated fast enough to complete at least one rotation during each measurement period, but slow enough for the measurement receiver to complete each frequency sweep over a small fraction of the paddle wheel rotation. The rotation rate should not be a multiple of the frequency sweep time. The typical default for NASA’s reverberation chambers is five revolutions per minute, and the measurement time is adjusted based upon spectrum analyzer sweep time to provide adequate sampling so as to capture the maximum radiated emissions from the device under test. Using a calibrated signal source, as shown in Figure 4.8, all loss factors can be measured together:

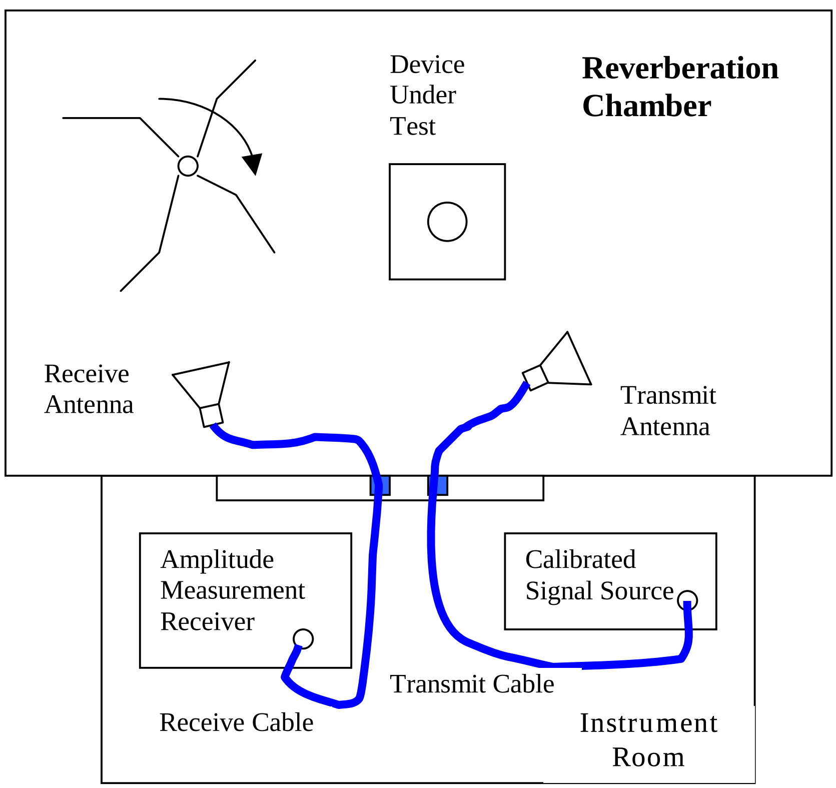


Figure 4.8: : Diagram of Reverberation Chamber radiated emission measurement setup

$$P_{Xmt\ (dBm)} - P_{Meas\ (dBm)} = \alpha_{Cbr\ (dB)} + \alpha_{RcvCbl\ (dB)} + \alpha_{XmtCbl\ (dB)}$$ **Equation 4-13**

where

$P_{Xmt\ (dBm)}$ = power transmitted from calibrated signal source (relative to 1 mW).

$\alpha_{XmtCbl\ (dB)}$ = cable loss from calibrated signal source to transmit antenna connector (input relative to output).

If the transmit cable is disconnected from the transmit antenna, and connected to the input of the amplitude measurement receiver, the transmit cable loss can be measured directly.

$$\alpha_{XmtCbl\ (dB)} = \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{Transmit\ Cable\ Cal}$$ **Equation 4-14**

Because the amplitude measurement receiver should always be located outside the reverberation chamber, it is convenient to group the chamber loss and receive cable loss together. Also, to obtain a reduced noise floor, and/or eliminate unwanted effects of wireless phone in-band transmissions, it was desirable to attach pre-amplifiers/filters/bias-tee/etc. in-line, before the amplitude measurement receiver. These data were incorporated as an additional factor. For the testing described herein, these additional factors are added to the chamber loss and receive cable loss to obtain a total measurement transfer function:

$$\alpha_{RC\ Tot\ (dB)} = \alpha_{Cbr\ (dB)} + \alpha_{Rcv\ Cbl\ (dB)} + \alpha_{Other\ (dB)}$$ **Equation 4-15**

This new expression can be substituted for the chamber and receive cable losses in Equation 4-13, and it can be rearranged to provide a way to obtain the total measurement transfer function:

$$\alpha_{RC\ Tot\ (dB)} = \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{Chamber\ Cal} - \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{Transmit\ Cable\ Cal}$$

$$= \alpha_{CbrCal\ (dB)} - \alpha_{XmtCbl\ (dB)}$$ **Equation 4-16**

This equation introduces a new term, the chamber calibration factor: $\alpha_{CbrCal\ (dB)}$, which is experimentally measurable, but contains the unnecessary transmit cable loss (i.e., not applicable to the device-under-test measurement). Subtracting the transmit cable loss relates the calibrated source output power to the transmit antenna connector. It is assumed that the transmit antenna is efficient. It must be noted that α is an *attenuation* factor. Therefore, any active elements (i.e., amplifiers) that provide positive gain may result in a *negative* value in $\alpha_{Other\ (dB)}$, and, therefore, also in $\alpha_{CbrCal\ (dB)}$ and $\alpha_{RC\ Tot\ (dB)}$. Incorporating Equation 4-16 into Equation 4-12, we obtain a new formula for measuring EIRP in a reverberation chamber:

$$\boxed{EIRP_{(dBm)} = P_{Meas\ (dBm)} + \alpha_{CbrCal\ (dB)} - \alpha_{XmtCbl\ (dB)}}$$ **Equation 4-17**

Equation 4-17 is very useful for a simple five-step laboratory measurement process:

Step 1). Configure as shown in Figure 4.9. Measure $\alpha_{XmtCbl\ (dB)}$ at each required frequency;

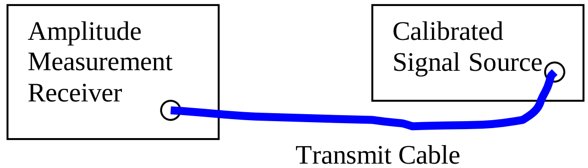


Figure 4.9: Setup for transmit cable calibration.

Step 2). Configure as shown in Figure 4.8. Measure $\alpha_{CbrCal\,(dB)}$ at each required frequency;

Step 3). Remove calibrated source and terminate transmit path connection. Measure $P_{Meas(dBm)}$ with wireless phone powered OFF, to obtain a noise floor baseline;

Step 4). Measure $P_{Meas(dBm)}$ with wireless phone powered ON, in each desired operational mode;

Step 5). Use Equation 4-17 to calculate wireless phone EIRP in each desired operational mode, as well as the associated noise floor.

4.4.2.4 Measurement Tolerances

Unless otherwise stated for a particular measurement, the tolerances are estimated to be:

A: Distance:	± 5%
B: Frequency	± 2%
C: Amplitude Measurement Receiver:	± 2 dB
D: Amplitude Measurement System:	± 5 dB

The measurement process included a calibration element whereby all losses were subtracted from the measured data using exactly the same instrumentation configuration, thus reducing these uncertainties to that of the amplitude measurement receiver. An additional maximum field uniformity uncertainty of +/- 3 dB was introduced into both the semi-anechoic and reverberation chamber measurements. An additional maximum antenna factor calibration uncertainty of +/- 1.2 dB was introduced into the semi-anechoic chamber measurements. This additional factor results in an overall amplitude measurement system uncertainty of no greater than about +/- 5 dB.

4.4.2.5 Bandwidth and Scan Time

The RTCA/DO-233 procedure recommended that measuring-equipment bandwidths be chosen so that ambient levels are 6 dB below emission limits, and dwell times should be at least 15 msec/kHz. These requirements are essentially identical to MIL-STD-462D [25]. RTCA/DO-233 recommended a single, slow sweep over each frequency band, to meet the required measurement time. As a measurement receiver operates, it displays the amplitude at each frequency during a sweep. Because the reverberation chamber boundary condition changes with paddle position, multiple measurement samples are required at different paddle positions in order to find the maximum coupling amplitude. More samples are required at lower frequencies to provide confidence that the peak amplitude was accurately measured. To reduce test time for the mode-stirred measurements, it was decided to use multiple, short sweeps instead of a single long sweep. The same approach was used in the semi-anechoic chamber for measurement comparability.

There are several references applicable to measurement bandwidths. Some of them are listed in Table 17. RTCA DO-160D is directly applicable to assessing the potential for spurious radiated emissions to interfere with commercial aircraft communication/navigation systems, and specifies that bandwidths of 10 kHz "shall be used in the notches (aircraft communication/navigation receive bands, including GPS) with no correction factor being applied". The purpose for the reduced bandwidth is to improve measurement sensitivity. For this test, it was decided to incorporate the DO-160D measurement bandwidths, up to 1000 MHz. The 100-kHz bandwidth was also applied above 1000 MHz, except for the GPS band, where 10 kHz was again used, as specified by DO-160D. This assumption is reasonable for VOR, LOC and GS because the channel bandwidths are no greater than 10 kHz. GPS, however, uses about a 3-MHz channel bandwidth. A 10-kHz measurement bandwidth used in the GPS band could, therefore, underestimate an interfering signal amplitude by up to ~24 dB. Based upon initial results, it was planned to modify these bandwidths to best quantify the peak amplitude of any observed emissions. This modification occurred in the GPS frequency band, and will be discussed in Section 4.4.4.

Table 18 shows each frequency band of interest, the selected resolution bandwidth, sweep times, and minimum measurement times for semi-anechoic chamber testing.

Table 17: Comparison of Measurement Bandwidths from Several Standards.

Frequency Band	**RTCA DO-160D [26]**	**RTCA DO-233 [2]**	**ANSI C63.4-2000 [27]**	**ETSI EN 301 908-7 V1.1.1 [28]**	**MIL-STD-462D [25]**
30-400 MHz	10 kHz	100 kHz	100 kHz	100 kHz	100 kHz
400- 1000 MHz	100 kHz*	100 kHz	100 kHz	100 kHz	100 kHz
Over 1000 MHz	1 MHz*	1 MHz	1 MHz	1 MHz	1 MHz

*Specified to be 10 kHz in aircraft communication/navigation bands for categories M & H.

Table 18: Frequency Bands, Measurement Bandwidths, and Measurement Times for Semi-anechoic Chamber (SAC) Testing.

Frequency Band	**MHz**	**3 dB BW (kHz)**	**8561E & E4407B Sweep Time (ms/Sweep)**	**8561E & E4407B Dwell Time per Sweep (ms/MHz)**	**Sweeps Rqd for RTCA/DO-233 150 ms Dwell Time**	**RTCA/DO-233 Minimum SAC Measurement Time (S)**
Band 1	105-120	10	375	25.00	60	22.5
Band 2	325-340	10	375	25.00	60	22.5
Band 3	960-1215	100	64	0.25	598	38.3
Band 4	1565-1585	10	500	25.00	60	30.0

Semi-anechoic chamber testing was performed using a support fixture having a maximum rotation rate of 105 sec. To allow a margin for slower rates due to loading, the minimum semi-anechoic chamber measurement time was 120 sec for each mode, band and phone orientation.

For reverberation-chamber testing, it is usually necessary to perform more measurements at lower frequencies to gain confidence that an accurate estimate of the maximum amplitude has been obtained. The last column of Table 19 shows the most recent recommendations for desired number of independent samples for calibrating reverberation chambers (DO-160D Draft 8 [29]). However, with the reduced bandwidths used for lower frequencies, the spectrum analyzer completes fewer sweeps per paddle wheel revolution. Table 19 shows the decrease in spectrum analyzer sweeps per paddle revolution with narrower-resolution bandwidths. Practically, the spectrum analyzer display can be monitored for how quickly the maximum level stabilizes. Test measurements verified that reverberation chamber measurement times of 120 sec were adequate for determining peak emissions amplitude for each mode and band. (Only one phone orientation was required.)

Table 19: Frequency Bands, Measurement Bandwidths, and Sampling for Reverberation Chamber (RC) Measurements.

Frequency Band	MHz	3 dB BW (kHz)	8561E & E4407B Sweep Time (ms/Sweep)	RC Paddle Rotation Rate (S/Rev)	RC Sweeps per Paddle Revolution	# of Indep. Samples (DO-160D Draft 9) Desired for RC
Band 1	105-120	10	375	10	26.67	60
Band 2	325-340	10	375	10	26.67	36
Band 3	960-1215	100	64	10	156.25	18
Band 4	1565-1585	10	500	10	20.00	18

4.4.2.6 Amplitude Measurement Sensitivity

A primary goal for this effort was to demonstrate a process for measuring radiated emissions from wireless phones. Amplitude measurement sensitivity was a key element. Previous UOK Wireless EMC Center measurements utilized the following guideline (see Table 20), provided by the FAA. Units for “Antenna Sensitivity” are specified at the amplitude measurement receiver, and, therefore, do not include cable and antenna factor losses. A 10-dB margin was added to this value, and reported as the “Required Noise Floor.”

Table 20: Frequency Bands, Measurement Bandwidths, and Sampling for Reverberation Chamber Measurements Used by the UOK for PED Threat Assessment.

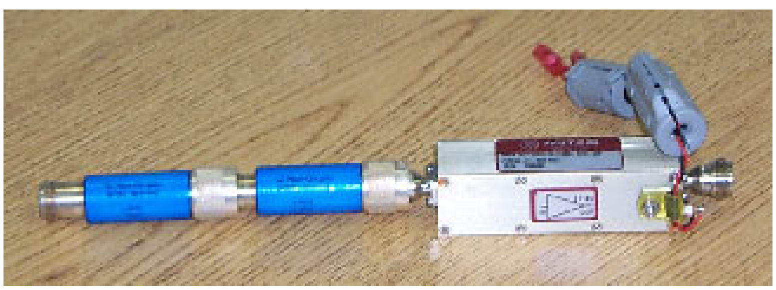
System	Frequency Range (MHz)	Antenna Sensitivity (dBm)	Required Noise Floor (dBm)
VOR	108 - 117.95	-99	-109
LOC	108.1 - 117.95	-106	-116
GS	329.15 - 335	-93	-103
DME	960 - 1215	-83	-93
GPS	1565 1585	-120	-130

NASA analysis of RTCA/DO-233 interference threshold data, and comprehensive IPL data allowed a more detailed estimate for required amplitude measurement sensitivity. Applying the conversion factor of dBmW=dBmV-107 to data provided in RTCA/DO-233, the worst-case minimum signal required for interference at each aircraft radio receiver was obtained. (See Table 21, column H.) (Please note that Section 4.3 of this report contains a much more detailed estimation of minimum interference signal amplitude at navigation radio receivers.) Data for minimum IPL were also provided in RTCA/DO-233; however, more recently acquired (and more comprehensive) data for minimum IPL have been obtained by DAL and EWI [30]. To provide the most conservative available estimate for desired measurement sensitivity, the lowest available IPL was subtracted from Table 21, Column H. The highlighted numbers in Column L were used as a guideline for minimum measurement sensitivity. This analysis was used to provide specification requirements for emission measurement instrumentation.

Table 21: NASA Analysis for Required Measurement Sensitivity.

A	B	C	D	E	F	G	H	I	J	K	L
System	**Antenna Shadow Loss (dB) (RTCA/DO-233)**	**Antenna Factor (dB) (RTCA/DO-233)**	**Aircraft Antenna Cable Loss (dB) (RTCA/DO-233)**	**ICAO Field Level (dB µV/m) (RTCA/DO-233)**	**Required Signal at Receiver (dB µV) (E-(B+C+D))**	**Minimum Signal to Interference Ratio (dB) (RTCA/DO-233)**	**Required Threat Signal at 50 Ohm Receiver (dBm) (F-107-G)**	**Minimum IPL (dB) (RTCA/DO-233)**	**Minimum IPL (dB) (Delta)**	**Minimum IPL (dB)**	**Desired Measure-ment Sensitivity EIRP (dBm) (H+K-6dB)**
VHF1	10	10.5	3	37	13.5	15	-108.5	40.5	37.5	37.5	-77
VHF2	3	10.5	3	37	20.5	15	-101.5	38	44.7	38	-69.5
VHF3	3	10.5	3	37	20.5	15	-101.5	53	37.8	37.8	-69.7
ILS (LOC)	3	9	3	32	17	40	-130	48.8	30.5	30.5	**-105.5**
VOR	10	9	3	39	17	40	-130	49.9	41.8	41.8	**-94.2**
GLS	3	19	3	46	21	40	-126	54.6	42.8	42.8	**-89.2**
DME	3	28	3	56	22	8	-93	69.1		69.1	-29.9
ATC	3	28	3	65	31	8	-84	61.3	31	31	-59
TCAS	3	28	3	65	31	8	-84	54.8	27	27	-63
GPS	0	31	3	33	-1	8	-116	82.4	53	53	**-69**
SATCOM	0	0	3	31	28	15	-94	87		87	-13

Using the desired measurement sensitivity estimates of Table 21 for the VOR, LOC and GS frequency bands as a guide, pre-amplifiers and filters were specified, procured and assembled as shown in Figure 4.10. The preamplifiers provided a gain of over 60 dB, allowing extremely sensitive measurements. Two low-pass filters were placed in series at the input of the preamplifier to prevent high-amplitude, out-of-band handset transmit signals from causing nonlinear effects and damage to the preamplifiers.



Miteq Pre-amplifier AU-1291-N-1103-1179-WP
Freq: 0.3 - 500 MHz
Gain: 61.2 dB
Noise Figure: <1.2
P. O. @ -1dB GC: ≥ 10dBm

Low Pass Filters, 450 MHz cutoff
Mini-Circuits NLP-450

Figure 4.10: : Pre-amplifier/filter arrangement and specifications for VOR/LOC and GS frequency band measurements.

A GPS survey antenna (Figure 4.11), with built-in preamplifier and filtering, was used for GPS frequency-band measurements. This antenna was not accompanied by antenna factor calibration data, which is typically supplied with standard EMC reference antennas, so a special calibration table acquisition process was developed to obtain accurate measurements in the semi-anechoic chamber (see Section 0). With the specified instrumentation, minimum measurement sensitivities and noise floors were achieved as shown in Table 22.

Figure 4.11: A Micropulse GPS antenna and remote power setup for GPS frequency band measurements. (Micropulse 2104NW, 55 dB gain, L1/L2, 12-VDC supply voltage via Bias Tee.)

Table 22: Noise Floors Achieved with Specialized Instrumentation and Facilities in Four Aircraft Navigation Frequency Bands. The Minimum Accurate Measurement Sensitivities were Estimated to be 6 dB Above Noise Floor.

Frequency Band	**Reverberation Chamber A**		**Semi-Anechoic Chamber**	
	Noise Floor: (dBm)	**Min. Meas. Sensitivity (dBm) (+6 dB)**	**Noise Floor: (dBm)**	**Min. Meas. Sensitivity (dBm) (+6 dB)**
1: 105-120 MHz	-114	-108	-102	-96
2: 325-340 MHz	-108	-102	-105	-99
3: 960-1215 MHz	-47	-41	-52	-46
4: 1565-1585 MHz	-100	-94	-91	-85

4.4.2.7 Data Acquisition Software

To shorten test time, improve accuracy, and permit real-time interpretation of radiated emission-measurement results, a data acquisition software package was developed. The software uses Agilent's Visual Engineering Environment (VEE), and functions with either an Agilent E4407B spectrum analyzer with built-in tracking generator source, or an HP8560 Series spectrum analyzer with HP85644A tracking generator source externally attached. Tracking generator sources permit simple and rapid characterization of cable/chamber transfer functions by providing a calibrated amplitude signal at the same frequency being measured by the spectrum analyzer at an instant of time. A detailed description of the software functionality is described in [31].

The SW functions in three instrument-control modes:

SW Mode 1. The tracking generator source output is commanded to fixed amplitude, and frequency synthesized with the spectrum analyzer to sweep over a user-specified frequency range. The spectrum analyzer is commanded to a user-specified resolution bandwidth, sweep time, reference level, and attenuation. The user can specify the measurement duration (dwell time), so that a peak amplitude measurement may be obtained over a test-object or paddle wheel rotation. The value, $P_{Xmt}\,(dBm) - P_{Meas}\,(dBm)$, is computed for each frequency, and stored into a text file with the instrument settings. This mode is used to measure $\alpha_{RcvPath}\,(dB)$ for the semi-anechoic method, and $\alpha_{XmtCbl}\,(dB)$ and $\alpha_{CbrCal}\,(dB)$ for the reverberation method.

SW Mode 2. The spectrum analyzer is commanded to a user-specified frequency range, resolution bandwidth, sweep time, reference level, attenuation, and measurement duration (dwell time). Measured data are adjusted by user-specified CblCal and CbrCal factors, and displayed on the screen for real-time evaluation of radiated emissions. The raw measurement data, the specified CblCal and CbrCal factors, and the adjusted data are stored with each specified frequency into separate columns of a spreadsheet, with the instrument settings. The tracking generator source is not addressed in this mode. This mode is used to measure the EIRP from the device under test, in both semi-anechoic and reverberation chambers.

The CblCal and CbrCal factors are applied differently depending upon whether a semi-anechoic or reverberation measurement is being performed:

Semi-Anechoic Chamber Measurement:

$$\mathrm{EIRP}_{(dBm)} = \mathrm{P}_{\mathrm{Meas}\,(dBm)} + \mathrm{CblCal}_{(dB)} + \mathrm{CbrCal}_{(dB)}$$

where $\mathrm{CblCal}_{(dB)} = \alpha_{\mathrm{RcvPath}\,(dB)}$ from Equation 4-8

$\mathrm{CbrCal}_{(dB)} = \mathrm{AF}_{(dB)} + 2.23$ from Equation 4-9

Reverberation Chamber Measurement:

$$\mathrm{EIRP}_{(dBm)} = \mathrm{P}_{\mathrm{Meas}\,(dBm)} - \mathrm{CblCal}_{(dB)} + \mathrm{CbrCal}_{(dB)}$$

where $\mathrm{CblCal}_{(dB)} = \alpha_{\mathrm{XmtCbl}\,(dB)}$ from Equation 4-14

$\mathrm{CbrCal}_{(dB)} = \alpha_{\mathrm{CbrCal}\,(dB)}$ from Equation 4-17

(Note that the CblCal factor is *added* in the semi-anechoic measurement and *subtracted* in the reverberation measurement.)

SW Mode 3. The spectrum analyzer is commanded to a user-specified frequency range, resolution bandwidth, sweep time, reference level, attenuation, and measurement duration (dwell time). Raw measurement data, with each specified frequency, are stored into a data file with the instrument settings. The program continues to run in a closed-loop mode, re-setting the spectrum analyzer ("clear-write") after each measurement duration period, and adding a column of data at each frequency until the loop is terminated. This program is used to study how radiated emissions change over a period of time.

4.4.3 Interactive Control of CDMA and GSM Handsets

Measurement of radiated emissions from wireless phones is significantly more complex than from other PEDs. Unlike PDAs, laptop computers, music players, televisions, games and CB/FRS radios, wireless phones require physical-layer interaction with a base station in order to exercise the breadth of their functionality. This interaction allows control of handset transmit parameters likely to influence the spurious radiated emissions from the device. In the laboratory, transmitter control can be accomplished either with base station simulators, proprietary keypad entry codes (supplied by the manufacturer), or a proprietary cable interface that connects between the phone and a programming device. (See Figure 4.12.) The UOK Wireless EMC Center has a partnership with wireless phone manufacturers, service providers, and test instrumentation providers, which allows access to these tools. The UOK Wireless EMC Center had completed preliminary radiated-emission measurements for the FAA prior to becoming involved with this effort. NASA LaRC contracted with UOK to evaluate and report CDMA and GSM handset physical-layer parameters that can influence spurious radiated emissions, and can be controlled in a laboratory. The UOK Wireless EMC Center provided an analysis of operating modes with a standard protocol for spurious radiated emissions testing [32]. The UOK provided eight wireless handsets to support experimental testing, which incorporated the programming options as shown in Table 23.

Table 23: Eight Wireless Handsets Provided by the UOK Center for Wireless EMC for Radiated Emissions Testing at NASA-LaRC.

Handset Designation	Manufacturer/Model	Programming Type
CDM1	A/1	Keypad
CDM2	A/1	Base Station, Keypad
CDM3	B/1	Base Station
CDM4	B/2	Test Harness
GSM1	C/1	Keypad
GSM2	A/2	Base Station, Keypad
GSM3	A/2	Base Station, Keypad
GSM4	A/2	Base Station, Keypad

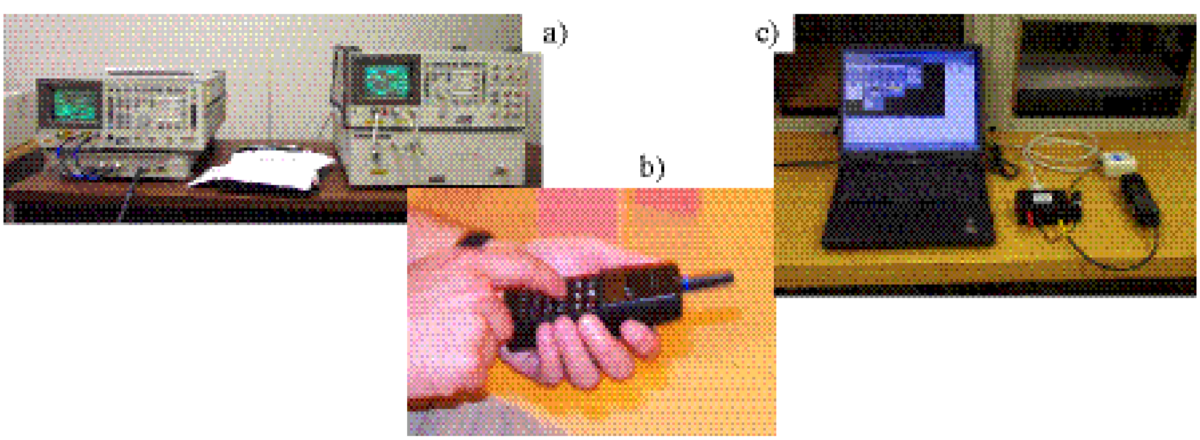


Figure 4.12: Three methods of controlling operating modes of wireless handsets: a) Base Station Simulators; b) Keypad entry of proprietary codes; c) Test harness interface.

4.4.3.1 CDMA Handset Operating Modes

The UOK Wireless EMC Center provided procedures and instrumentation to control RF Power output level, puncture rate, and vocoder rate for CDMA handsets. Keypad entry codes were limited in their ability to control puncture rate and vocoder rate. The CDMA Base Station Simulator could control the handset RF transmit power level by initiating a call in a closed-loop mode, whereby the handset transmit power would automatically increase with a specified decrease in simulator transmit power. The test harness interface could control all three parameters, with RF power control based upon a numerical entry into a proprietary software package running on a personal computer, and issuing commands via an RS232 serial bus. It was necessary to experimentally determine equivalent handset transmit power levels depending upon base station simulator versus test harness interface commands. Table 24 shows the available control options and equivalencies of the three programming methods.

Table 24: Mode Control Options for Wireless Handsets Provided by UOK, for Testing at NASA LaRC.

*Base station simulator set to "Sector A" power, closed loop mode.

**Software command set to "TXAGC" via Test Harness Interface.

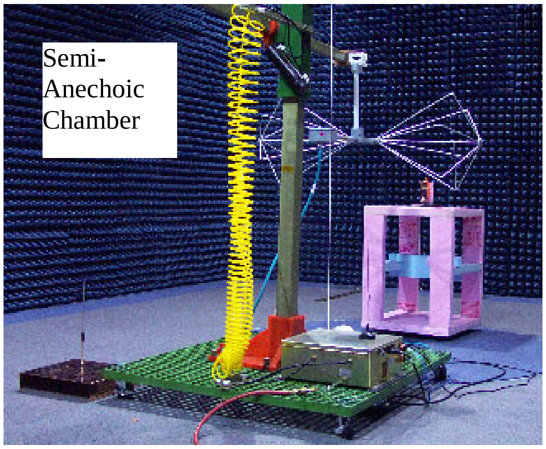
Type	**Control Method**	**Transmit Power Level**	**Channel**	**Puncture Rate**	**VOCODER Rate**	**DTX Setting**	**DRX Setting**	**Speech CODEC Rate**
CDM	Keypad (KPD)	Maximum Nominal	Not Avail	Variable	Not Avail.			
CDM	Base Station Simulator (BS)	Max= "Always Up" Med= -50dBm* Min= -25 dBm*	Not Avail	Full Half Quarter Eighth Variable	Not Avail.			
CDM	Test Harness Interface (THI)	Max= 511** Med= 280** Min= 225**	Not Avail	Full Half Quarter Eighth Variable	Full (13k) Half (8k)			
GSM	Keypad (KPD)	Max= 33 Med= 27 Min= 13	Max= 100 Med= 52 Min= 1			DTX On DTX Off	Not Avail.	Not Avail.
GSM	Base Station Simulator (BS)	Max= 1 Med= 8 Min= 15	Max= 100 Med= 52 Min= 1			DTX On DTX Off	DRX On DRX Off	Full Rate Enh. Full Rate

4.4.3.2 GSM Handset Operating Modes

The UOK Wireless EMC Center provided procedures and instrumentation to control RF Power output level, DTX, DRX, and Speech CODEC Rate for GSM handsets. Keypad entry codes were limited in their ability to control DRX and Speech CODEC rate. The GSM Base Station Simulator could control the handset RF transmit power level by commanding a "TX Level" parameter, with values from 1 to 15. There was no test harness interface available for the GSM handsets. Table 24 shows the available control options and equivalencies of the programming methods.

4.4.4 Measurement Data

From August 6-24, 2001, NASA-LaRC teamed with the UOK Wireless EMC center to extensively test wireless handsets for spurious radiated emissions in various operating modes. The UOK provided a standard operation protocol, keypad entry codes, programming interface and base station simulator equipment, and eight wireless handsets (four CDMA, four GSM) for the three-week radiated emission measurement program at NASA. NASA developed the process for measuring peak spurious radiated power from the wireless handsets into aircraft radio frequency bands, and assembled a standard instrumentation package and custom software to quickly characterize spurious radiated emissions in terms of EIRP, when measured in either a semi-anechoic or reverberation chamber. This section provides test details and data for wireless handset radiated emissions, as affected by operating mode, programming method, antenna retraction/extension, handling and manipulation, battery charge level, and interactions (intermodulation) with other transmitting handsets. Finally, data from identical tests performed in both semi-anechoic and reverberation chambers are provided and compared. Selected photographs of facilities and instrumentation are shown in Figure 4.13.



Emission Measurement Workstation

Base Station Simulators

Figure 4.13 Selected photographs of facilities and instrumentation used to measure spurious radiated emissions from CDMA and GSM wireless handsets.

4.4.4.1 Radiated Emissions Depending Upon Operating Mode

A primary objective for the measurement project was to determine which operating modes can be described as "worst-case", in terms of wireless handset spurious radiated emissions. Each handset was operated in extensive combinations of operating modes (see Table 24) using available command capability, to gain insight into configurations resulting in the highest emissions. Detailed procedures for both semi-anechoic and reverberation chambers, along with the detailed test matrix are provided in Appendix B. An exhaustive compilation of radiated-emission measurements for all operating modes of each handset is provided in Appendix C. For comparison, each handset was turned ON and OFF repeatedly, for full 120-sec measurement duration. The ON-OFF testing did not require any keypad codes, base station interaction or test harness interface. ON-OFF testing data are also included in Appendix C. In this section, selected data (from Appendix C) are shown to represent the extent to which each operating mode parameter influenced wireless handset spurious radiated emissions into aircraft communication and navigation frequency bands. Nearly all reported data were acquired using the reverberation chamber measurement process to gain advantages of reduced time and lower noise floors. Section 4.4.4.6 provides reverberation versus semi-anechoic chamber comparison data used to establish comparability between the two measurement processes.

CDMA Handsets

Close inspection of Appendix C data from all four CDMA handsets in all bands reveals a negligible variation of spurious radiated emissions with changes in transmitter output power level. The CDM4 handset had the capability of being programmed by the Test Harness Interface (THI), which allowed the most precise control of transmit power level, as compared to the keypad (KPD) and Base Station (BS) control methods. Figure 4.14 shows a comparison of the spurious radiated emission levels for CDM4 in Frequency Band 2, with the handset commanded to transmit in low, medium and full transmit power. In this case, as with the other three CDMA units and other frequency bands, spurious radiated emission level appeared to depend upon factors other than the transmitter output power.

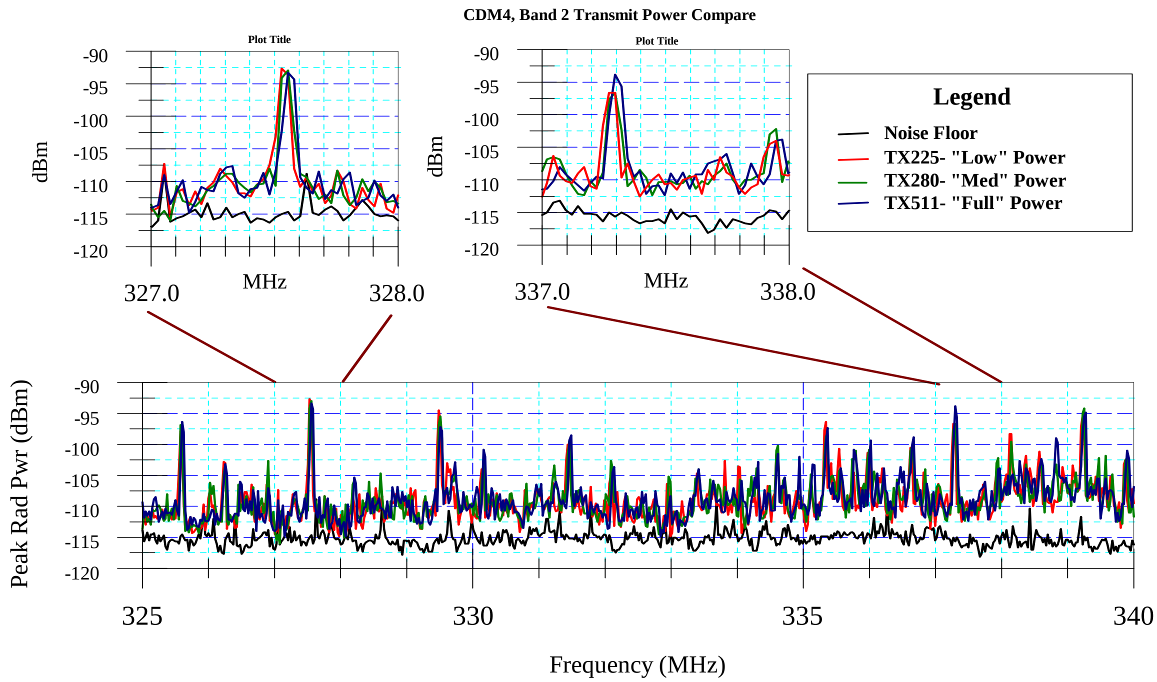


Figure 4.14: Peak radiated power (EIRP) in aircraft Frequency Band 2, for the CDM4 handset configured for "Low", "Med", and "High" transmitter output power. Two 1-MHz spans are expanded to reveal the typical case of similar spurious radiated emissions amplitudes, regardless of transmitter output power setting.

Previous testing for EMI from wireless phones to hearing aids revealed that CDMA puncture rate could be a primary factor [33]. Because of this previous history, puncture rate was closely scrutinized for affecting spurious radiated emissions in the aircraft navigation frequency bands. Figure 4.15 provides a close look at the handset/frequency band combination that appears to provide the most variation in data when comparing different CDMA puncture rates. From Figure 4.15, it can be seen that the CDM4 handset would sometimes produce spurious signals at different frequencies in Band 1. For the Band 1 data, it is most important to note the nearly identical emission amplitudes for the different puncture rates at 107.90 MHz and 119.65 MHz. Plot C.16, from Appendix C shows the Quarter puncture rate to exhibit five emission spikes that are not present for any other setting in Frequency Band 4. However, the overall amplitudes of the signals were not appreciably higher than spurious signals that were consistently present regardless of puncture rate setting. Overall, measurement data indicate that puncture rate was not a significant factor for emissions in aircraft navigation radio frequency bands for the four handsets tested.

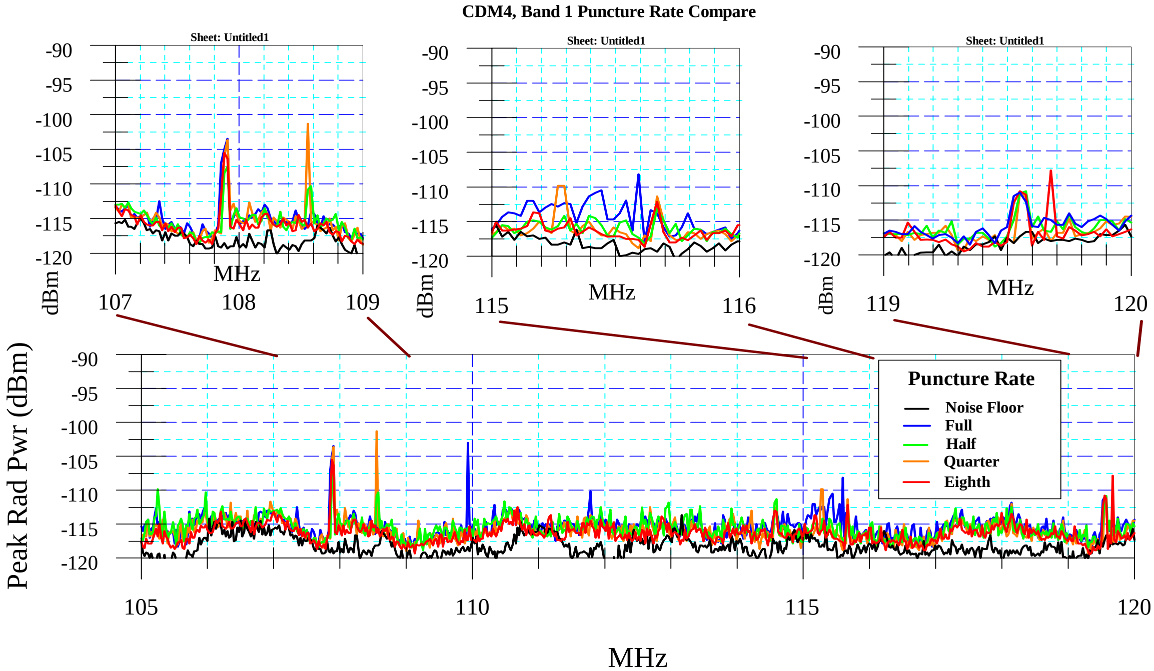


Figure 4.15 Peak radiated power (EIRP) in aircraft Frequency Band 1, for the CDM4 handset configured for "Full", "Half", "Quarter", and "Eighth" puncture rates. Three expanded views show a more detailed comparison.

Another transmit signal parameter that could be controlled by THI was the vocoder rate, which was selectable between 8 kBPS and 13 kBPS. The CDM4 handset was the only unit that could be used to provide comparison data. Figure 4.16 shows that vocoder rate has a negligible effect on the spurious radiated emission in the RF navigation frequency bands.

Perhaps the most interesting data were obtained by manually turning each handset ON and OFF repeatedly, for full 120-sec measurement duration. The ON-OFF testing did not require any KPD codes, BS interaction or THI. For the CDMA handsets, ON-OFF testing consistently produced peak emission levels the same or slightly higher than from all other modes tested. Emission plots from ON-OFF testing would typically track the general trends shown in plots from other modes tested, which indicated that the handset circuitry responsible for radiating the signals was active whenever the handset was powered ON. However, ON-OFF testing often produced significant signals outside all general trends of the other modes tested. Appendix C plots C.1 and C.5, for CDM1 Band 1 and CDM2 Band 1, show this very clearly. For the CDMA handsets, there were two cases where other operating modes produced spurious signal amplitudes in excess of the ON-OFF testing. See Table 25 for a summary of the comparison plots shown in Appendix C.

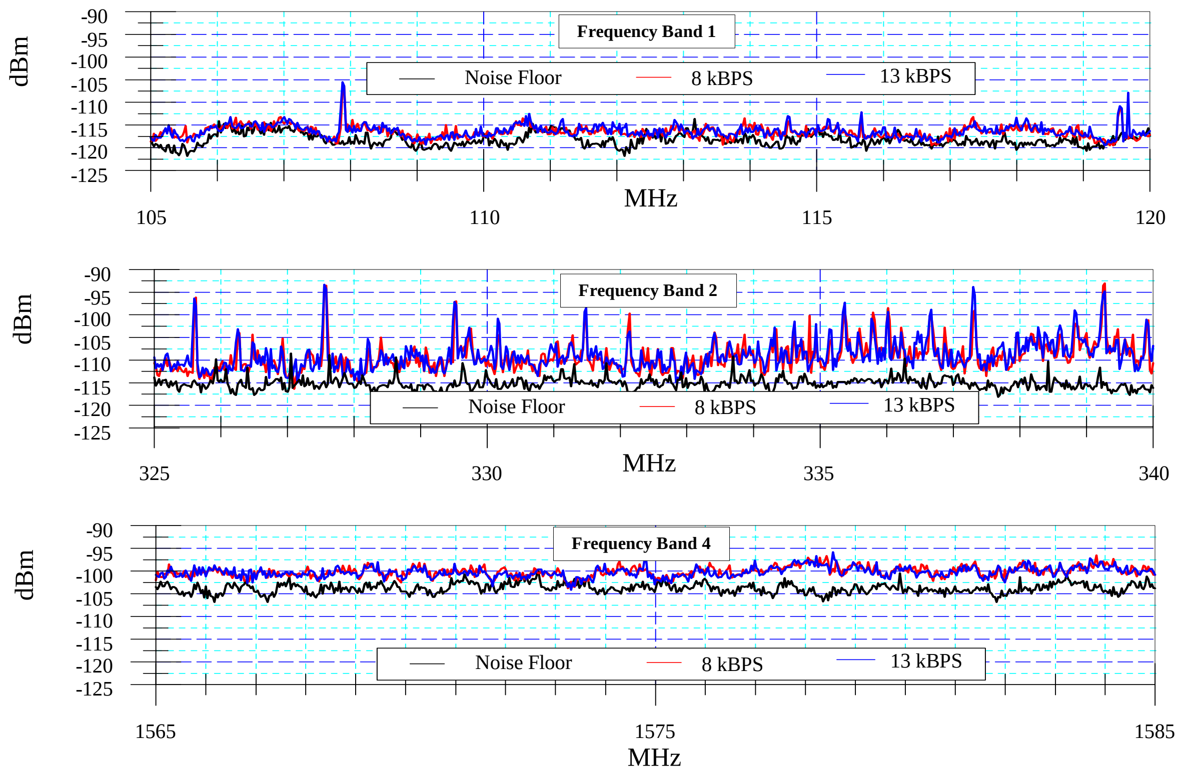


Figure 4.16: Peak radiated power (EIRP) in aircraft Frequency Bands1, 2 and 4 for the CDM4 handset configured for 8 kBPS and 13 kBPS vocoder rates.

Table 25: Matrix Representing Measured Peak Spurious Emission Levels During ON-OFF Cycling of CDMA Handsets, as Compared to Levels During other Operational Modes. (Band 3 is not included due to inadequate measurement sensitivity.)

	CDM1	**CDM2**	**CDM3**	**CDM4**
Band 1	⇑	⇑	⇔	⇔
Band 2	⇔	⇑	⇔	⇑
Band 4	⇔	⇓	⇓	⇔

⇑: ON-OFF cycling produced higher emission levels than all other CDMA operational mode tests.
⇔: ON-OFF cycling produced emission levels similar to other CDMA operational mode tests.
⇓: ON-OFF cycling produced emission levels less than other typical CDMA operational mode tests.

GSM Handsets

Combined plots of all GSM handset data are provided in Appendix C. While none of the GSM handsets were configured for THI programming, the GSM standard allows more extensive handset transmitter control by the BS simulator and KPD codes than the CDMA standard. In particular, the GSM base station simulator can command the handset to 15 graduated transmit power settings. For proposed aircraft installations, this feature has been advocated because it would enable an aircraft-mounted pico-cell to provide service to GSM handsets while rendering them unable to transmit during critical flight phases (takeoff, approach & landing).

Close inspection of Appendix C plots from all four GSM handsets in all bands reveals a negligible variation of spurious radiated emissions with changes in transmitter output power level, except for one case: GSM1, Band 4. It can readily be seen from Figure C.20 (Appendix C) that large spikes over 20 dB in amplitude over the other Frequency Band 4 data were measured when commanding the handset to transmit at *reduced* power. This result was unexpected, and tends to refute the assumption that the EMI risk of GSM handsets can be reduced by remotely commanding the transmit power to a lower setting. The test matrix does not include medium power testing for this handset, because the emission spikes were not recognized as significant until post-processing of the data.

Consistent radiated signals were present at 117.1 MHz and 338.0 MHz for all GSM handsets, in all operating modes. These signals were equally present on the GSM1 handset, even though its manufacturer and design layout were entirely different than the GSM2, 3, and 4 handsets.

The original test plan did not include collecting data using different handset channels. However, the original protocol for controlling the handset-operating mode via keypad codes and base station simulator specified different channels. When this fact was discovered upon initial testing, it was decided to expand the original test matrix to perform measurements at a "high" channel (100), a "medium" channel (62), and a "low" channel (1) for all GSM handsets. (It was discovered that the GSM base station simulator would emit a spurious signal in Band 3 when a GSM handset was transmitting on channel 124. Channel 100 was selected as the maximum to avoid this problem.) Figure 4.17 shows a comparison between transmit channels 1, 62 and 100 for the GSM1 handset. Transmit Channel 100 exhibits a unique spike at 330.95 MHz that is not present with the other channels. However, as with all the handset-mode testing, the emission levels are extremely low. In retrospect, it may have been more comprehensive to test low, medium and high channels for both transmit and receive for all GSM and CDMA handsets.

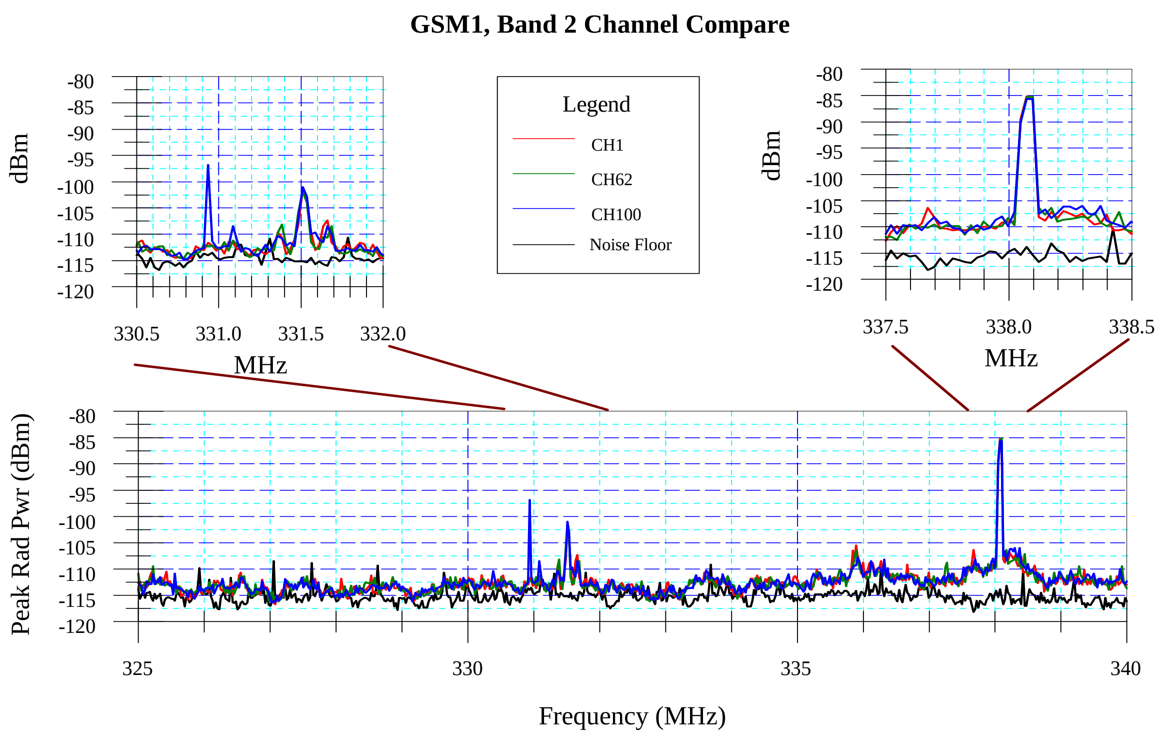


Figure 4.17: Peak radiated power (EIRP) in aircraft Frequency Band 2 for the GSM1 handset. Comparison between handset transmit channels 1, 62 and 100.

Three combinations of DTX and DRX were included for radiated emission testing: DTX OFF/DRX ON, DTX ON/DRX ON, and DTX ON/DRX OFF. Only the BSS was capable of controlling the DRX parameter, so testing was limited to the GSM2, GSM3 and GSM4 handsets. Because the GSM2, 3 and 4 handsets were identical models from the same manufacturer, it was expected that their radiated emission plots would be similar, as was verified by the data. Figure 4.18 shows a data comparison for the GSM2 handset in aircraft frequency band 1 when DTX and DRX were varied. While there were some variations in emission spikes, none dominated the others in overall amplitude. For the most part, the observed radiated emission data were nearly identical when varying the DTX and DRX parameters.

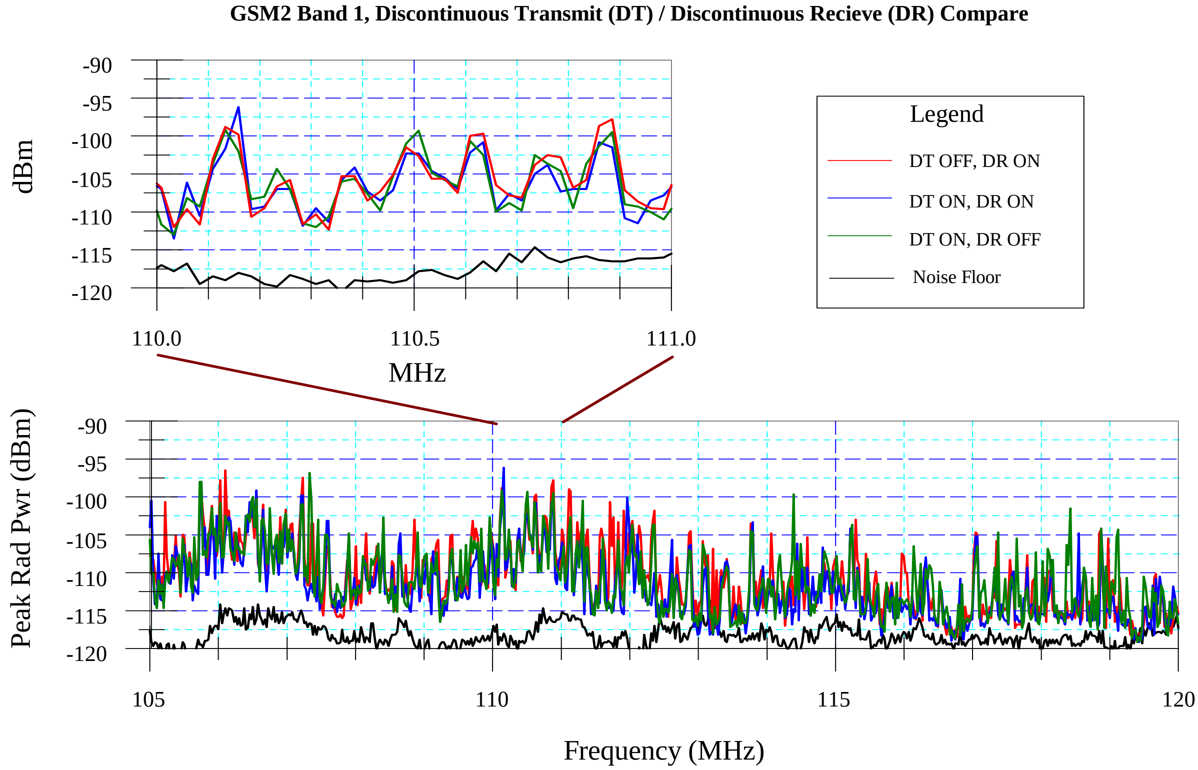


Figure 4.18: Peak radiated power (EIRP) in aircraft Frequency Band 1 for the GSM2 handset. A comparison between the DTX and DRX states. All measurements are with the following settings: maximum transmit power, Channel 62, Enhanced Full Rate Speech CODEC, and Base Station Simulator Control.

It was anticipated that the Enhanced Full Rate (EFR) speech CODEC would be the "worst" case setting for potential spurious radiated emissions. To verify this assumption, each GSM handset was also tested in each frequency band using the standard Full Rate (FR) speech CODEC. Figure 4.19 shows a comparison between FR and EFR Speech CODEC settings for the GSM2 handset in Frequency Band 1. While the spurious radiated-emission signatures were found to be identical for FR versus EFR in the other frequency bands, the Band 1 data showed spikes 5 to 10 dB higher. It is possible that the FR setting resulted in enhanced emissions for this handset in Frequency Band 1.

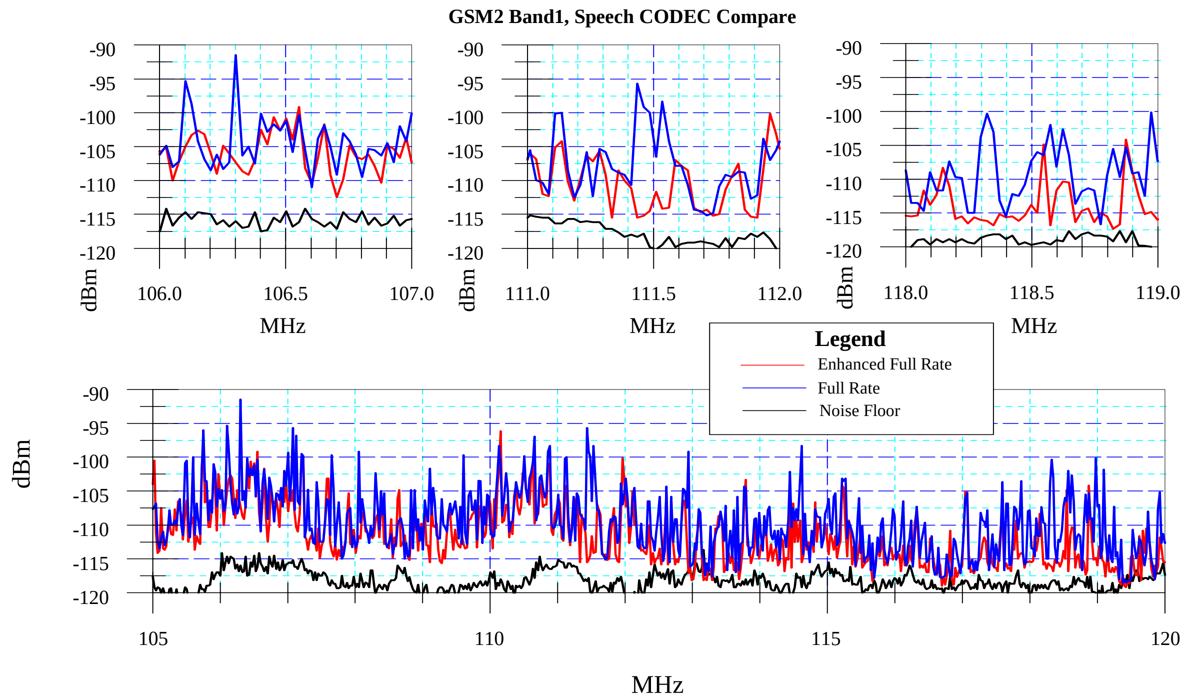


Figure 4.19: Peak radiated power (EIRP) in aircraft frequency band 1 for the GSM2 handset. Comparison between full rate and enhanced full rate speech CODEC settings. All measurements are with the following settings: maximum transmit power, Channel 62, DTX on, DRX on and base station simulator control.

As with the CDMA handsets, additional data were obtained by turning each handset ON and OFF repeatedly, for full 120-sec measurement duration. The ON-OFF testing did not require any KPD codes, BS interaction or THI. For the GSM handsets, ON-OFF testing consistently produced peak emission levels which were the same, or sometimes higher, than for all other modes. Emission plots from ON-OFF testing would typically track the general trends shown in plots from other modes, which indicated that the handset circuitry responsible for radiating the signals was active whenever the handset was powered ON. However, ON-OFF testing often produced significant signals outside all general trends of the other modes tested. Appendix C plots C.17 and C.18, for GSM1 Bands 1 and 2, show this result very clearly. For the GSM handsets, there was one other case where another operating mode produced spurious signal amplitudes in excess of those from ON-OFF testing. This case was for GSM1 Band 4, where the reduced transmit power level caused spikes higher than for all other modes, including the ON-OFF testing. To assist in interpreting the comparison plots of Appendix C, please see Table 26.

Table 26: Matrix Representing Measured Peak Spurious Emission Levels During ON-OFF Cycling of GSM Handsets, as Compared to Levels During other Operational Modes Testing. (Band 3 is not included due to inadequate measurement sensitivity.)

	GSM1	**GSM2**	**GSM3**	**GSM4**
Band 1	⇔	⇑	⇔	⇔
Band 2	⇑	⇔	⇔	⇔
Band 4	⇔	⇔	⇔	⇔

⇑: ON-OFF cycling produced higher emission levels than all other GSM operational mode tests.
⇔: ON-OFF cycling produced emission levels similar to other GSM operational mode tests.
⇓: ON-OFF cycling produced emission levels less than other typical GSM operational mode tests.

Overall, the spurious radiated emissions measured from the eight handsets (four CDMA, four GSM) were at very low amplitude levels. For these handsets, operating mode did not appear to result in significant differences in emissions in the aircraft RF navigation frequency bands. Figure 4.20 shows a summary plot of maximum spurious radiated emissions from individual CDMA and GSM wireless handsets operated in all modes as tested at NASA LaRC. The noise floor is also shown, including the FCC-allowable limits assuming 1-W transmitter power output.

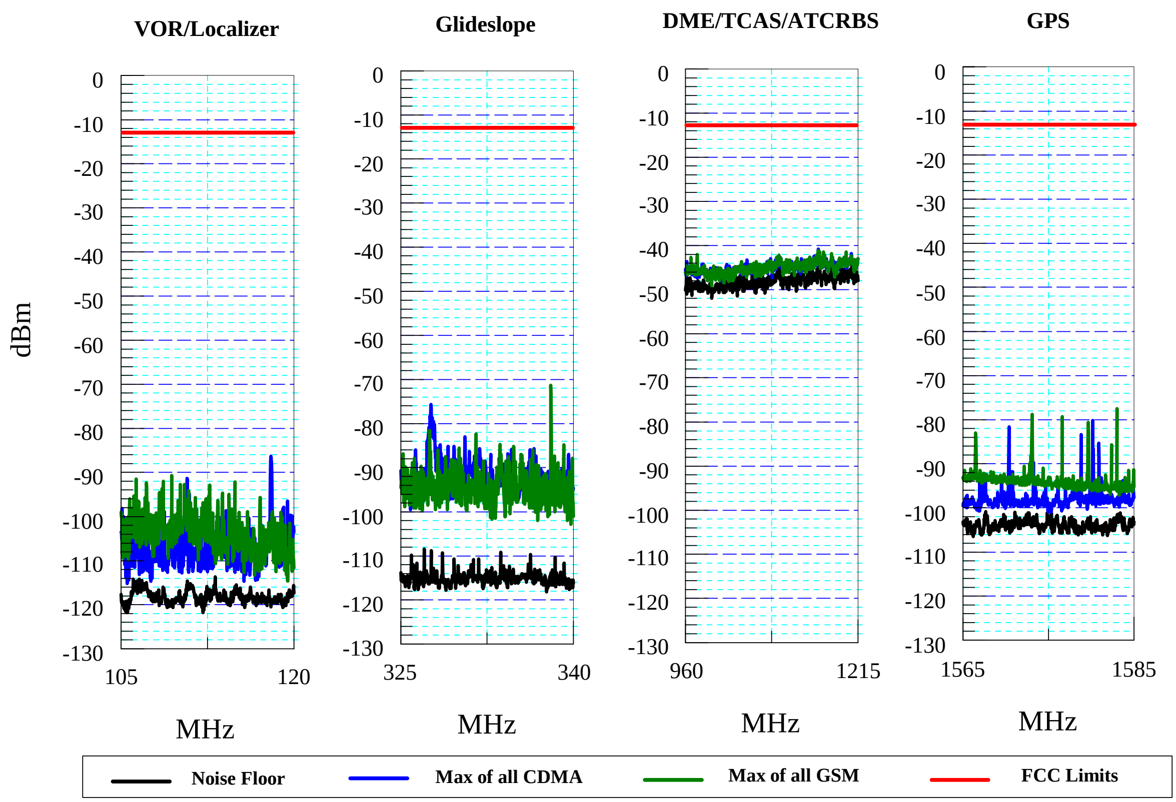


Figure 4.20: Maximum spurious radiated emissions (EIRP) from individual CDMA and GSM wireless handsets operated in all modes as tested at NASA LaRC. Also shown are the noise floor, and the FCC allowable limits assuming 1-W transmitter power output.

4.4.4.2 Radiated Emissions Depending Upon Programming Method

Section 4.4.3 describes how the operating modes of CDMA and GSM handsets were controlled via KPD codes, BS simulator, and THI. This approach was based upon the assumption that the handsets would respond the same regardless of which control method was used. To validate this assumption, spurious radiated emission data were obtained for two handsets having dual-control capability.

CDM2 was the only CDMA handset that could be operated by KPD code and BS simulator control. The data for each operating mode are plotted in Figure 4.21. For these plots, Figures C.6 and C.8 were modified to color all traces green, except the KPD trace. Comparability between KPD and BS simulator control can readily be determined for CDM2 Band 2. Since the CDM2 Band 4 traces appear to have a somewhat different pattern between KPD and BS, it is difficult to resolve whether the differences could be attributed to the reduced puncture rate instead. CDM2 data for Band 1, using KPD control were not included.

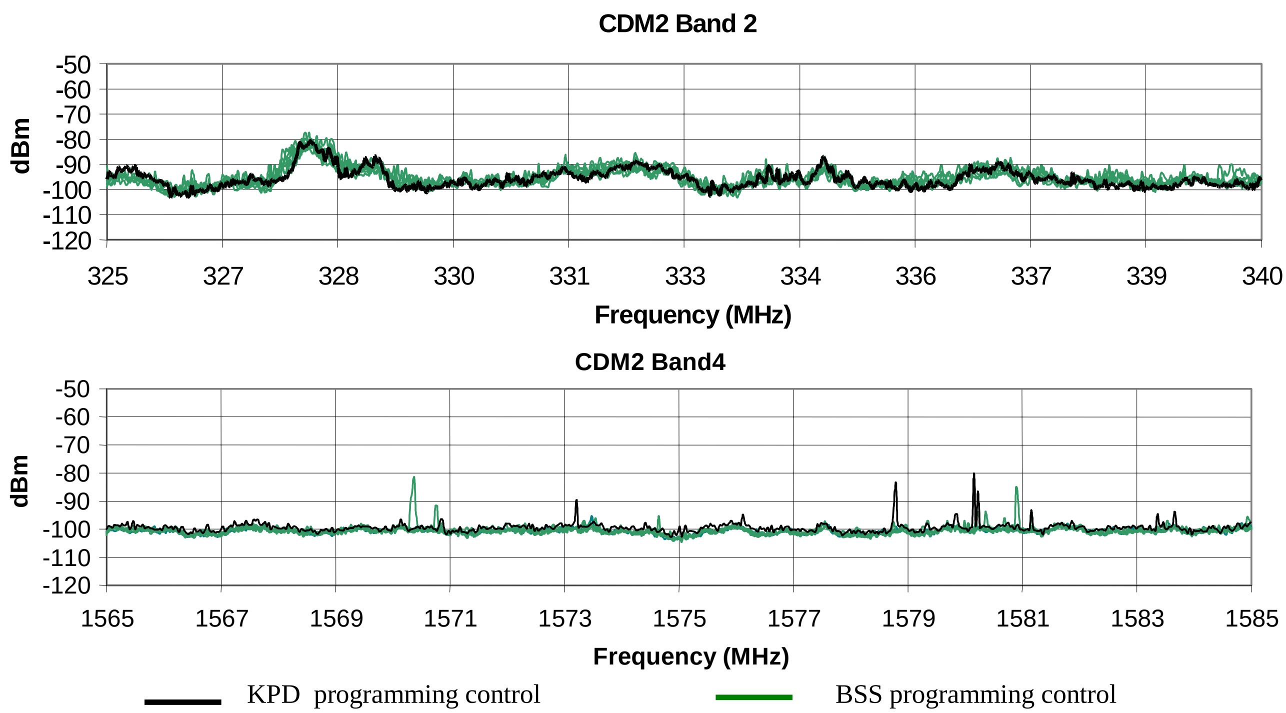


Figure 4.21: Peak radiated power (EIRP) in aircraft Frequency Bands 2 and 4 for the CDM2 handset. A comparison between emissions using KPD control vs. BS simulator control is shown. Keypad measurements were performed with maximum transmit power and variable puncture rate.

The GSM3 handset was operated by KPD code and BS simulator control, and the data are plotted in Figure 4.22. For these plots, Figures C.25, C.26 and C.28 were modified to color all traces green, except the KPD trace. For Frequency Bands 1 and 2, the handsets clearly radiated 10-15 dB higher emission levels when commanded by the BS simulator, versus KPD codes. It is noteworthy that the 117.1-MHz and 338.0-MHz signals were present to about the same amplitude regardless of program control method. For frequency band 4, there was no discernable difference between the two techniques.

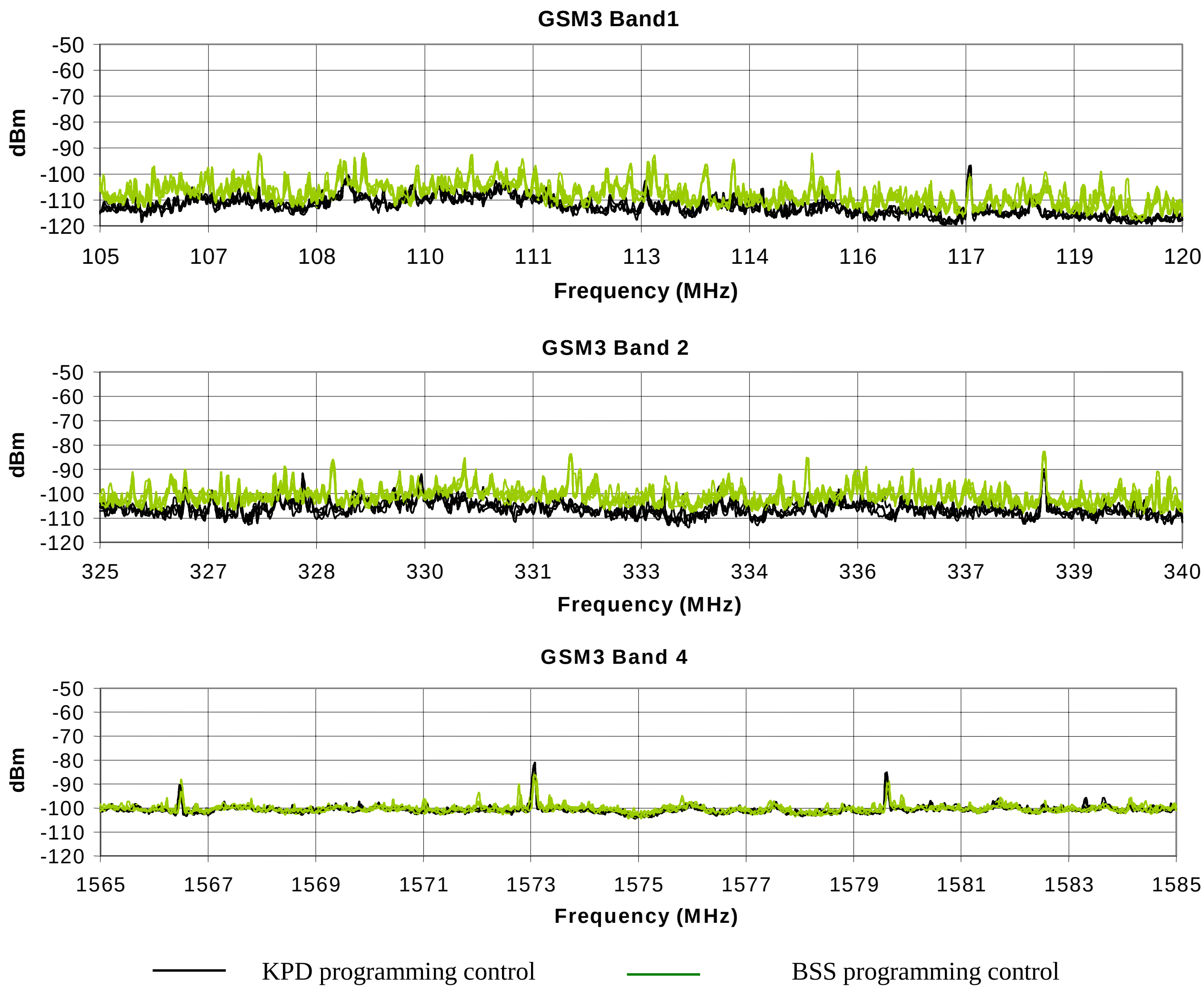


Figure 4.22: Peak radiated power (EIRP) in aircraft frequency bands 1, 2 and 4 for GSM3 handset. A comparison between emissions using KPD control vs. BS simulator control is shown. Keypad measurements were performed with maximum transmit power on channels 1, 62 and 100.

4.4.4.3 Radiated Emissions Depending Upon Phone Handling and Manipulation

All spurious radiated emissions measurements discussed so far were obtained with the wireless handset antennas extended (except GSM1, whose antenna did not extend), with the unit placed upon a styrofoam dielectric support, 80 cm in height, with no objects touching the unit during operation (free standing). In practice, however, people need to handle their devices in order to operate them. It is conceivable that specific signals may radiate more or less to the surrounding environment depending upon electromagnetic interaction with the user. Appendix C includes data collected for the following three operating conditions for each of the eight handsets, in each of the four frequency bands:

a. Handset free standing, with antenna extended

b. Handset free standing, with the antenna retracted

c. Handset manipulated by user for 30 seconds in each of four states (total 120 seconds) with antenna extended.

Figure 4.23 shows the four states of manipulation that were used in testing. To evaluate the extent to which phone handling and manipulation influenced spurious radiated emissions in aircraft radio frequency bands. Operating condition a) and c) data from Appendix C are summarized in Table 27. In this table, results from the four manipulation states are combined. Operating conditions a) and b) are compared in the next section.

Figure 4.23: Four states of handset manipulation during spurious radiated emission testing. In all cases, the handset was transmitting with the same operational mode settings.

Emission levels tended to increase typically 5 to 10 dB for Frequency Band 1 when manipulating the handsets. While the scope of this test was too limited to draw an authoritative conclusion, it could be presumed that the user serves as an enlarged antenna system for VHF-band spurious signals. Emission levels tended to decrease typically 2 to 5 dB for Frequency Band 4 when manipulating the handsets. It could be presumed that the user serves as more of an absorbing body for spurious signals radiated at these higher frequencies. Again, the scope of the test was too limited to draw an authoritative conclusion.

The 5-to 10-dB increase in Band 1 spurious emissions (caused by handset manipulation) does not add directly to the cumulative maximum spurious radiated emission plot shown in Figure 4.20. If Appendix C, Figure C.5 is compared to C.37 for the CDM2 handset, it can be seen that the "MPmax Prvar BS" trace is about 7 dB lower than the other traces at the maximum emission frequency of 118.00 MHz. Therefore, handling and manipulation only provided about a 3-dB enhancement of the worst-case emission from all CDMA handsets.

It should also be noted that the GSM2 handset produced the highest spurious radiated-emission levels in Frequency Band 2, primarily because the ON-OFF testing traces were about 10 dB higher than all the others at the 338.05 MHz peak. (See Figure C.22) The ON-OFF traces are not compared to the phone-handling traces shown in Figure C.54. For this handset, switching the unit ON and OFF appeared to cause higher emissions in Frequency Band 2 than manipulating it in the other four ways.

Table 27: A Spurious Radiated Emissions Level Comparison Between Freestanding with Antenna Extended Versus Manipulated Handset. The Observations were Based upon Data Shown in Appendix C, Figures C.33 to C.64. (Band 3 is not included due to inadequate measurement sensitivity.)

	CDM1	**CDM2**	**CDM3**	**CDM4**	**GSM1**	**GSM2**	**GSM3**	**GSM4**
Band 1 105-120 MHz	⇑ (10 dB)	⇑ (5-10 dB)	⇑ (1-4 dB)	⇑ (5-20 dB)	⇔**	⇑ (5-10 dB)	⇑ (5-10 dB)	⇑ (5-10 dB)
Band 2 325-340 MHz	⇓ (2-5 dB)	⇑ (2 dB)	⇑ (2-3 dB)	⇑ (2-4 dB)	⇑ (2-4 dB)	⇓ (2-3 dB)	⇔	⇔
Band 4 1565-1585 MHz	⇓ (2 dB)	⇓* (20 dB)	⇓ (2 dB)	⇓ (1-4 dB)	⇔	⇓ (2-5 dB)	⇓ (5-8dB)	⇓ (2-3 dB)

⇑: Handset manipulation produced higher emission levels than freestanding unit.
⇔: Handset manipulation produced similar emission levels to freestanding unit.
⇓: Handset manipulation produced lower emission levels than freestanding unit.
* possibly due to an intermittent handset condition that was not present during both measurements
** Appendix C plot C.49 shows numerous spikes for the free-standing unit operating condition, however these spikes were believed to be intermittent noise caused by damaged shielding materials on the stirrer motor housing in the reverberation chamber. The damaged shielding was repaired prior to the handset manipulation test.

4.4.4.4 Radiated Emissions Depending Upon Antenna Retraction/Extension

As noted in the previous section, spurious radiated emission data were collected with antennas extended and retracted, with the handsets freestanding upon a styrofoam support (see Figure 4.24). If signal emissions were emanating from the antenna, rather than from the body of the handset, their amplitude could be expected to be different with the antenna retracted, versus extended. To evaluate the extent to which antenna position influenced spurious radiated emissions in aircraft radio frequency bands, operating condition a) and b) data from Appendix C are summarized in Table 28.

Figure 4.24: Each handset was tested with its antenna retracted versus extended. Measurements were performed with handsets freestanding upon a Styrofoam support.

For the most part, emission variations due to antenna position were within the expected measurement uncertainty. Only two cases showed significant variations, CDM2 Band 1 and GSM2 Band 1. For CDM2 Band 1, numerous spikes (~10 dB above the noise floor) were present with the antenna extended, that were not present with the antenna retracted. However, for the two frequencies where emissions were always present (108.1, 118.0 MHz), the emissions with the antenna retracted were about 2 dB higher than with the antenna extended. For GSM2 Band 1, several spikes (~10 dB above the noise floor) were observed with the antenna extended, but their maximum amplitude remained below -100 dBm. Manipulation of the handset still dominated the emission signature. This testing did not reveal any significant effect of antenna position on spurious radiated emissions in aircraft communication and navigation radio frequency bands.

Table 28: A Spurious Radiated Emissions Level Comparison Between Extended Antenna Versus Retracted Antenna. The Observations were Based upon Data Shown in Appendix C, Figures C.33 to C.64. (Band 3 is not included due to inadequate measurement sensitivity.)

	CDM1	**CDM2**	**CDM3**	**CDM4**	**GSM1**	**GSM2**	**GSM3**	**GSM4**
Band 1 105-120 MHz	⇔	⇑ (10 dB)	⇑ (1-4 dB)	⇔	**	⇑ (2-10 dB)	⇑ (2-4 dB)	⇑ (2-4 dB)
Band 2 325-340 MHz	⇔	⇔	⇔	⇑ (2-4 dB)	**	⇑ (2-3 dB)	⇑ (1-2 dB)	⇔
Band 4 1565-1585 MHz	⇔	⇓* (20 dB)	⇓ (2 dB)	⇑ (1-4 dB)	**	⇑ (2-5 dB)	⇓ (1-2 dB)	⇑ (2-3 dB)

⇑: Extended antenna produced higher emission levels than retracted antenna.
⇔: Extended antenna produced similar emission levels to retracted antenna.
⇓: Extended antenna produced lower emission levels than retracted antenna.
* possibly due to an intermittent handset condition that was not present during both measurements
** GSM1 antenna not designed to extend.

Some additional measurements were obtained in the handset transmit frequency bands also (820-960 MHz). These data include test cases with the antenna extended versus retracted, with the handset free standing versus next to the operator's head. The data are currently being evaluated as a basis for further testing to better understand how to reduce transmitted signal coupling to an operator's head.

4.4.4.5 Radiated Emissions Depending Upon Battery Charge Level

The functionality of the data acquisition software was extended to allow unattended measurement of emissions at specified time intervals. (See Section 4.4.2.7.) The software allowed periodic sampling of handsets configured to transmit continuously until their battery completely discharged. To accomplish the test, handsets were set to operate with a freshly charged battery at the maximum transmit power setting, and left in the test chamber overnight. During the three-week period of the measurement program, most of the eight handsets were tested in each of the four frequency bands. Data for this test are still in the process of being evaluated.

4.4.4.6 Radiated Emissions Depending Upon Test Chamber Type (Reverberation/Semi-Anechoic)

Section 4.4.2 and Appendix B contain equivalent processes and procedures for performing spurious radiated-emissions testing in either semi-anechoic or reverberation chambers. While reverberation chamber testing is faster and more thorough, it was believed that control of wireless handsets by BS simulators would be degraded by the extreme multipath conditions present in the reverberation chamber. During the first two days of testing, identical measurements with an AMPS handset were performed in both types of chamber to quantify comparability of spurious radiated-emission data (see Figure 4.27). It was also established that both GSM and CDMA base stations could reliably initiate and maintain calls, and effectively control the physical layer circuitry in the GSM and CDMA handsets.

Reverberation chamber versus semi-anechoic chamber tests afforded the opportunity to compare minimum measurement sensitivities between the two measurement techniques. Figure 4.25 shows the resulting noise floor comparisons for frequency bands 1, 2, and 3.

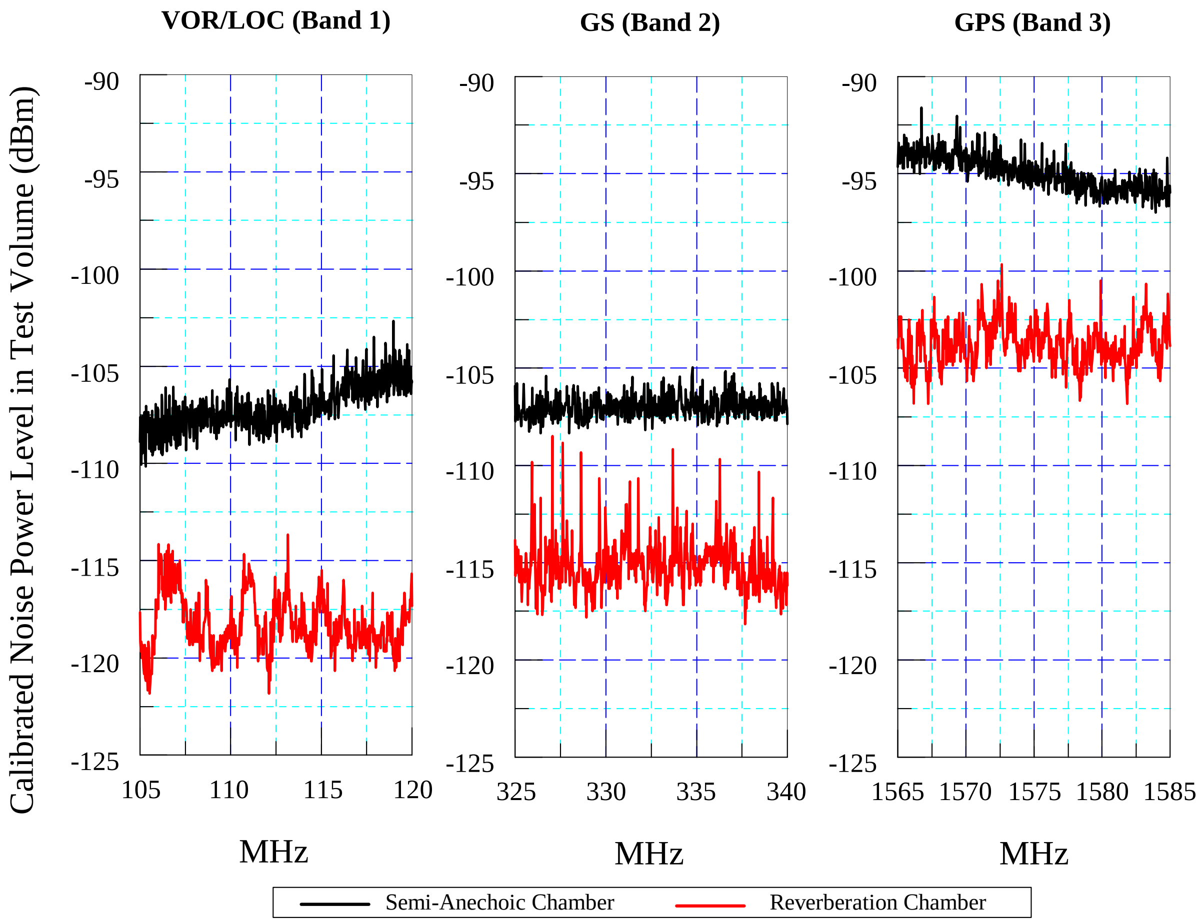


Figure 4.25: Comparison of noise floors for semi-anechoic versus reverberation chambers. These data are calibrated to account for pre-amplifiers and cabling used during spurious radiated emission measurements.

The semi-anechoic chamber spurious radiated-emission process (described in Section 0) and procedure (described in Section B.2 of this report) provide estimates of peak-radiated power from the device under test (DUT), assuming an isotropic radiation pattern. Given this fact, the semi-anechoic chamber data should be artificially high by the amount of directivity of the DUT. For the semi-anechoic testing, handsets were rotated 360 deg., in three rotational orientations during emission measurements. (See Figure 4.26.) Because the emissions are unintentional, and the device is electrically small, the directivity can be expected to be about 4 dB. (See Section 3.2.3, Figure 3.8.)

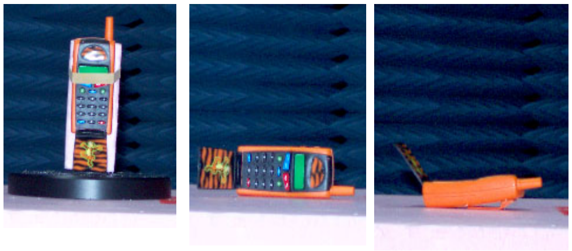


Figure 4.26: Three test orientations for wireless handsets tested in the semi-anechoic chamber. The entire Styrofoam support rotated 360 deg. for each test orientation.

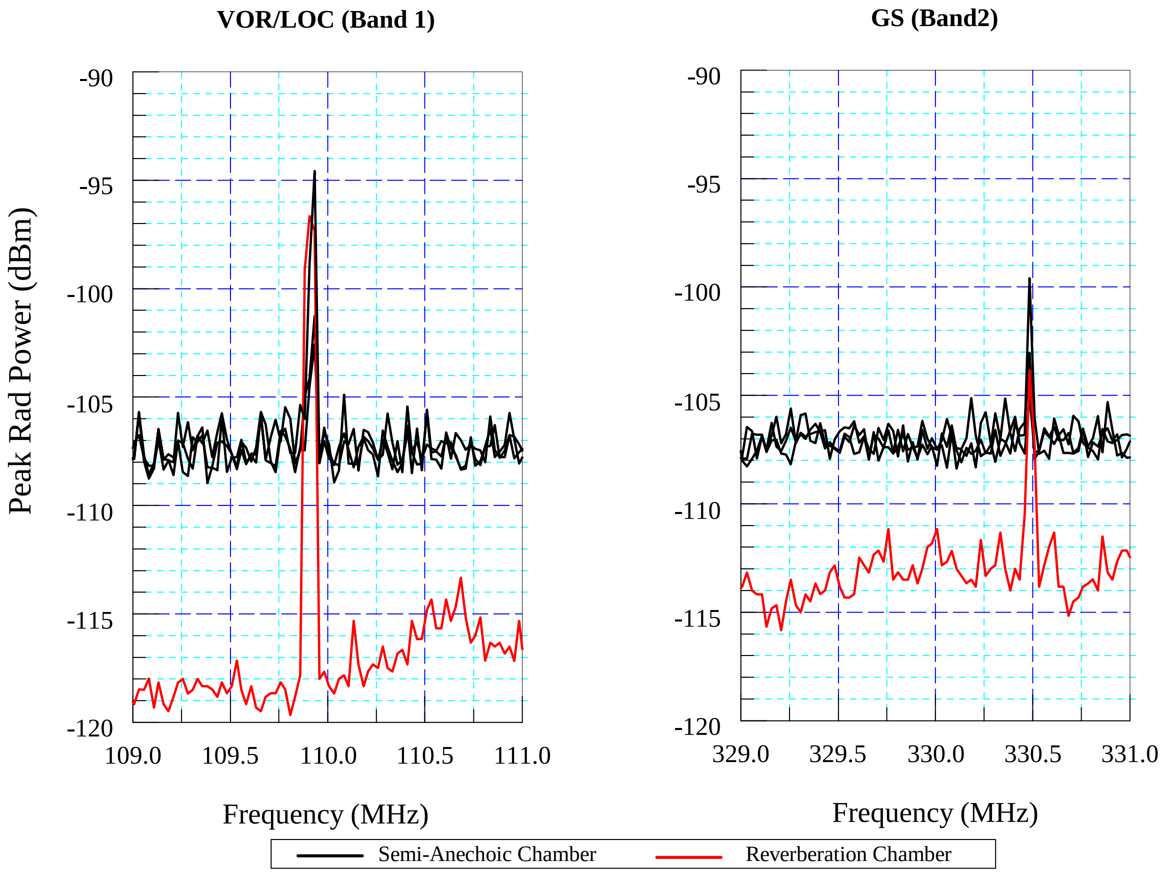


Figure 4.27: Comparison of spurious radiated emission measurements for semi-anechoic versus reverberation chambers, using an AMPS handset.

4.4.5 Intermodulation Interference and Analysis: Wireless Technology Threat to Aircraft Frequency Bands

4.4.5.1 Intermodulation Interference Caused by Multiple Phone Interactions

One of the efforts described in this report involves measurements of RF emission from cellular phones in several aircraft communication and navigation bands. In this effort, measurements were conducted in anechoic and reverberation chambers for RF emissions from eight CDMA, GSM and AMPS phones in four aircraft bands, including LOC, GS, VOR, and GPS. During this effort, evidence of intermodulation effects due to multiple cellular phones in the proximity of each other was unexpectedly observed.

In one set of measurements, several GSM, CDMA and AMPS phones were placed in the proximity of one another inside the test chambers (reverberation and anechoic chambers) while set at maximum transmit power. A third-order intermodulation product was unexpectedly observed in the DME band, with the unwanted frequency component being as high as approximately -15 dBm. This level was much higher than typical spurious signals emitted from the phones, which were in the range of –80 dBm in the communication and navigation bands. This signal would exist only with two or more phones transmitting at the same time. Further investigation through measurement and analysis validated the intermodulation phenomenon. In addition, intermodulation products were also observed in the GPS band, but at a much lower power level. Figure 4.28 and Figure 4.29 demonstrate the intermodulation phenomenon that was observed.

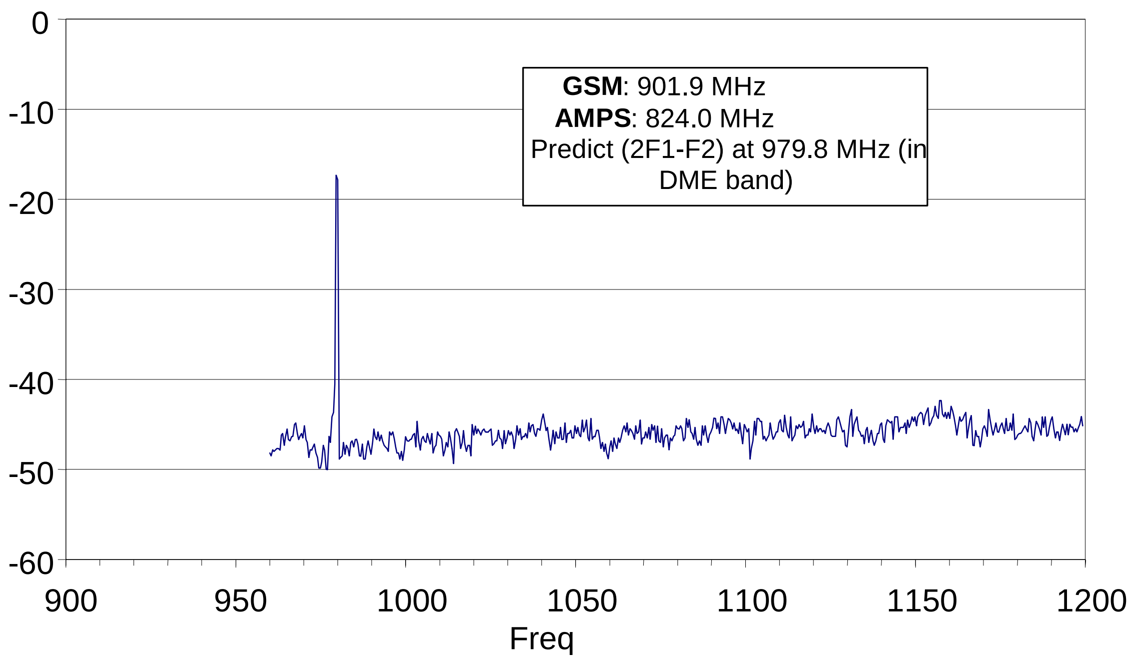


Figure 4.28: Demonstration of intermodulation products in DME band. Comparing prediction versus measurement.

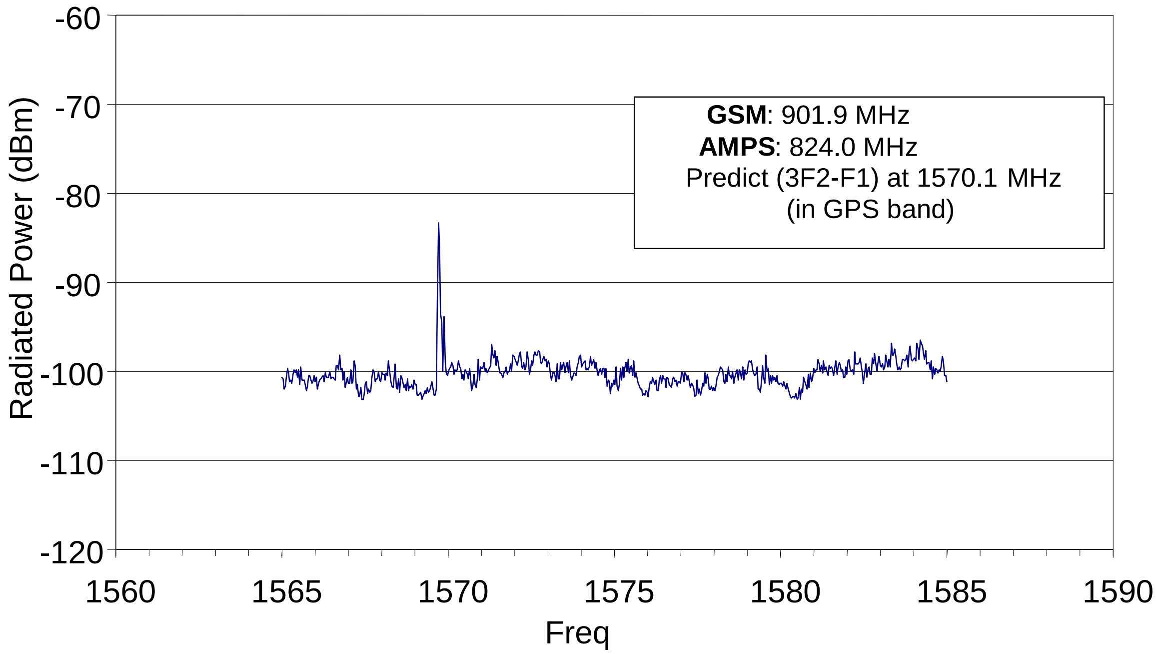


Figure 4.29: Demonstration of intermodulation products in GPS band. Comparing prediction versus measurement.

Types of Intermodulation Interference

Intermodulation products are unwanted frequency components resulting from the interaction of two or more spectral components passing through a device with nonlinear behavior, such as a mixer, an amplifier, an output stage of a transmitter, or input stage of a receiver. The unwanted components are related to the fundamental components by sums and differences of the fundamentals and various harmonics.

An example of the intermodulation products for two signals includes:

$\mathbf{f_1 \pm f_2; 2f_1 \pm f_2; 2f_2 \pm f_1; 3f_1 \pm 2f_2;}$ **etc.**

Intermodulation products generally fall into one of the following categories:

- **Transmitter-generated intermodulation**

In this case, the transmitted signal from one transmitter is received at the output of another transmitter, typically via the antenna. If the signal is of adequate strength, it will mix with the second transmitter's carrier in the non-linear final amplifier. The newly mixed signal is then amplified and transmitted along with the desired carrier.

- **Receiver-generated intermodulation**

In this case, external strong signals (two or more) algebraically mix to produce the intermodulation frequency, usually in the first mixer or the first amplifier of the receiver. The receiver perceives the mix frequency as if it were a real signal.

- **Externally-generated intermodulation**

  This interference phenomenon is attributable to many sources, such as dissimilar metals, dirty interconnects, loose mechanical connectors, or corroded metal connections. These sources form non-linear electrical junctions, which act as "diodes" or "mixers" ("rusty-bolt" effect). When these devices are excited by one or more signals with sufficient strength, they generate intermodulation products. Electromechanical switches, antenna tower sections with heavily corroded joints, and broken solder beads are example sources of this intermodulation category.

Receiver-generated intermodulation is a concern for aircraft receivers whose antenna ports are regularly subjected to high-power FM broadcasts. Many ICAO and RTCA documents were developed specifically to address this issue. Receiver MOPS, including the RTCA/DO-192, -195, -196, addressed this specific type of intermodulation interference in their specifications.

The intermodulation generated by multiple phones within the test chamber was determined to be transmitter-generated intermodulation. Combinations of filters and attenuators were used during the measurements to ensure that desensitization and intermodulation did not occur within the receiver.

Demonstration of Intermodulation Products in Aircraft Bands

As stated previously, laboratory measurements show intermodulation products from interactions of multiple phones falling within the aircraft navigation bands. Examples include a third-order term ($2f_2 - f_1$) falling inside the DME band, and a fourth-order term ($3f_1 - f_2$) falling inside the GPS band. The equipment includes a GSM phone and an AMPS phone; that were both commanded to transmit at their maximum power. The GSM phone transmits in the frequency band allocated for use in Europe, and the AMPS phone is an example of phones using a frequency band allocated for use in the US.

Each of the phones was commanded to transmit at a specific frequency channel, and their outputs were measured using a spectrum analyzer. A system of filters and attenuators was used to prevent undesired effects in the receiver stage. The GSM phone was transmitting at 901.9 MHz, and the AMPS (analog) phone was transmitting at 824 MHz, as measured on the spectrum analyzer. The frequencies measured did not match exactly with the intended frequencies (corresponding to channel numbers on the cellular phone) for transmission. This mismatch principally was due to the uncertainty in the frequency resolution associated with the set display on the spectrum analyzer. A simple calculation showed a third-order intermodulation product $2f_1 - f_2$ was 979.8 MHz, which is inside the DME band. In addition, a fourth-order intermodulation product $3f_2 - f_1$ was computed to be 1570.1 MHz, which is inside the GPS interference bandwidth. Figure 4.28 and Figure 4.29 illustrate the results measured in a reverberation chamber in comparison with analytical prediction.

It can also be observed that the third-order intermodulation term in Figure 4.28 is at approximately –17 dBm, which is well above spurious emission levels from any of the phones measured in the aircraft band as reported in this document. A fourth-order intermodulation product in the GPS band is observed to be significantly lower, in the –82 dB range, as shown in Figure 4.29

It is generally observed that commercial software packages for intermodulations primarily focus on odd-order intermodulation rather than even-order. One reason is that odd-order intermodulation products tend to be closer to one of the signals and therefore are more difficult to filter out. Figure 4.28 and Figure 4.29 illustrates that the third-order product is about 65 dB higher than the fourth-order product in this case. Even so, the results demonstrate that the even-order products are real, and should not be ignored without considering aircraft path loss and receiver susceptibility thresholds.

4.4.5.2 Intermodulation Analysis

In light of intermodulation products generated by the interaction between GSM phones and CDMA or AMPS phones, as demonstrated in Section 4.4.5.1, it is of interest to investigate possible interference with aircraft bands due to other combinations of wireless devices. In this section, an analysis was conducted for intermodulation products, up to fifth order, generated from many different combinations of portable wireless communication devices. The resulting frequencies are then compared with aircraft receiver bands for possible interference.

A list of portable wireless devices considered in this analysis, including their allocated transmit frequency bands, is shown in Table 29 below, and the aircraft bands considered are listed in Table 30.

Table 29: Portable Wireless Technology Considered in Intermodulation Analysis

Wireless Technology	**Handset Transmit Frequency (MHz)**
CDMA/ TDMA/ AMPS	824-849
GSM	880-915
PCS	1850- 1910
Bluetooth/ 802.11b	2400-2497 2400-2483
DCS 1800/DCS 1900	1710-1785
Integrated Digital Enhanced Network (IDEN)	806-821

Table 30: Aircraft Bands Considered in Intermodulation Interference Analysis

Aircraft Systems	**Abbreviation**	**Receive Frequency Range (MHz)**
HF Communications	HF	2.850-23.350
Marker Beacon	MB	74.8 –75.2
VHF Omni-Range	VOR	108 – 117.95
Localizer	LOC	108.1-111.95
Very High Frequency Communication	VHF	118 - 137
Glide Slope	GS	328.6 –335.4
Distance Measurement Equipment/ Tactical Air Navigation	DME/TACAN	962 - 1213
Air Traffic Control Transponder – Mode S	ATC Mode S	1030
Traffic Collision Avoidance System	TCAS	1090
Airborne Mobile Satellite Service	AMSS	1530 –1559
Global Positioning System	GPS	1575.42 +/- 2
Microwave Landing System	MLS	5031 - 5090.7

Many combinations of wireless devices from Table 29 were used in the analysis. The list is shown below. These combinations were not intended to be sufficiently; rather they represent a good cross-section of current wireless technologies:

CDMA/TDMA/AMPS and GSM
CDMA/TDMA/AMPS and PCS
GSM and 802.11b
CDMA/TDMA/AMPS and 802.11b
GSM and DCS 1800/1900
CDMA/TDMA/AMPS and iDEN
PCS + iDEN

For each combination, a number of low-order intermodulation products (not all possible products) were computed up to fifth order. These products include $\mathbf{f_1 \pm f_2}$; $\mathbf{2f_1 \pm f_2}$; $\mathbf{2f_2 \pm f_1}$; $\mathbf{3f_1 - 2f_2}$, $\mathbf{3f_2 - 2f_1}$, $\mathbf{3f_1 - f_2}$, $\mathbf{3f_2 - f_1}$. The resulting intermodulation products were compared with the aircraft bands listed in Table 30, and the specific intermodulation product terms with interference potential were noted. The results are shown in Table 31.

Table 31: Wireless Device Combinations and Potential Intermodulation Interference with Aircraft Bands.

Wireless Devices	**Intermod. Product Frequency Range (MHz)**	**Intermod. Product Term***	**Potential Aircraft Bands Interfered**
(CDMA/TDMA/AMPS) and GSM	31 -91	$f_2 - f_1$	MB
	911 - 1006	$2f_2 - f_1$	DME/TACAN
	942 – 1097	$3f_2 - 2f_1$	DME/TACAN, ATC Mode S, TCAS
	1557 - 1667	$3f_2 - f_1$	GPS, AMSS
(CDMA/TDMA/AMPS) and PCS	1001 - 1086	$f_2 - f_1$	DME/TACAN, ATC Mode S
(CDMA/TDMA/AMPS) and 802.11b	0 – 147	$3f_2 - f_1$	HF, MB, VOR, LOC, VHF
	1551 - 1659	$f_2 - f_1$	AMSS, GPS
GSM and 802.11b	0 - 345	$3f_2 - f_1$	HF, MB, VOR, LOC, VHF, GS
	1485 - 1603	$f_2 - f_1$	AMSS, GPS
GSM and DCS 1800/1900	0-120	$2f_2 - f_1$	HF, MB, VOR, LOC, VHF
	0-1035	$3f_2 - f_1$	HF, MB, VOR, LOC, VHF, GS, DME/TACAN, ATC Mode S
(CDMA/TDMA/AMPS) and iDEN	1569 -1639	$3f_2 - f_1$	GPS
PCS + iDEN	1029 - 1104	$f_2 - f_1$	DME/TACAN, ATC Mode S, TCAS

* For simplicity, the orders of $\mathbf{f_2}$ and $\mathbf{f_1}$ are interchangeable. For example $\mathbf{2f_2 - f_1}$ could also represent $\mathbf{2f_1 - f_2}$.

From Table 31, there appears to be a large number of combinations of wireless devices that may have the potential to interfere with aircraft systems. Among them, the AMPS phone and GSM phone combination has a very low probability of existence due to spectrum allocation. Typically, either a CDMA/TDMA/AMPS or a GSM system exists, but not both simultaneously. This combination is the same one that generated intermodulation products in the laboratory measurement described previously in Section 4.4.5.1.

Of the remaining combinations, only the GSM and DCS 1800/1900 combination would have an odd intermodulation product ($2f_2 - f_1$) falling within the aircraft bands. In this case, the LOC and VOR systems may be affected. The even-order intermodulation tends to be of lower amplitude; thus, the remaining combinations would be less of a concern for the specific intermodulation products considered.

The above analysis was preliminary and limited in the number of intermodulation terms and in the number of combinations of wireless device that were considered. The main purpose was to illustrate the effect of intermodulation and aircraft in-band interference. More investigation on this topic is needed to further quantify the effects. It may not be possible to conduct testing on all combinations of wireless devices and the intermodulation terms due to cost and the fast-changing pace of wireless technology. Instead, theoretical analysis may provide insight into the maximum emissions from these intermodulation terms, from which better determinations can be made about the possibility of threats to aircraft systems.

4.5 Results and Conclusions: CDMA/GSM Mobile Unit Threat Assessment

1. The NASA/UOK team demonstrated a viable process for measurement of spurious radiated emissions of CDMA and GSM wireless handsets, in both semi-anechoic and reverberation chamber test facilities. The process can easily be extended to measure spurious radiated emissions from all existing and emerging wireless voice and data devices.

2. None of the four CDMA and four GSM wireless handsets tested would individually be likely to interfere with aircraft VOR, LOC, GS, or GPS navigation radios. The following tables illustrate safety margins using measurement data.

Table 32: CDMA (IS-95, 824-849 MHZ) Handset Threat Assessment

	VOR	LOC	GS	GPS
Nav Radio Minimum Interference Threshold (dBm) (reasonable min / absolute min)	-106/-159 [a]	-112/-159 [a]	-102/-145 [a]	-126.5[b]
Path Loss Data (average of fleet minimums)[c] (dB)	62	56	59	59
CDMA Radiated Emission Level (EIRP max.) (dBm)	-86	-86	-76	-80
Safety Margin (reasonable min / absolute min) (row 1 + row 2 – row 3) [a] (dB)	**+42/-11** [a]	**+30/-17** [a]	**+33/-10** [a]	**+12.5**

[a] "Reasonable Minimum" interference threshold was taken to be the RTCA/DO-192, DO-195, DO-196 specified minimum receiver sensitivities, with a 26 dB required signal-to-interference ratio for LOC and GS receivers. (Defined as "Type 2" in RTCA/DO-233. RTCA/DO-233 provided data only for the localizer receiver, but the ratio is assumed to be the same for GS due to similarities between the two systems.) "Absolute Minimum" interference threshold was taken as the minimum sensitivity of a known commercial radio receiver, with a 46-dB required signal-to-interference ratio for LOC and GS. (Defined as "Type 1" in RTCA/DO-233. Again, RTCA/DO-233 only provided data for the localizer receiver, but the ratio is assumed to be the same for GS due to similarities between the two systems.) For VOR, the "Absolute Minimum" signal-to-interference ratio was measured as 46 dB, and published in RTCA/DO-199.

[b] RTCA/DO-229B, Narrow band enroute interference threshold for GPS/WAAS

[c] Path Loss data shown, is an average of the minimum coupling values measured from various airplanes' passenger cabin locations, to particular navigation radio receiver avionics bay RF connections.

Table 33: GSM (ETSI GSM 11.22) Handset Threat Assessment

	VOR	LOC	GS	GPS
Nav Radio Minimum Interference Threshold (dBm) (reasonable min / absolute min)	-106/-159 [a]	-112/-159 [a]	-102/-145 [a]	-126.5 [b]
Path Loss Data (average of fleet minimums) [c] (dB)	62	56	59	59
GSM Radiated Emission Level (EIRP max.) (dBm)	-91	-91	-71	-78
Safety Margin (reasonable min / absolute min) (row 1 + row 2 – row 3) [a] (dB)	**+47/-6** [a]	**+35/-12** [a]	**+28/-15** [a]	**+10.5**

3. If a CDMA or GSM wireless handset radiated spurious signals equal to the maximum allowable FCC limits, it would result in large NEGATIVE safety margins, even when considering "reasonable minimum" radio receiver interference thresholds:

Table 34: Threat Assessment for Emissions up to FCC (22.917, 24.238) Limits for Cellular & PCS Wireless Handsets

	VOR	LOC	GS	GPS
Nav Radio Minimum Interference Threshold (dBm)	-106/-159 [a]	-112/-159 [a]	-102/-145 [a]	-126.5 [b]
Path Loss Data (average of fleet minimums) [c] (dB)	62	56	59	59
Spurious Emission Limits (for 1-W Transmitter) (dBm)	-13	-13	-13	-13
Safety Margin (reasonable min / absolute min)) (row 1 + row 2 – row 3) [a] (dB)	**-31/-84** [a]	**-43/-90** [a]	**-30/-73** [a]	**-54.5**

4. Each handset was commanded according to an extensive matrix of operational modes, while spurious radiated emissions were measured. CDMA handsets were commanded to multiple power output levels, puncture rate settings, and vocoder rate settings. GSM handsets were commanded to multiple power output levels, DTX and DRX, and speech CODEC settings. While the operating mode often resulted in discernable differences in the spurious radiated spectrum, dominant spectral components did not vary appreciably due to mode changes. Interestingly, repeatedly turning the handset power ON-OFF caused the most significant changes in the spurious radiated spectrum.

5. It was demonstrated that intermittent spurious radiated emissions would sometimes increase up to 10 dB when touching the keypad, touching the antenna, or retracting the antenna on the test handsets. However, when compared to the highest emission levels in all operating modes, these manipulations resulted in only a 3-dB increase for the highest emission levels.

6. It was demonstrated that GPS- and DME-band emissions occur, due to intermodulation between GSM and other wireless handset types, when the handsets were placed in close proximity to one another. It was identified that other combinations of common passenger transmitters could potentially produce intermodulation products in aircraft communication and navigation radio-frequency bands.

7. It was identified that the FCC does not restrict airborne use of PCS wireless handsets. FCC limits for spurious radiated emissions for PCS handsets are the same as for cellular handsets. However, only cellular handsets are restricted from airborne operation by the FCC (47CFR22.925 [60]).

5 Recommendations for Subsequent Analysis and Action

This report is intended to fit into an overall strategy for demonstrating assessment and EMI mitigation techniques for assisting the FAA in setting future policies regarding the use of wireless transmitters onboard aircraft. Items 4 and 5 of the following recommendations fit this strategy, but do not specifically result from the PED signal-threat assessment to aircraft navigation radios described within this report.

1. Quantify Threat from Existing and Emerging PEDs:

    a. Build upon the measurement process reported herein to establish a standard set of procedures for measuring spurious radiated emissions in aircraft navigation radio-frequency bands (VOR, LOC, GS, DME, TCAS, GPS) from common and emerging wireless transmitters (CB, FRS, GMRS, Cellular, PCS, GSM, 3G, Bluetooth, IEEE 802.11X, etc.) Incorporate techniques for identifying signal characteristics other than peak amplitude (i.e., modulation types and parameters, duty cycle, bandwidth, etc.), for more accurately quantifying the potential for EMI to aircraft communication and navigation radios.

    b. Use the radiated-emission process established in this report to measure numerous off-the-shelf devices. Build database to establish confidence in signal compatibility for certain product types, and identify particular products that threaten aircraft signals.

    c. Establish a fast-response capability for suspected PED EMI incidents.

    d. Study the potential for devices transmitting on different frequencies, and possibly regulated by different national standards, to generate intermodulation products in aircraft navigation radio-frequency bands.

2. Expand Database of Aircraft Pathloss Measurements:

    a. Acquire/purchase existing measurement data funded by airlines. (B-737, B-767, B-777, DC-10).

    b. Explore new partnerships for further pathloss measurements (i.e., United, USAirways, American, Airbus, Boeing, etc.)

    c. Perform statistical analysis of pathloss probability distributions based upon seat location, airplane type, and airplane version.

3. Determine Limits for Aircraft Navigation Radio Susceptibility to PED EMI:

    a. Develop susceptibility measurement process for aircraft navigation radios.

    b. Measure multiple types of aircraft navigation radios to establish database of typical susceptibility to PED EMI.

    c. Assess different susceptibility threshold requirements for different minimum service levels and IFR conditions, and different types of PED EMI.

4. Health and Safety/Multi-User Analysis:

   Evaluate SAR distributions for multiple transmitters on aircraft for passenger and flight-crew safety. This task could be combined with studies of loading and coverage issues related to network capacity due to multipath and reverberation.

5. Legacy Avionics Immunity Analysis:

   Evaluate close-in field intensities generated by all classes of new wireless technology potentially present on commercial aircraft (i.e., wireless phones, wireless LANs, FRS, UWB, etc.). Determine limitations and restrictions that may be required for compatibility with systems certified to levels below RTCA DO-160C requirements for passenger cabin equipment.

6. Onboard Detection and Mitigation of Unauthorized Passenger Devices

   a. Quantify and categorize approaches to threat detection (installed vs. portable, sensitivity vs. false alarm, public band vs. aircraft band, amplitude detector vs. modulation decoder, etc.).

   b. Evaluate existing and emerging techniques for threat mitigation (i.e., remote power control and deactivation, jamming, etc.).

   c. Collect data on aircraft passenger-cabin RF environments during flight.

   d. Demonstrate existing detection systems.

   e. Collect data on in-use systems.

7. Provide technical data and advocate aircraft EMI concerns to consumer-device regulatory agencies and working groups.

6 References

[1] RTCA/DO-199, *Potential Interference to Aircraft Electronic Equipment from Devices Carried Aboard*, Prepared by SC-156, September 16, 1988.

[2] RTCA/DO-233, *Portable Electronic Devices Carried on Board Aircraft*, Prepared by SC-177, August 20, 1996.

[3] Perry, T., and Geppert, L.: "Do Portable Electronics Endanger Flight? The Evidence Mounts", *IEEE Spectrum*, September, 1996.

[4] Helfrick, A., "Avionics & Portable Electronics: Trouble in the Air?", *Avionics News*, September 1996, http://www.bluecoat.org/reports/Helfrick_96_PED.pdf

[5] Ladkin, Peter B., "Electromagnetic Interference with Aircraft Systems: why worry?", Article RVS-J-97-03, University of Bielefeld, October 20, 1997, http://www.rvs.uni-bielefeld.de/publications/Incidents/DOCS/Research/Rvs/Article/EMI.html.

[6] Donham, Bruce, "Electromagnetic Interference from Passenger-Carried Portable Electronic Devices", *Boeing Aero Magazine*, No. 10, March 2000, http://www.boeing.com/commercial/aeromagazine/aero_10/interfere.pdf.

[7] Ross, Elden, *Personal Electronic Devices and Their Interference With Aircraft Systems*, NASA/CR-2001-210866, June 2001, http://techreports.larc.nasa.gov/ltrs/PDF/2001/cr/NASA-2001-cr210866.pdf.

[8] 14CFR 91.21, "Portable Electronic Devices", *US Code of Federal Regulations, Federal Register*, February 1, 2002, http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_14/14cfr91_00.html.

[9] AC 91.21-1a (FAA Advisory Circular), *Use of Portable Electronic Devices Aboard Aircraft*, Oct. 2, 2000, http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/MainFrame?OpenFrameSet.

[10] Rollins, Courtney H., "Electromagnetic Compatibility Testing for the NASA Langley Research Center Boeing 757-200", *AIAA DASC Conf*., Oct. 2001, ISBN:0-7803-7036-8, IEEE Cat. #01CH37219C.

[11] *Aeronautical Telecommunications*, International Civil Aviation Organization (ICAO), Annex 10, Volume I.

[12] RTCA/DO-192, *Minimum Operational Performance Standards for Airborne ILS Glide Slope Receiving Equipment Operating within the Radio Frequency Range of 328.6 – 335.4 MHz,* Prepared by SC-153, July 19, 1986.

[13] RTCA/DO-195, *Minimum Operational Performance Standards for Airborne ILS Localizer Receiving Equipment Operating within the Radio Frequency Range of 108-112 MHz*, Prepared by SC-153, November 17, 1986.

[14] RTCA/DO-196, *Minimum Operational Performance Standards for Airborne VOR Receiving Equipment Operating within the Radio Frequency Range of 108-117.95 MHz*, Prepared by SC-153, November 17, 1986

[15] International Telecommunication Union, Recommendation ITU-R M.1477 (2000).

[16] RTCA/DO-208, *Min. Operational Perf. Standards for Airborne Supplemental Navigation Equipment using Global Positioning System (GPS),* July 12, 1991, Change 1 issues September 21, 1993.

[17] RTCA/DO-229B, *Min. Operational Perf. Standards for Global Positioning System (GPS)/ Wide Area Augmentation System,* Oct. 6, 1999.

[18] RTCA/DO-253A, *Min. Operational Perf. Standards for GPS Local Area Augmentation System Airborne Equipment,* Nov. 28, 2001.

[19] RTCA/DO-228, *Min. Operational Perf. Standards for Global Navigation Satellite Systems (GNSS) Airborne Antenna Equipment*, Oct. 20, 1995.

[20] RTCA/DO-235, *Assessment of Radio Frequency Interference Relevant to the GNSS*, Prepared by RTCA/SC-159 WG6, January 29, 1997.

[21] Delta Airlines/NASA Data, Provided to NASA in support of Cooperative Agreement NCC-1-381.

[22] Veda Inc., *CV-580 RF Coupling Validation Experiment Report*, Report #79689-96U/P30041, 11/15/1996.

[23] Fuller, Gerald, *747-222 Path Loss Test, Las Vegas, Nevada Fall 1999*, Prepared under NASA PO #L-10005.

[24] Ladbury, J., Koepke, G., and Camell, D., *Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility,* NIST Technical Note 1508, Jan. 1998.

[25] MIL-STD-462D, *Measurement of Electromagnetic Interference Characteristics*, January 11, 1993.

[26] RTCA DO-160D, *Environmental Conditions and Test Procedures for Airborne Equipment,* Prepared by SC-135, July 29, 1997.

[27] ANSI C63.4-2000, *Interim Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz,* published by the IEEE, December 8, 2000.

[28] Draft ETSI EN 301 908-7 V1.1.1, *Electromagnetic Compatibility and Radio Spectrum Matters; Base Stations and User Equipment for IMT-2000 Third Generation Cellular Networks: Part 7: Harmonized Standard for IMT-2000, CDMA TDD Covering Essential Requirements of Article 3.2 of the R&TTE Directive,* April 2001.

[29] RTCA DO-160D Draft #8 (FINAL DRAFT) for the Change Notice to Section 20, *Environmental Conditions and Test Procedures for Airborne Equipment*, Prepared by SC-135, March 27, 2000.

[30] Delta Airlines Engineering, *ENGINEERING REPORT Delta/NASA Cooperative Agreement NCC-1-381 Deliverable Reports*, Report # 10-76052-20, Dec. 8, 2000.

[31] Koppen, Sandra V., *A Description of the Software Element of the NASA Portable Electronic Device Radiated Emissions Investigation,* NASA/CR-2002-211675, May 2002.

[32] Kuriger, Cartwright, Grant, and Hierman, *Analysis of CDMA and GSM Wireless Phone Operating Modes and Standard Protocol for Spurious Emissions Testing*, University of Oklahoma Report to NASA, under Purchase Order L-70786D Deliverable for Task 3, July 31, 2001.

[33] Fry, T.L., Grant, H., and Schlegel, R.E., *Investigation of the Interaction Between CDMA Wireless Phones and Hearing Aids, A Study Performed for the CDMA Development Group,* Center for the Study of Wireless Electromagnetic Compatibility, University of Oklahoma, Norman, Oklahoma, March, 1999.

[34] IEEE Computer Society, LAN/MAN Standards Committee, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-speed Physical Layer in the 5 GHZ Band,* September 16, 1999.

[35] IEEE Computer Society, LAN/MAN Standards Committee, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-speed Physical Layer in the 2.4 GHZ Band,* September 16, 1999.

[36] Bluetooth SIG, *Bluetooth Specification Version 1.1*, February 22, 2001.

[37] G. Bichot, L Litwin, K. Ramaswamy, "Wireless Digital Home Networking: The Physical Layers of Bluetooth, IEEE 802.11b, and IEEE 802.11a", *IEEE Consumer Electronics Society Newsletter,* February 2002.

[38] *IEEE Standards Wireless Zone - Overview*, February 7, 2002. http://standards.ieee.org/wireless/overview.html .

[39] Olavsrud, Thor, "IEEE Gives Bluetooth Version Thumbs Up", *Synchrologic Mobile and Wireless News Digest,* March 23, 2002. Web page www.synchrologic.com/mobile_news.html .

[40] Eurocae ED-14, *Environmental Conditions and Test Procedures for Airborne Equipment,* July, 1997.

[41] ANSI/IEEE Std. 100-1988, *IEEE Standard Dictionary of Electrical and Electronics Terms,* Fourth Edition, July 8, 1988.

[42] Koepke, Hill, and Ladbury, “Directivity of the Test Device in EMC Measurements”, *2000 IEEE International Symposium on Electromagnetic Compatibility*, August 21-25, 2000.

[43] *Most US Households Now Have a Mobile Phone- Survey*, http://home.intekom.com/cellular/mobileoffice/news_2000/news-12222000_most_us_phones.htm , Dec. 21, 2000.

[44] *CTIA’s Semi-Annual Wireless Industry Survey,* 2001, http://www.wow-com.com/pdf/CTIA2001Survey.pdf , 2001

[45] The Windows Platform Development Website, *Wireless Support in Windows,* http://www.microsoft.com/hwdev/tech/network/wireless/winsupport.asp, and *Bluetooth Wireless Technologies,* http://www.microsoft.com/hwdev/tech/network/bluetooth/default.asp , Oct. 7, 2002.

[46] *The BlueZ Project Website*, http://bluez.sourceforge.net , Oct. 7, 2002

[47] *Top 15 Notebook PCs,* PCWorld.com Website, Oct. 7, 2002, http://www.pcworld.com/reviews/article/0,aid,103169,00.asp .

[48] “FAA says you can use PDA on jet”, *USA Today*, Aug. 19, 2002, http://www.usatoday.com/tech/news/techpolicy/2002-08-19-faa-rules_x.htm .

[49] Auerbach, Jon G., (Staff Reporter of *The Wall Street Journal*), “Cell Phones On Planes”, http://www3.primushost.com/~clp/news/telecom/Cell_phones_on_planes.html

[50] http://www.epinions.com/content_8035143300?sp=ink , Oct. 4, 2002.

[51] http://www.blackberry.net/support/faqs/networks/index.shtml , Oct. 4, 2002.

[52] Petersen, Andrea, (Staff Reporter of *The Wall Street Journal*), "Wireless Devices Let Users Receive E-Mail Anywhere – and They Do", http://www.flatironpartners.com/Article_4_26_00.html , Oct. 7, 2002

[53] Helfrick, A., and Wilson, A., "Investigations Into a System for the Detection and Location of Potentially Harmful Radiation from Portable Electronics Carried Onboard Aircraft", IEEE/AIAA Digital Avionics Systems Conference Proceedings, November, 1998.

[54] De Donno, Capt. Fabio, "Portable Electronic Devices On Airplanes, Detection of Electromagnetic Interference On Board Of Aircraft, A Survey on Portable Phones Interference On Aircraft", Presentation Charts, *Seventh Flight Safety Conference*, March 28-30, 2000.

[55] Ross, G. F., "Transmission and Reception System for Generating and Receiving Base-band Duration Pulse Signals Without Distortion for Short Base-band Pulse Communication System", U. S. Patent 3,728,632, dated April 17, 1973. (Avail. From http://www.multispectral.com/history.html)

[56] Fontana, R. J., *Recent Applications of Ultra Wideband RADAR and Communications Systems, Ultra-Wideband, Short Pulse Electromagnetics,* Klewer Academic/Plenum Publishers 2000. (Avail. From http://www.multispectral.com/history.html)

[57] McEwan, T. E., "Ultra-Wideband RADAR Motion Sensor", U. S. Patent 5,361,070, dated November 1, 1994 (Avail. From http://www.multispectral.com/history.html)

[58] Stover, D., "RADAR on a Chip, 101 Uses In Your Life", *Popular Science*, March 1995, p. 107.

[59] Federal Register / Vol. 67, No. 95 / Thursday, May 16, 2002, *Ultra-Wideband Transmission Systems*, ET Docket No. 98-153, 17 FCC Rcd. 7435 (2002)

[60] 47CFR Ch.1, Part 15.209, "Radiated Emission Limits; General Requirements", *US Code of Federal Regulations, Federal Registe,r* dated December 18, 2001.

[61] *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, DA 02-1658, ET Docket No. 98-153, (Order), Released July 12, 2002.

[62] *World Jet Inventory,* Jet Information Services Inc., 2002, available from http://www.jetinventory.com.

Appendices

Appendix A: Abbreviations, Definitions and Variables

A.1 Acronyms

2G	Second generation wireless technology
2.5G	Intermediate second-generation wireless technology
3G	Third Generation wireless technology
ADF	Automatic Direction Finder
ADI	Attitude Directional Indicator
AM	Amplitude Modulation
AMPS	Analog Mobile Phone System or Advanced Mobile Phone Service
AMSS	Airborne Mobile Satellite Service
ANSI	American National Standards Institute
AP	Access Point
ARP	Aerospace Recommended Practice
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
BSS	Basic Service Set

BS	Base Station
CB	Citizen’s Band
CCK	Complementary Code Keying
CD	Compact Disc
CDMA	Code Division Multiple Access
CFR	Code of Federal Regulations
CISPR	International Special Committee on Radio Interference
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CODEC	Coder-Decoder
CP	Connection Point
CTIA	Cellular Telecommunications & Internet Association
CW	Continuous Wave
DAL	Delta Airlines
DCS	Digital Communications System
DECT	Digital Enhanced Cordless Telecommunications
DLL	Data Link Layer
DME	Distance Measuring Equipment
DSSS	Direct Sequence Spread Spectrum
DRH	Dual Ridge Horn
DRX	Discontinuous Receive
DTX	Discontinuous Transmit
DUT	Device Under Test
DVD	Digital Video Disc
EIRP	Effective Isotropic Radiated Power
EDGE	Enhanced Data for Global Evolution
E^3	Electromagnetic Environmental Effects
EFR	Enhanced Full Rate
EGNOS	European Geostationary Navigation Overlay Service
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ERAU	Embry Riddle Aeronautical University
ETSI	European Telecommunications Standards Institute
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
EWI	Eagles Wings Incorporated
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FHSS	Frequency Hopping Spread Spectrum
FM	Frequency Modulation
FR	Full Rate
FRS	Family Radio System
GBAS	Ground Based Augmentation System
GMRS	General Mobile Radio System
GNSS	Global Navigation Satellite System
GPR	Ground Penetrating Radar
GPRS	General Packet Radio Service
GPS	Global Positioning System
GS	Glideslope
GSM	Global System for Mobile communications
HRFWG	Home Radio Frequency Working Group
IBSS	Independent Basic Service Set

ICAO	International Civil Aviation Organization
IDEN	Integrated Digital Enhanced Network
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFR	Instrument Flight Rule
ILS	Instrument Landing System
IPL	Interference Path Loss
IrDA	Infrared Data Association
ISM	Industry, Scientific, and Medical
ITU	International Telecommunication Union
JAA	Joint Aviation Authorities
KPD	Keypad
LAAS	Local Area Augmentation System
LAN	Local Area Network
LaRC	Langley Research Center
LLC	Logical Link Control
LOC	Localizer
LORAN C	Long Range Navigation
MAC	Media Access Control
MB	Marker Beacon
MLS	Microwave Landing System
MOPS	Minimum Operational Performance Standards
MRA	Mutual Recognition Agreements
NASA	National Aeronautics and Space Administration
NATS	North American Terrestrial System
NIC	Network Interface Card
NIST	National Institute of Standards and Technology
NSA	Normalized site attenuation
NTIA	National Telecommunications and Information Administration
OATS	Open Area Test Site
OMEGA	Optimized Method for Estimated Guidance Accuracy VLF Navigation System
OSI	Open Systems Interconnection
PAN	Personal Area Networks
PCMCIA	Personal Computer Memory Card International Association
PC	Personal Computer
PCS	Personal Communications System
PDA	Personal Digital Assistant
PDC	Personal Digital Communication
PED	Portable Electronic Device
PHY	Physical Layer Device
PSTN	Public Switched Telephone Network
RF	Radio Frequency
RMS	Root Mean Square
RTCA	formerly Radio Technical Commission on Aeronautics, now simply RTCA
RTT	Radio Transmission Technology
SAC	Semi-Anechoic Chamber
SAE	Society for Automotive Engineers
SAR	Specific Absorption Rate
SATCOM	Satellite Communications
SBAS	Satellite Based Augmentation System
SBIR	Small Business Innovation Research

SC	Special Committee
SCEFR	Speech CODEC Enhanced Full Rate
SCFR	Speech CODEC Full Rate
SIG	Special Interest Group
SOHO	Small Office/Home Office
SWAP	Shared Wireless Access Protocol
TACAN	Tactical Air Navigation
TACS	Tactical Air Control System
TCAS	Traffic Alert and Collision Avoidance System
TD-CDMA	Time Division – CDMA
TDD	Time Division Duplexing
TDMA	Time-division multiple access
TD-SCDMA	Time Division – Synchronization CDMA
THI	Test Harness Interface
T-PED	Intentionally Transmitting Portable Electronic Device
TSO	FAA's Technical Standard Order
TTL	Transistor Transistor Logic
UAL	United Air Lines
UMTS	Universal Mobile Telephone System
UOK	University of Oklahoma
US	United States
UTC	Universal Time Coordinated
UTRA	UMTS Terrestrial Radio Access
UWB	Ultrawideband
UWCC	Universal Wireless Communications Consortium
VDE	Verband Deutscher Elektringenieure (German Equivalent of IEEE)
VEE	Visual Engineering Environment
VHF	Very High Frequency
VLF	Very Low Frequency
Vocoder	Voice Coder
VOR	Very High Frequency Omni directional Range
WAAS	Wide Area Augmentation System
W-CDMA	Wideband CDMA
WECA	Wireless Ethernet Compatibility Alliance
WEP	Wireless Equivalent Privacy
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

A.2 Definition of Terms

Access Point (AP) - A hardware device that serves as a connection to a wired LAN when used with a computer or other wireless clients.

Ad Hoc Mode - a wireless LAN operating mode that provides direct or peer-to-peer connections between clients. No access point is used.

Basic Service Set (BSS) - IEEE 802.11 infrastructure mode that employs at least one access point connected to a wired network and several wireless devices or stations.

Client - a computer connected to a network that is able to communicate with other computers on the network.

Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) - An IEEE 802.11 protocol used by WLANs that senses the medium before establishing access and attempts to minimize collisions caused by simultaneous transmissions from multiple radios. The receiving station communicates that data were received by sending an explicit acknowledgement (ACK) within a packet. If the transmitting station does not receive an ACK, it will resend the data.

Complementary Code Keying (CCK) - An advanced coding technique specified in IEEE 802.11b standard that utilizes 64 8-bit code words as a means of representing data. This technique increases data rates and decreases interference. Further discussion of this coding technique is beyond the scope of this paper.

Data Link Layer (DLL) - The Data Link Layer is one of the lower layers of the Open Systems Interconnection network model. It is composed of two sub layers, Logical Link Control and Media Access Control. It is responsible for addressing, data services, security, and communication protocols.

Direct Sequence Spread Spectrum (DSSS) -a modulation mode employed by IEEE 802.11 and 802.11b devices. DSSS uses radio transmissions to spread data packets over a fixed range of the frequency band.

Institute of Electrical and Electronics Engineers (IEEE) - A membership organization composed of engineers, scientists, and students involved with setting standards for computers and communication.

Infrastructure Mode - A wireless LAN operating mode that provides connections between clients using an access point. The access point also provides access to a wired network.

Frequency Hopping Spread Spectrum (FHSS) - A modulation mode employed by IEEE 802.11 and Bluetooth devices. FHSS uses radio transmissions to spread data packets over a frequency band by hopping among several frequencies at a defined sequence and rate.

Independent Basic Service Set (IBSS) - IEEE 802.11 ad hoc or peer-to-peer mode that allows wireless devices or stations to communicate directly without an Access Point.

Industry, Scientific, and Medical (ISM) - ISM designates the 2.4-GHz frequency band, which is an unlicensed frequency band used for industry, safety, and medical applications.

Isochronous - A form of data transmission that guarantees to provide a certain minimum data rate, as required for time-dependent data such as video or audio.

Logical Link Control (LLC) - A sub layer of Data Link Layer in the network OSI model. It is responsible for managing addresses and linking protocols.

Media Access Control (MAC) - A sub layer of Data Link Layer in the network OSI model. It is responsible for managing data services, security, and communication protocols.

Network Interface Card (NIC) - A device containing wireless network access components such as a radio unit, an antenna, a baseband unit, software, and other specific electronics. A NIC is inserted into a laptop PCMCIA slot and provides wireless capability to the computer.

Open Systems Interconnection (OSI) - The International Standards Organization (ISO) network model that defines a seven-layer network protocol stack. The layers are listed here.
1. Physical
2. Data Link
3. Network
4. Transport
5. Session
6. Presentation
7. Application

Personal Area Networks (PAN) - A network configuration that is composed of several local Bluetooth devices communicating by using a peer-to-peer or ad-hoc operating mode.

PHY - The Physical Layer is the lowest layer of the Open Systems Interconnection network model. It is responsible for transmitting messages over the physical transport medium. It is responsible for managing data rates, modulation method, and transmitter/receiver synchronization.

Wireless Ethernet Compatibility Alliance (WECA) - An industry group that promotes compatibility and interoperability for 802.11b devices.

Wireless Equivalent Privacy (WEP) - An IEEE 802.11 encryption technique used by the MAC sub layer of the Data Link Layer, which is part of the OSI network model.

Wireless Fidelity (Wi-Fi) - A standard promoted by Wireless Ethernet Compatibility Alliance that identifies devices that comply with 802.11b standard.

Wireless Local Area Network (WLAN) - A wireless communications network that provides connections to outside networks allowing the sharing of resources and Internet and email access. In a wireless network, PCs and other devices are networked together without wires or cables.

A.3 Variable List

Symbol	Units	Description
P_T	dBm	RMS power amplitude transmitted by a CW signal source
P_R	dBm	RMS power amplitude measured at the test receiver (spectrum analyzer)
$\alpha_{Rad(Location)}$	dB	Radiated path loss between the test antenna connector and the aircraft antenna connector
α_{AC}	dB	Aircraft cable loss
α_{TC1}	dB	Loss of Test Cable #1, between the signal source and the reference antenna connector.
α_{TC2}	dB	Loss of Test Cable #2, between the aircraft radio receiver rack location and the measurement receiver.
EIRP	dBm	Effective Isotropic Radiated Power
E	V/m	Electric Field Intensity
R	m	Distance between transmit and receive antennas
π	None	Universal constant = 3.141592654…
V	Volts	Voltage measured at amplitude measurement receiver
AF	dB	Antenna factor which relates electric field intensity at antenna to voltage at the antenna connector
α_{RcvCbl}	dB	Cable loss from antenna connector to amplitude measurement receiver
$\alpha_{RcvPath}$	dB	Total loss in the receive path
α_{Other}	dB	Miscellaneous losses
P_{Meas}	dB	Measured power
P_{Xmt}	dB	Power transmitted from a calibrated signal source
G_{Ref}	dBi	Antenna gain relative to an isotropic radiator
α_{XmtCbl}	dB	Cable loss from calibrated signal source to transmit antenna connector
α_{Cbr}	dB	Reverberation chamber loss
α_{CbrCal}	dB	Reverberation chamber calibration loss factor
α_{RCTot}	dB	Reverberation chamber total measurement transfer (or loss) function
f	Hz	frequency
e	None	Antenna efficiency

Appendix B: Procedures for Measuring Spurious Radiated Emissions from Wireless Phones

B.1 File Notation

To avoid confusion, the file notation for all data collection conformed to the following standard:

Filename:= XXX YYYYYY ZZZA MB BC OD ???????

{ Always required
Required only for Emission/Noise Floor measurements
Required only for Semi-Anechoic measurements }

Where:	XXX	= RCA, RCB, SAC (Chamber type designation.)
	YYYYYY	= CblCal, Nfloor, CbrCal, Emeas (Measurement Type.) (Note, for reverberation chamber measurements, CbrCal and Emeas may be followed by additional lossy items in chamber.)
	ZZZ	= GSM, CDM (Phone type)
	A	= Phone model (1, 2, …)
	B	= Phone Mode-of-operation designation: = CDMA: Pmax (KPD), Pup (BS), Pclo (BS), TXAGC (THI); PRFull, PRHalf, PRQuar, PREigh, PRVar; VRFull, VRHalf, VREigh, VRVar = GSM: Plvl (KPD), TXlvl (BS); DTOn, DTOff; DROn, DROff; SCFR, SCEFR
	C	= Frequency Band designation (1: 105-125, 2: 235-340, 3: 960-1215, 4: 1565-1585 MHz)
	D	= Phone Orientation (1,2,3)
	???????	= Special Test Suffix

Table 35: File Notation Table for Experimental Testing.

*For GSM handsets, the transmit channel was added between the speech CODEC and frequency band designations. Three channel options were used, "Ch1", "Ch62", and "Ch100".

XXX	YYYYYY	ZZZA	MB (Power)	(Puncture / Disc. Tran.)	(Disc. Rec.)	(Vocoder / Spch. Codec.)	BC	OD	??????
SAC RCA RCB	CblCal CbrCal Nfloor Emeas	CDM1 CDM2 CDM3 CDM4	Pmax PUp PClo TXAGC	PRFull PRHalf PRQuar PREigh PRVar		VRFull VRHalf VRQuar VREigh VRVar	B1 B2 B3 B4	O1 O2 O3	
		GSM1 GSM2 GSM3 GSM4	PLVL TXLVL	DTOn DTOff	DROn DROff	SCFR SCEFR *	B1 B2 B3 B4	O1 O2 O3	

A sub-directory structure was created on all test-control computers according to the plan:
C:\Aug2001Test\
C:\Aug2001Test\RCA\ (For data collected in reverberation chamber A.)
C:\Aug2001Test\RCB\ (For data collected in reverberation chamber B.)
C:\Aug2001Test\SAC\ (For data collected in the semi-anechoic chamber.)

B.2 Semi-Anechoic Chamber Procedure

B.2.1 Frequency Band 1 (105-120 MHz)

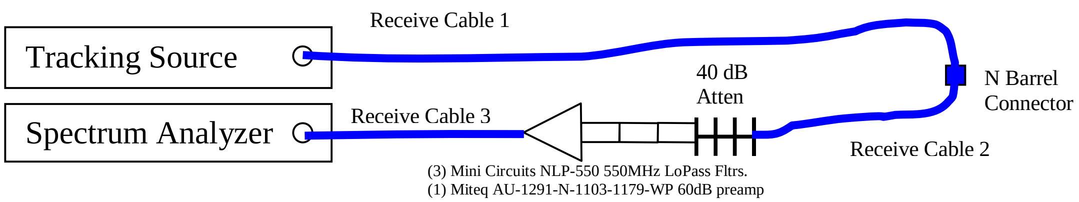
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	Model Numbers	Serial Numbers
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Reference Dipole Antenna		
Receive Antenna		
Base Station Antenna		
Pre-Amplifier(s)		
Filters		
Feedthru Attenuators		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		
Receive Cable 3		

Table B.1.1: Equipment List for semi-anechoic chamber test.

B.2.1.1 Receive Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= <u>-40 dBm</u>, RF <u>ON</u>.

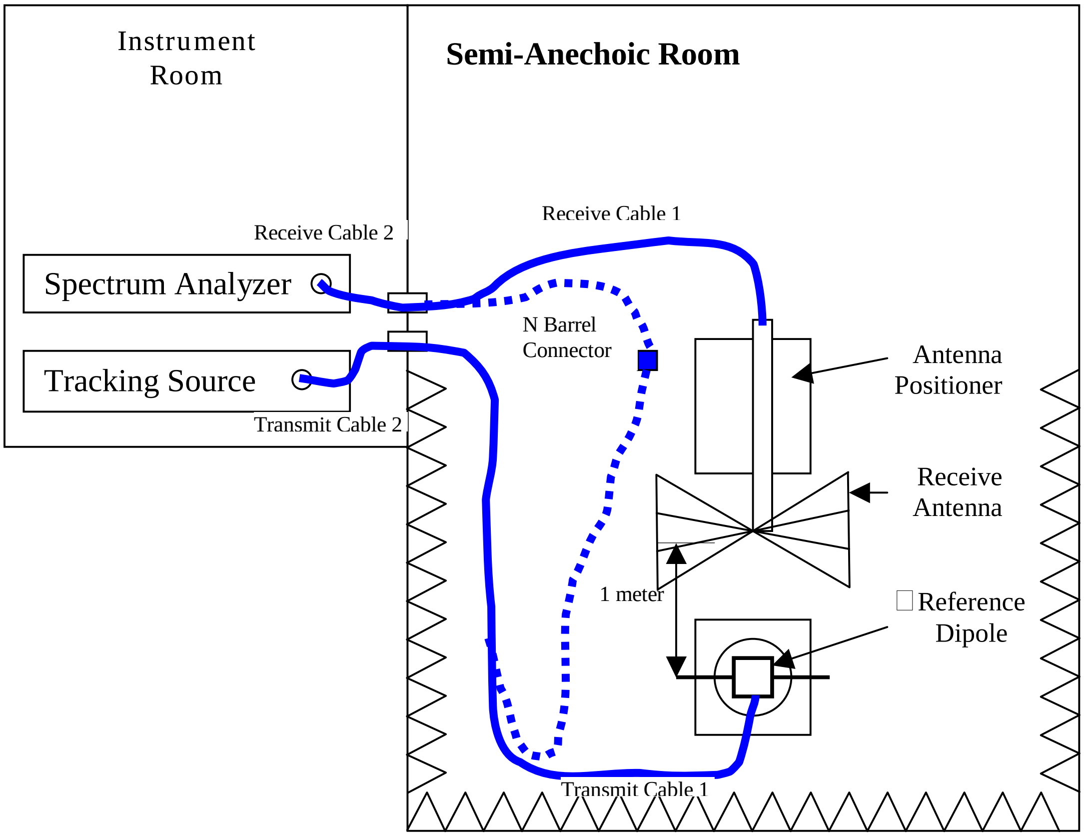
c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename = SAC CblCal B1
Frequency = <u>105 MHz to 120 MHz</u>
RBW = <u>10 kHz</u>
Sweep time = Default (375 msec)
Ref Lvl = <u>-10 dBm</u>
Dwell Time = <u>2 Sec</u>
SA Atten. Man. = <u>0 dB</u>
Ext. Atten. = <u>40 dB</u>

d) Allow data save. Exit.

B.2.1.2 Receive Antenna Height Determination and Antenna Factor Check

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown below, with Receive Cable 1 and Transmit Cable 1 connected together.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename	= SAC CblThru B1
Frequency	= 105 MHz to 120 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
SA Atten. Man.	= 0 dB
Ext. Atten.	= 0 dB

d) Allow data save. Exit.

e) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown on previous page, with Receive Cable 1 attached to the receive antenna and Transmit Cable 1 attached to the transmit antenna. Orient Biconical test antenna according to calibration data (Horizontal polarization). Orient Reference Dipole for the same polarization. Record Dipole Length (112MHz) _______________.

f) Manually, Set source to track spectrum analyzer, Frequency range= 105 MHz to 120 MHz. Output Power= 0 dBm, RF ON. (Spectrum analyzer in Clear-Write Mode.)

g) Adjust antenna height positioner until the maximum reading is observed on the spectrum analyzer display. Record height: ___________________________

h) Setup PED Monitor program with the following parameters:

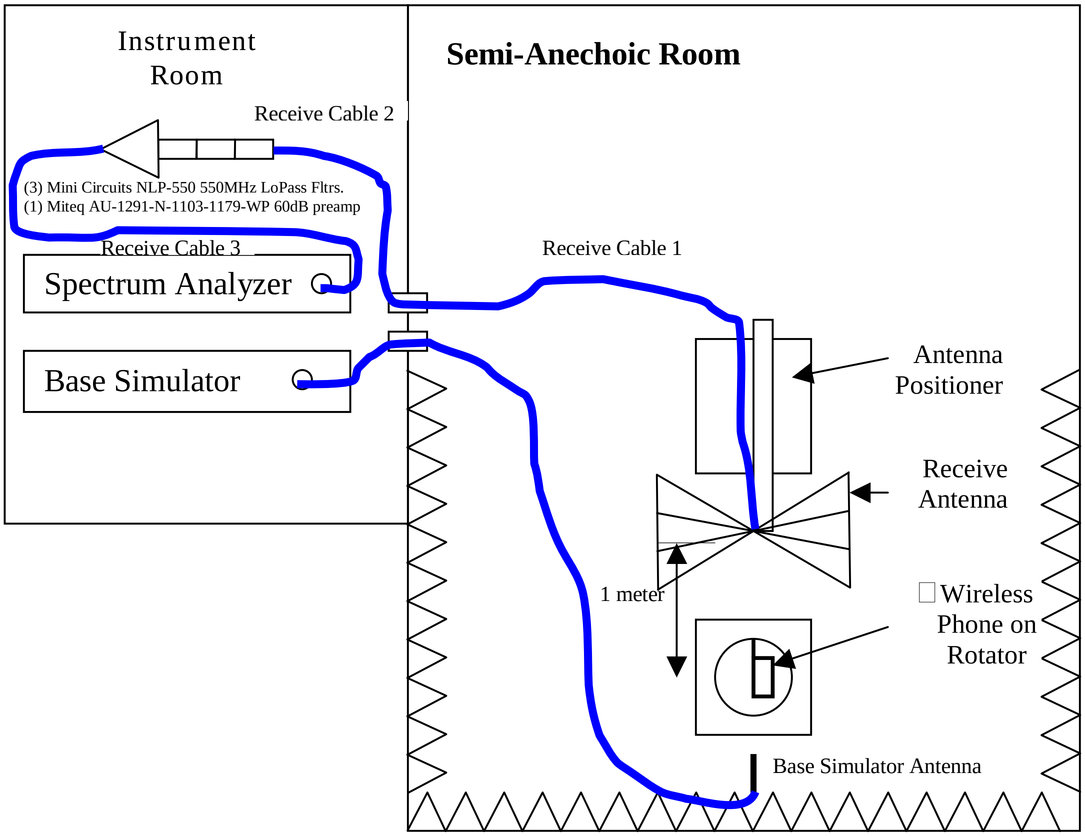
Filename	= SAC CbrRef B1
Frequency	= 105 MHz to 120 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
SA Atten. Man.	= 0 dB
Ext. Atten.	= 0 dB

i) Manually compare data between SAC CbrRef B1 and SAC CbrCal B1. The following expression should be true:

$$AF_{(dB)} + 2.23 \cong \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{CbrRef} - \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{CblThru} + G_{Ref\ (dBi)}$$

B.2.1.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) Source Output: RF <u>OFF</u> (or terminate into load). Turn PED <u>OFF</u> (if present). Turn Base Station Simulator <u>ON</u> (***if*** verified to be emission free in this band). Run rotator.

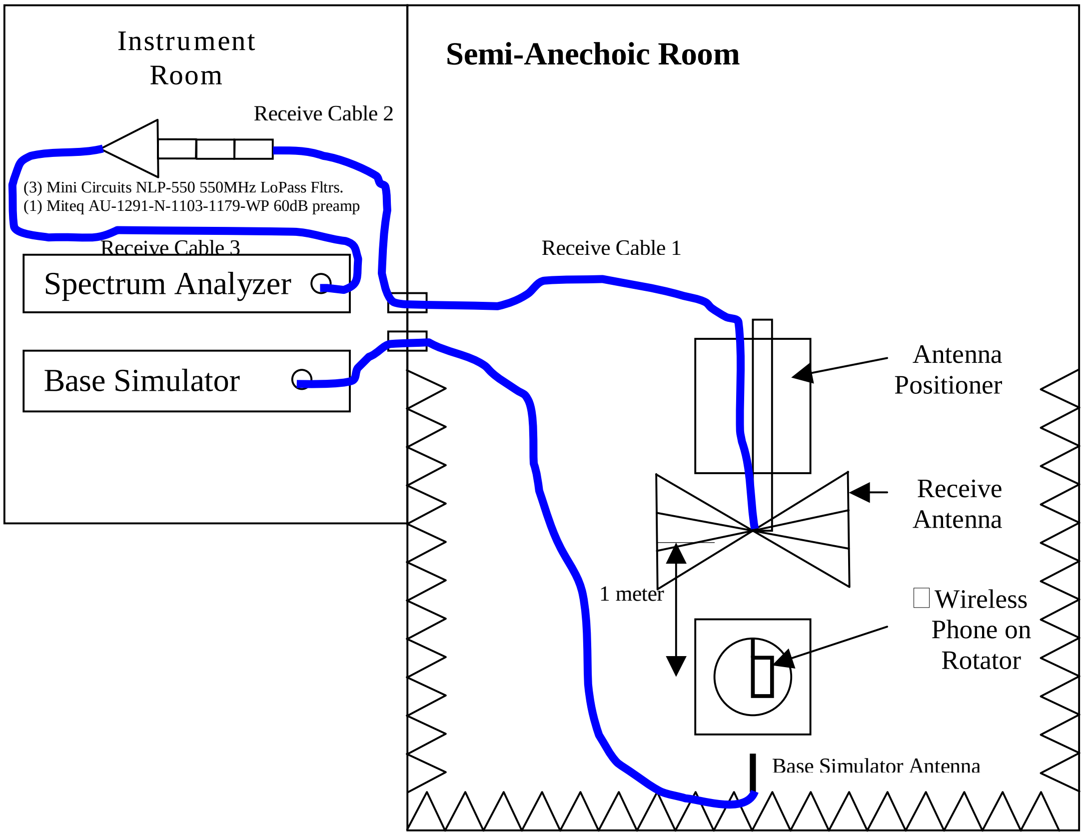
c) Setup PED Monitor program with the following parameters:

Filename = SAC Nfloor B1
Frequency = <u>105 MHz to 120 MHz</u>
RBW = <u>10 kHz</u>
Sweep time = Default (375 msec)
Ref Lvl = <u>-10 dBm</u>
Dwell Time = <u>120 Sec</u>
SA Atten. Man. = <u>0 dB</u>

d) Allow data save. Exit.

B.2.1.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) -Verify Source Output: RF OFF (or terminate into load).
-Place Phone in desired orientation, and turn phone ON.
-Command base station simulator or enter keypad code according to specified test protocol.
- Position receive antenna to optimal height.
-Run rotator.

c) Setup PED Monitor program with the following parameters:

Filename = SAC Emeas ZZZA MB B1 OD (□= See File Notation Section.)
Frequency = 105 MHz to 120 MHz
RBW = 10 kHz
Sweep time = Default (375 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

d) Allow data save. Exit.

B.2.2 Frequency Band 2 (325-340 MHz)

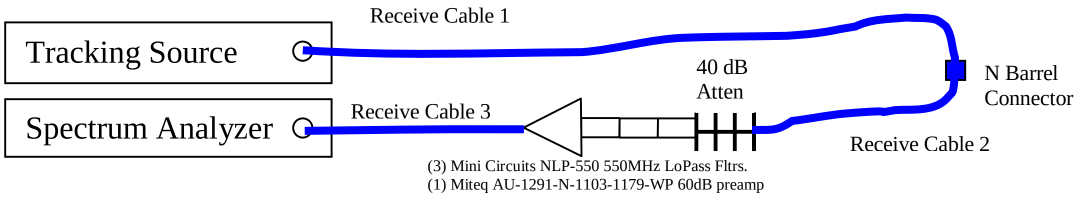
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	**Model Numbers**	**Serial Numbers**
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Reference Dipole Antenna		
Receive Antenna		
Base Station Antenna		
Pre-Amplifier(s)		
Filters		
Feedthru Attenuators		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		
Receive Cable 3		

Table B.1.2: Equipment List for semi-anechoic chamber test.

B.2.2.1 Receive Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -40 dBm, RF ON.

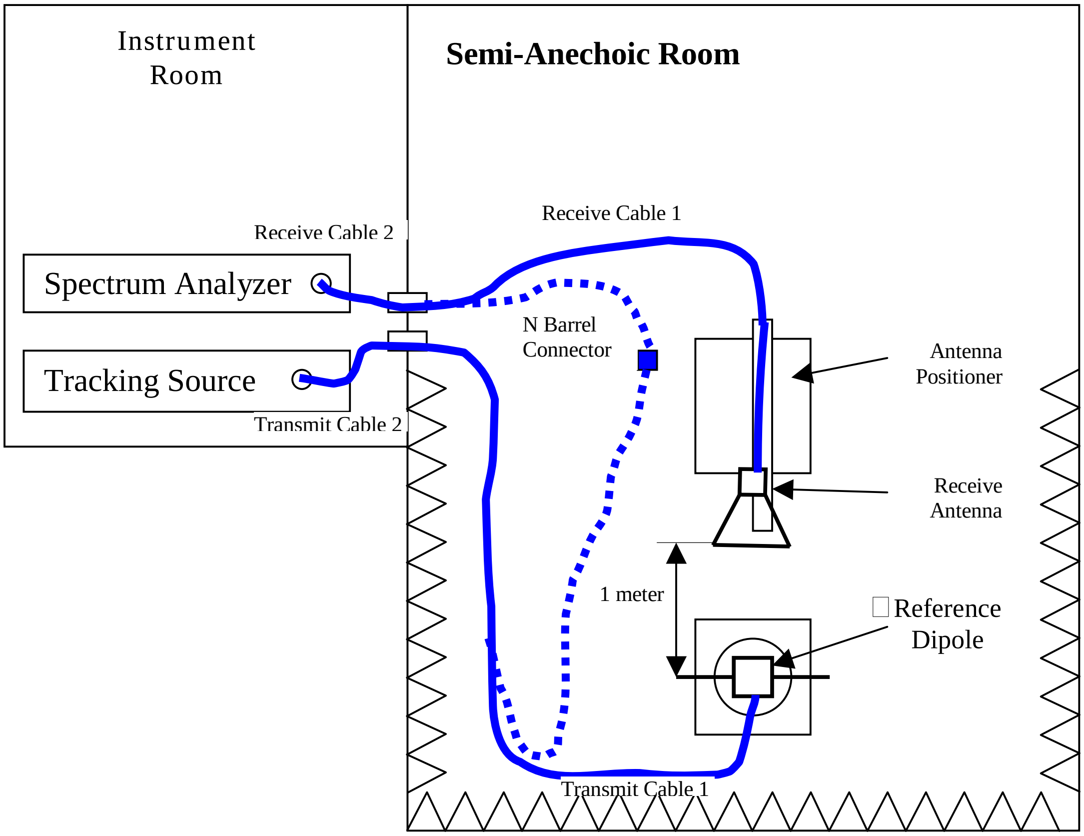
c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename = SAC CblCal B2
Frequency = 325 MHz to 340 MHz
RBW = 10 kHz
Sweep time = Default (375 msec)
Ref Lvl = -10 dBm
Dwell Time = 2 Sec
SA Atten. Man. = 0 dB
Ext. Atten. = 40 dB

d) Allow data save. Exit.

B.2.2.2 Receive Antenna Height Determination and Antenna Factor Check

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown below, with Receive Cable 1 and Transmit Cable 1 connected together.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename	= SAC CblThru B2
Frequency	= 325 MHz to 340 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
SA Atten. Man.	= 0 dB
Ext. Atten.	= 0 dB

d) Allow data save. Exit.

e) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown on previous page, with Receive Cable 1 attached to the receive antenna and Transmit Cable 1 attached to the transmit antenna. Orient Large Horn test antenna according to calibration data (Vertical polarization). Orient Reference Dipole for the same polarization. Set Dipole Length for 330 MHz _______________.

f) Manually, Set source to track spectrum analyzer, Frequency range= 325 MHz to 340 MHz. Output Power= 0 dBm, RF ON. (Spectrum analyzer in Clear-Write Mode.)

g) Adjust antenna height positioner until the maximum reading is observed on the spectrum analyzer display. Record height: ___________________________

h) Setup PED Monitor program with the following parameters:

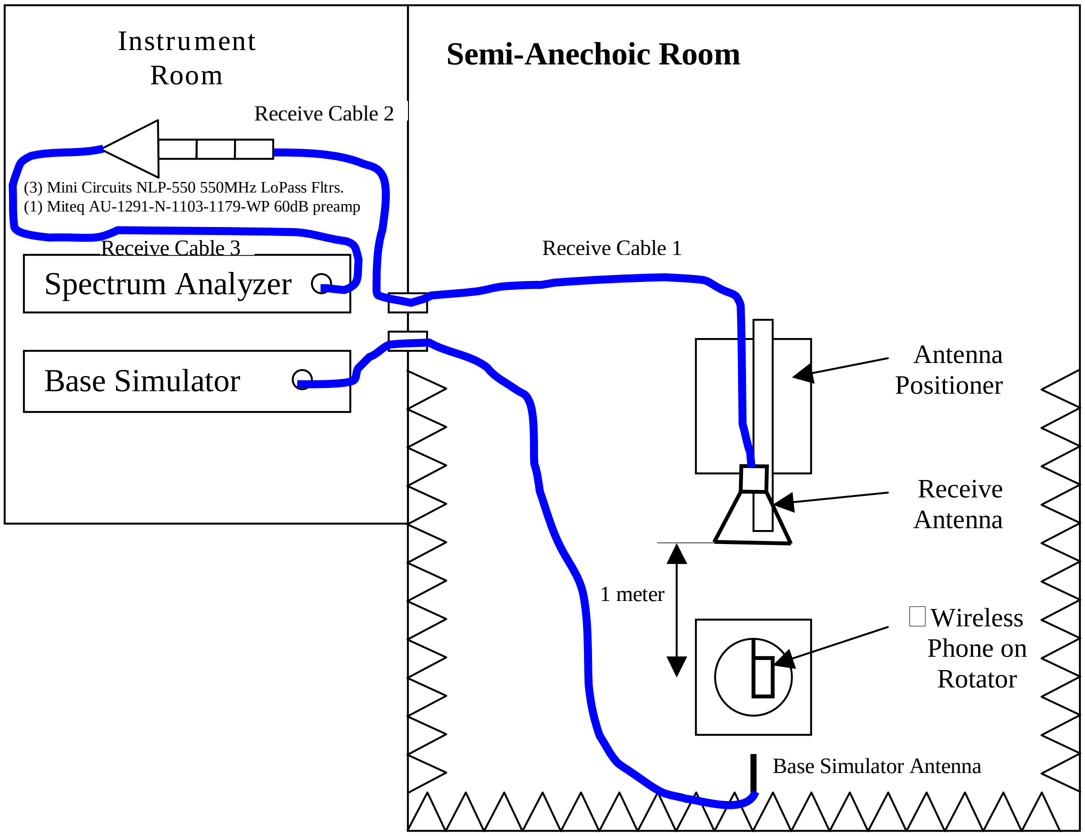
Filename	= SAC CbrRef B2
Frequency	= 325 MHz to 340 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
SA Atten. Man.	= 0 dB
Ext. Atten.	= 0 dB

i) Manually compare data between SAC CbrRef B2 and SAC CbrCal B2. The following expression should be true:

$$AF_{(dB)} + 2.23 \cong \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{CbrRef} - \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{CblThru} + G_{Ref\ (dBi)}$$

B.2.2.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) Source Output: RF <u>OFF</u> (or terminate into load). Turn PED <u>OFF</u> (if present). Turn Base Station Simulator <u>ON</u> (***if*** verified to be emission free in this band). Run rotator.

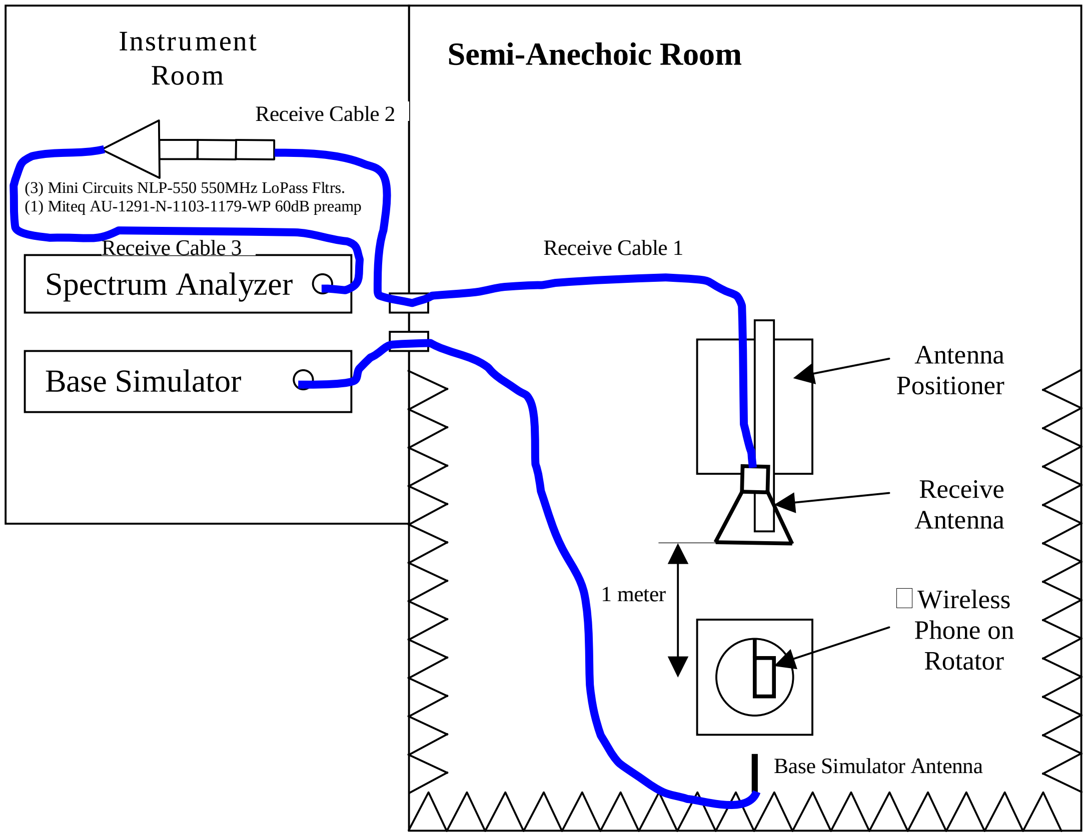
c) Setup PED Monitor program with the following parameters:

Filename = SAC Nfloor B2
Frequency = <u>325 MHz to 340 MHz</u>
RBW = <u>10 kHz</u>
Sweep time = Default (375 msec)
Ref Lvl = <u>-10 dBm</u>
Dwell Time = <u>120 Sec</u>
SA Atten. Man. = <u>0 dB</u>

d) Allow data save. Exit.

B.2.2.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) -Verify Source Output: RF OFF (or terminate into load).
-Place Phone in desired orientation, and turn phone ON.
-Command base station simulator or enter keypad code according to specified test protocol.
- Position receive antenna to optimal height.
-Run rotator.

c) Setup PED Monitor program with the following parameters:

Filename	= SAC Emeas ZZZA MB B2 OD (□= See File Notation Section.)
Frequency	= 325 MHz to 340 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 120 Sec
SA Atten. Man.	= 0 dB

d) Allow data save. Exit.

B.2.3 Frequency Band 3 (960-1215 MHz)

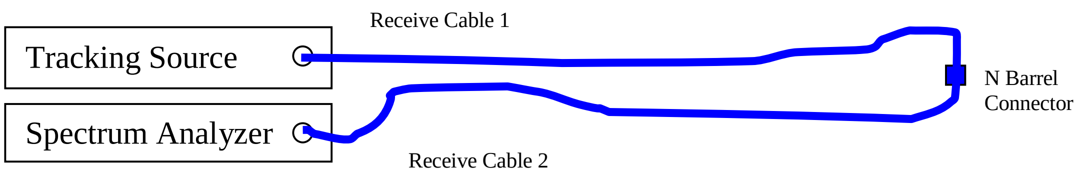
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	Model Numbers	Serial Numbers
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Reference Dipole Antenna		
Receive Antenna		
Base Station Antenna		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		

Table B.1.3: Equipment List for semi-anechoic chamber test.

B.2.3.1 Receive Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

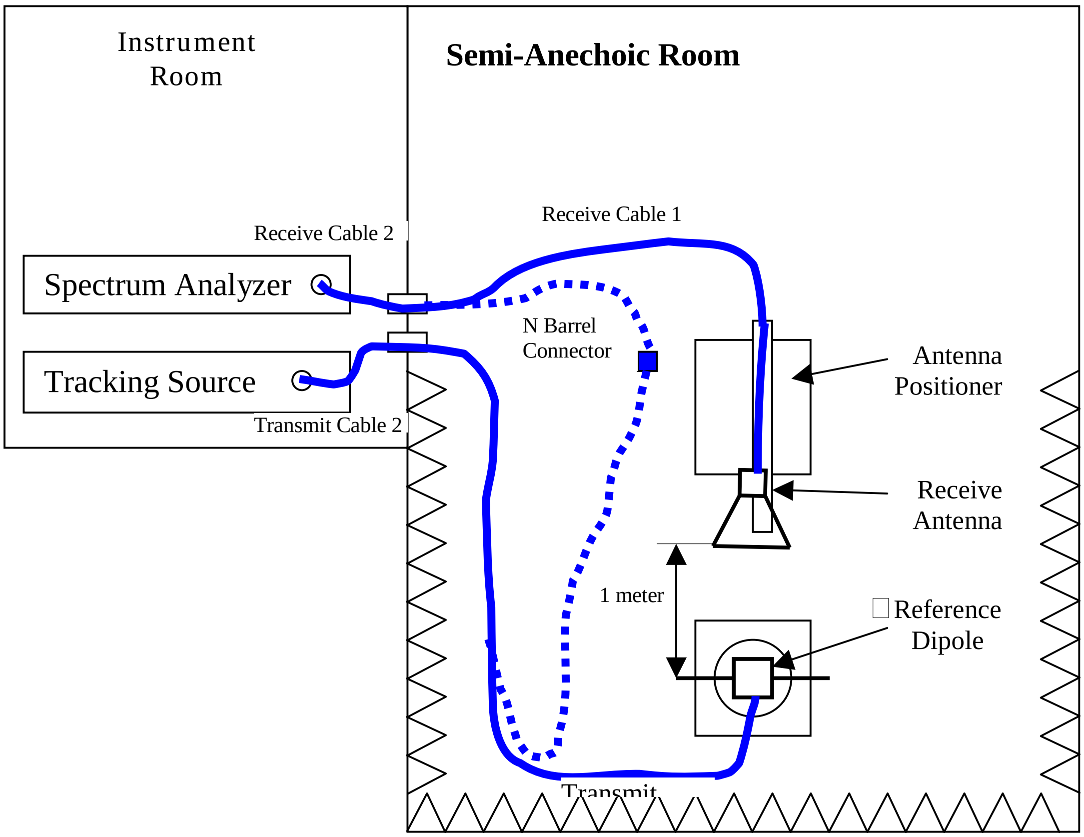
c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename = SAC CblCal B3
Frequency = 960 MHz to 1215 MHz
RBW = 100 kHz
Sweep time = Default (64 msec)
Ref Lvl = -10 dBm
Dwell Time = 2 Sec
SA Atten. Man. = 0 dB
Ext. Atten. = 0 dB

d) Allow data save. Exit.

B.2.3.2 Receive Antenna Height Determination and Antenna Factor Check

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown below, with Receive Cable 1 and Transmit Cable 1 connected together.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename	= SAC CblThru B3
Frequency	= 960 MHz to 1215 MHz
RBW	= 100 kHz
Sweep time	= Default (64 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
SA Atten. Man.	= 0 dB
Ext. Atten.	= 0 dB

d) Allow data save. Exit.

e) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown on previous page, with Receive Cable 1 attached to the receive antenna and Transmit Cable 1 attached to the transmit antenna. Orient Large Horn test antenna according to calibration data (Vertical polarization). Orient Reference Dipole for the same polarization. Set Dipole Length for 1GHz _______________.

f) Manually, Set source to track spectrum analyzer, Frequency range= 960 MHz to 1215 MHz. Output Power= 0 dBm, RF ON. (Spectrum analyzer in Clear-Write Mode.)

g) Adjust antenna height positioner until the maximum reading is observed on the spectrum analyzer display. Record height: ___________________________

h) Setup PED Monitor program with the following parameters:

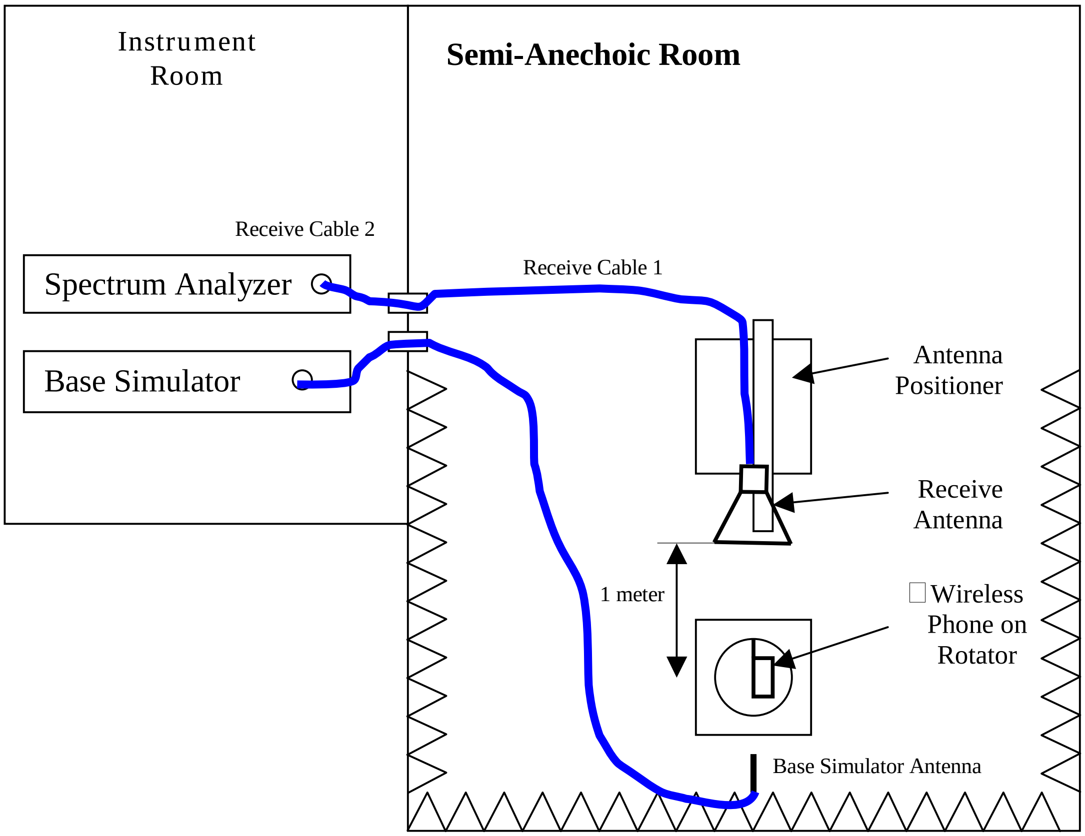
Filename	= SAC CbrRef B3
Frequency	= 960 MHz to 1215 MHz
RBW	= 100 kHz
Sweep time	= Default (64 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
SA Atten. Man.	= 0 dB
Ext. Atten.	= 0 dB

i) Manually compare data between SAC CbrRef B3 and SAC CbrCal B3. The following expression should be true:

$$AF_{(dB)} + 2.23 \cong \left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CbrRef} - \left[P_{Xmt\,(dBm)} - P_{Meas\,(dBm)}\right]_{CblThru} + G_{Ref\,(dBi)}$$

B.2.3.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) Source Output: RF <u>OFF</u> (or terminate into load). Turn PED <u>OFF</u> (if present). Turn Base Station Simulator <u>ON</u> (***if*** verified to be emission free in this band). Run rotator.

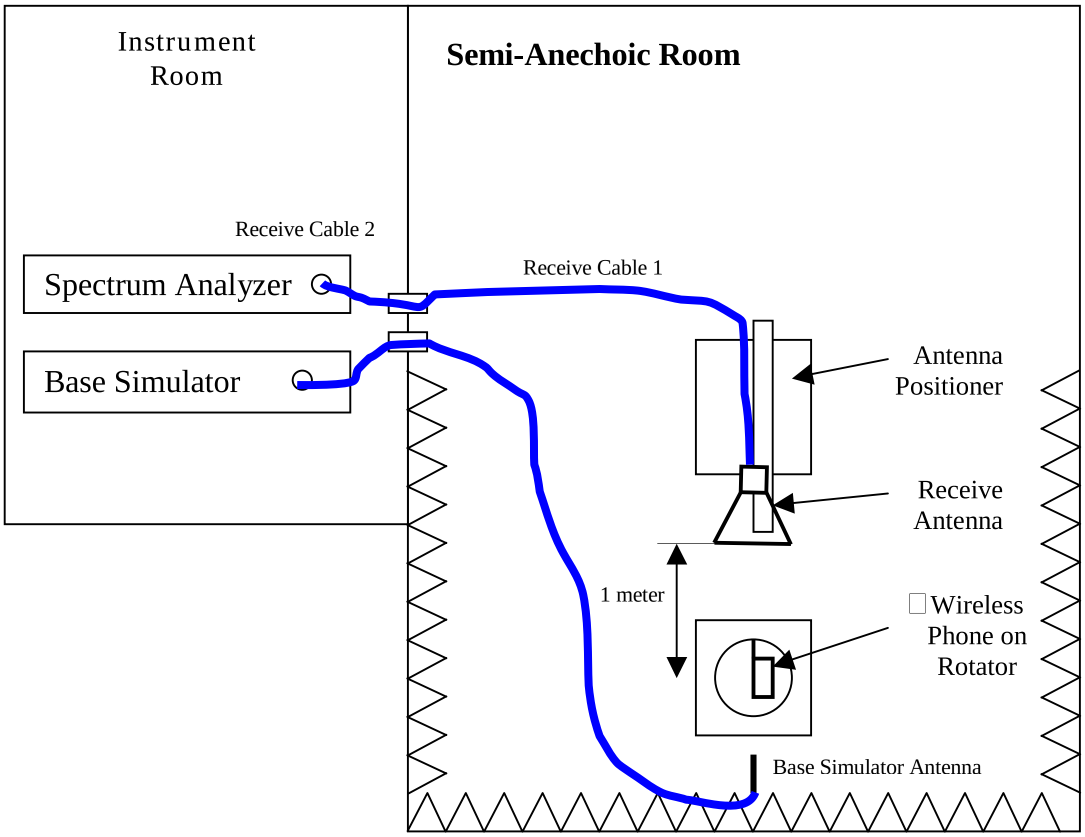
c) Setup PED Monitor program with the following parameters:

Filename = SAC Nfloor B3
Frequency = <u>960 MHz to 1215 MHz</u>
RBW = <u>100 kHz</u>
Sweep time = Default (64 msec)
Ref Lvl = <u>-10 dBm</u>
Dwell Time = <u>120 Sec</u>
SA Atten. Man. = <u>0 dB</u>

d) Allow data save. Exit.

B.2.3.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) -Verify Source Output: RF OFF (or terminate into load).
-Place Phone in desired orientation, and turn phone ON.
-Command base station simulator or enter keypad code according to specified test protocol.
- Position receive antenna to optimal height.
-Run rotator.

c) Setup PED Monitor program with the following parameters:

Filename	= SAC Emeas ZZZA MB B3 OD (□= See File Notation Section.)
Frequency	= 960 MHz to 1215 MHz
RBW	= 100 kHz
Sweep time	= Default (64 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 120 Sec
SA Atten. Man.	= 0 dB

d) Allow data save. Exit.

B.2.4 Frequency Band 4 (1565-1585 MHz)

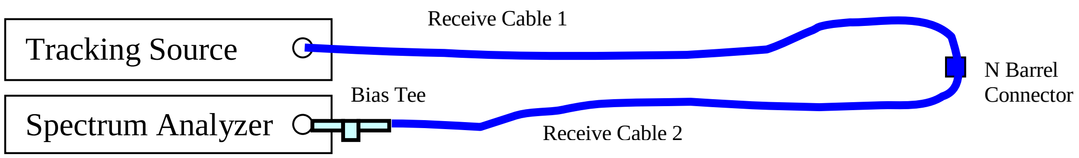
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	Model Numbers	Serial Numbers
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Reference Horn Antenna		
Receive Antenna		
Base Station Antenna		
Bias Tee		
12VDC Power Supply		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		

Table B.1.4: Equipment List for semi-anechoic chamber test.

B.2.4.1 Receive Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

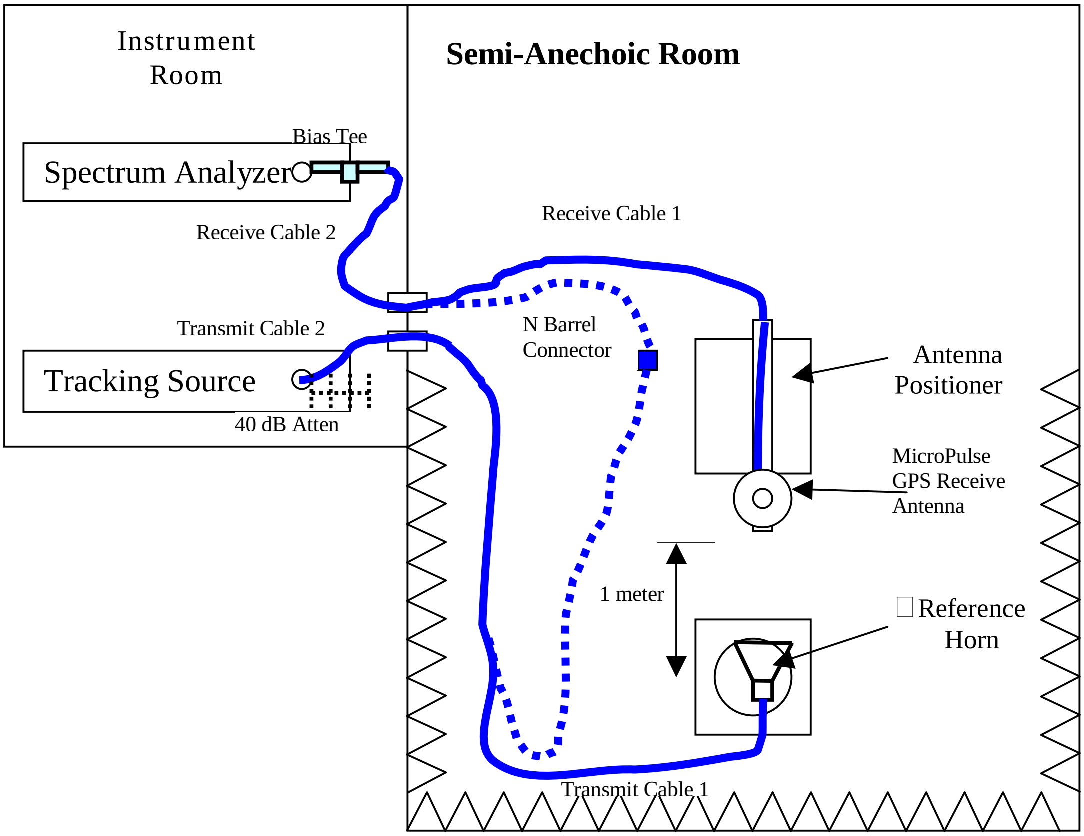
c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename = SAC CblCal B4
Frequency = 1565 MHz to 1585 MHz
RBW = 10 kHz
Sweep time = Default (500 msec)
Ref Lvl = -10 dBm
Dwell Time = 2 Sec
SA Atten. Man. = 0 dB
Ext. Atten. = 0 dB

d) Allow data save. Exit.

B.2.4.2 Receive Antenna Height Determination and Antenna Factor Determination

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown below, with Receive Cable 1 and Transmit Cable 1 connected together.



b) Set source to track spectrum analyzer, Output Power= <u>-10 dBm</u>, RF <u>ON</u>.

c) Setup PED Monitor program (Cable/Chamber Cal Mode) with the following parameters:

Filename = SAC CblThru B4
Frequency = <u>1565 MHz to 1585 MHz</u>
RBW = <u>10 kHz</u>
Sweep time = Default (500 msec)
Ref Lvl = <u>-10 dBm</u>
Dwell Time = <u>2 Sec</u>
SA Atten. Man. = <u>0 dB</u>
Ext. Atten. = <u>0 dB</u>

d) Allow data save. Exit.

e) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown on previous page, with Receive Cable 1 attached to the receive antenna and Transmit Cable 1 attached to the transmit antenna. Orient Reference Horn for Horizontal Polarization (according to Calibration Data).

f) Manually, Set source to track spectrum analyzer, Frequency range= 1565 MHz to 1585 MHz. Output Power= -60 dBm, Add 40dB precision attenuator to source output. RF ON. (Spectrum analyzer in Clear-Write Mode.) Beware not to transmit more than –100dBm to avoid overloading GPS antenna built-in preamplifier.

g) Adjust antenna height positioner until the maximum reading is observed on the spectrum analyzer display. Record height: ___________________________

h) Setup PED Monitor program with the following parameters:

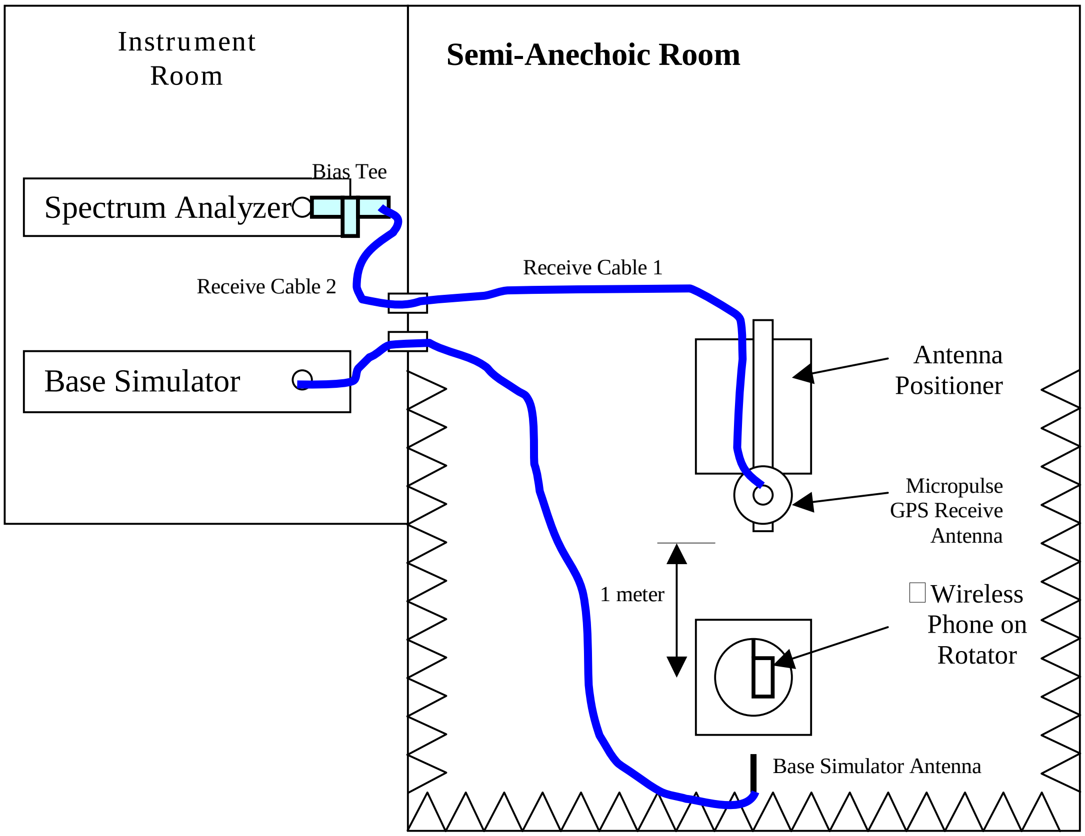
Filename	= SAC CbrRef B4
Frequency	= 1565 MHz to 1585 MHz
RBW	= 10 kHz
Sweep time	= Default (500 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
SA Atten. Man.	= 0 dB
Ext. Atten.	= 40 dB

i) Manually build calibration file for Micropulse GPS antenna using following equation, and calibrated gain data for reference horn. Name the file “Micropulse.dat”

$$AF_{(dB)} + 2.23 = \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{CbrRef} - \left[P_{Xmt\ (dBm)} - P_{Meas\ (dBm)}\right]_{CblThru} + G_{Ref\ (dBi)}$$

B.2.4.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) Source Output: RF <u>OFF</u> (or terminate into load). Turn PED <u>OFF</u> (if present). Apply 12VDC to Bias Tee. Turn Base Station Simulator <u>ON</u> (***if*** verified to be emission free in this band). Run rotator.

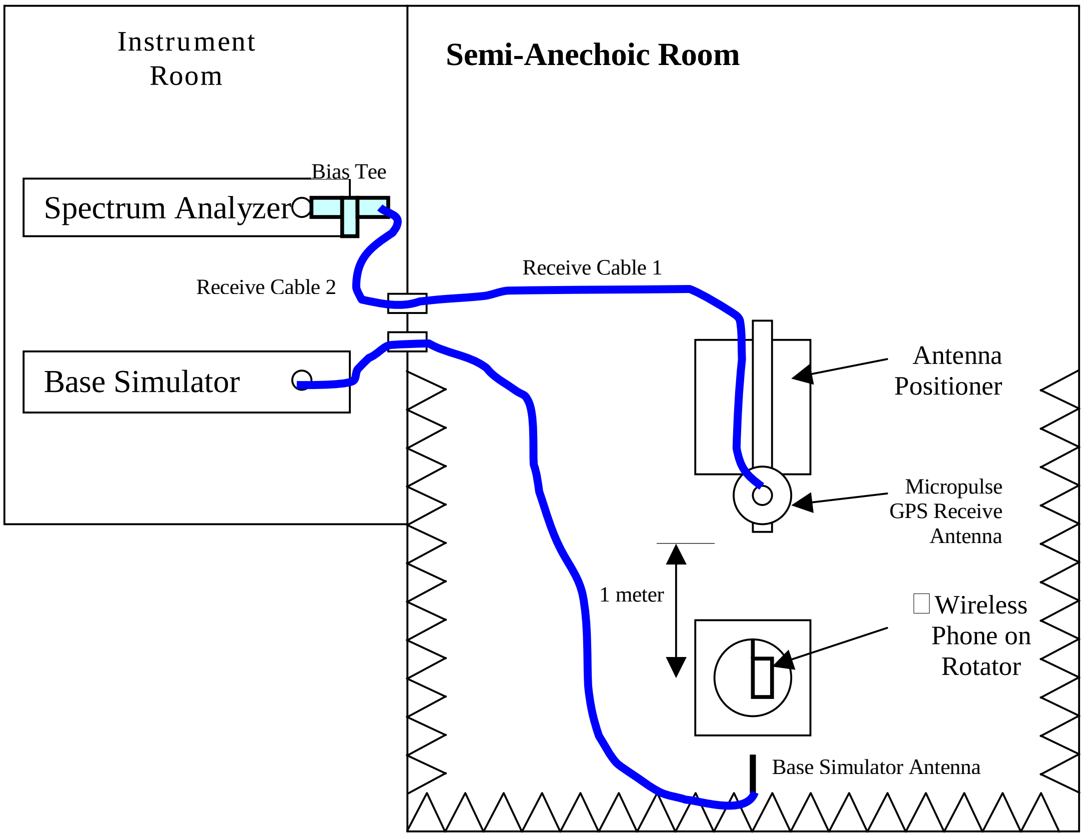
c) Setup PED Monitor program with the following parameters:

Filename	= SAC Nfloor B4
Frequency	= <u>1565 MHz to 1585 MHz</u>
RBW	= <u>10 kHz</u>
Sweep time	= Default (500 msec)
Ref Lvl	= <u>-10 dBm</u>
Dwell Time	= <u>120 Sec</u>
SA Atten. Man.	= <u>0 dB</u>

d) Allow data save. Exit.

B.2.4.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown.



b) -Verify Source Output: RF <u>OFF</u> (or terminate into load).
-Place Phone in desired orientation, and turn phone <u>ON</u>.
-Command base station simulator or enter keypad code according to specified test protocol.
- Position receive antenna to optimal height.
-Run rotator.

c) Setup PED Monitor program with the following parameters:

Filename	= SAC Emeas ZZZA MB B4 OD (□= See File Notation Section.)
Frequency	= <u>1565 MHz to 1585 MHz</u>
RBW	= <u>10 kHz</u>
Sweep time	= Default (500 msec)
Ref Lvl	= <u>-10 dBm</u>
Dwell Time	= <u>120 Sec</u>
SA Atten. Man.	= <u>0 dB</u>

d) Allow data save. Exit.

B.3 Reverberation Chamber Procedure

Print copies of these procedures for each reverberation chamber, and place in the "Test Procedures and Data Binder".

B.3.1 Frequency Band 1 (105-120 MHz)

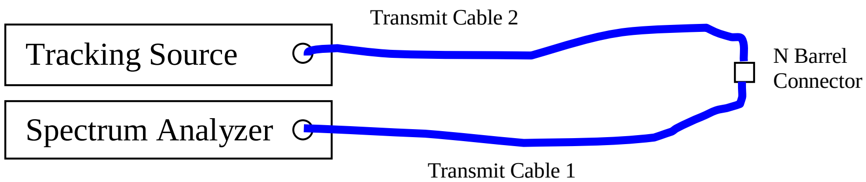
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	Model Numbers	Serial Numbers
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Transmit Antenna		
Receive Antenna		
Base Station Antenna		
Pre-Amplifier(s)		
Filters		
Feedthru Attenuators		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		
Receive Cable 3		

Table B.2.1: Equipment List for reverberation chamber __________ test.

B.3.1.1 Transmit Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

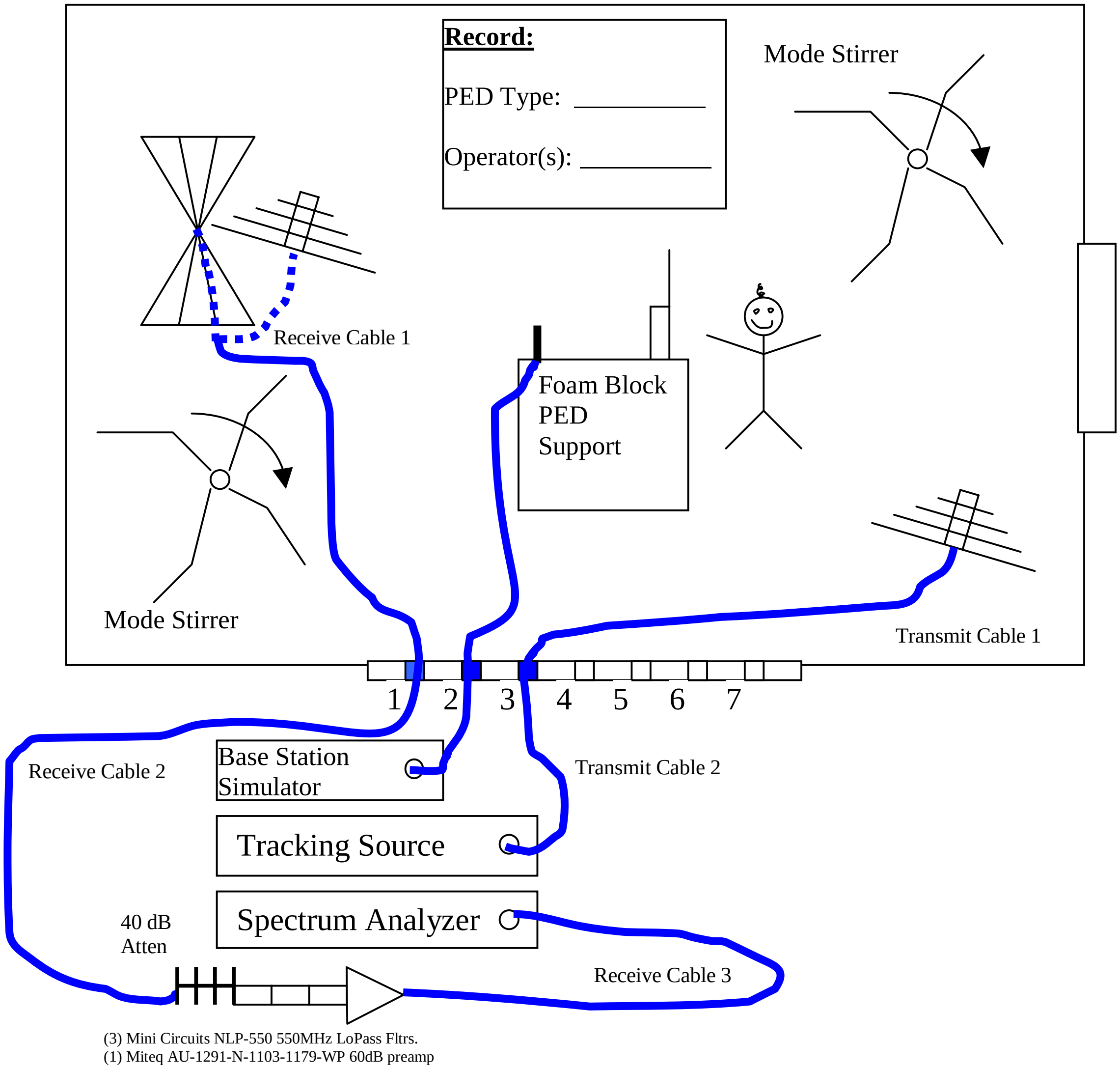
c) Setup PED Monitor program with the following parameters:

Filename	= RCX CblCal B1 (X= A, B, or C reverberation chamber.)
Frequency	= 105 MHz to 120 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 2 Sec
Atten. Manual	= 0 dB

d) Allow data save. Exit.

B.3.1.2 Receive Path & Chamber Calibration

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. If base station antenna and/or human operator will be present for measurement, they should also be present for chamber calibration. Rotate Paddles at 5 Rev/minute, continuous.



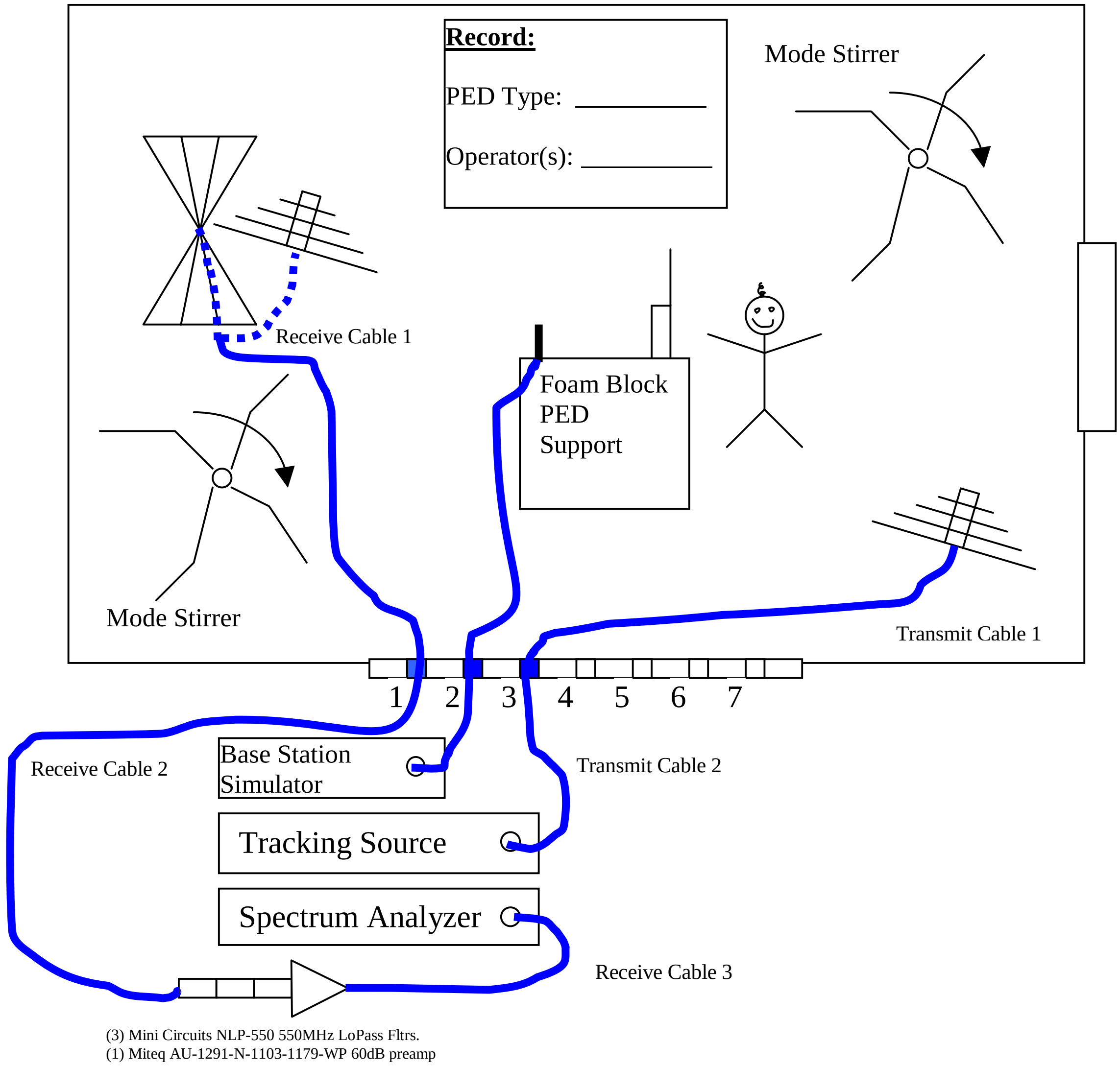
b) Source Output Power= -40dBm, RF ON. Turn PED OFF (if present). Turn Base Station Simulator OFF.

c) Setup PED Monitor program with the following parameters:

Filename	= RCX CbrCal B1 (X= A, B, or C reverberation chamber.)
Frequency	= 105 MHz to 120 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 120 Sec
SA Atten. Man.	= 0 dB, Ext. Atten. = 40 dB

B.3.1.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



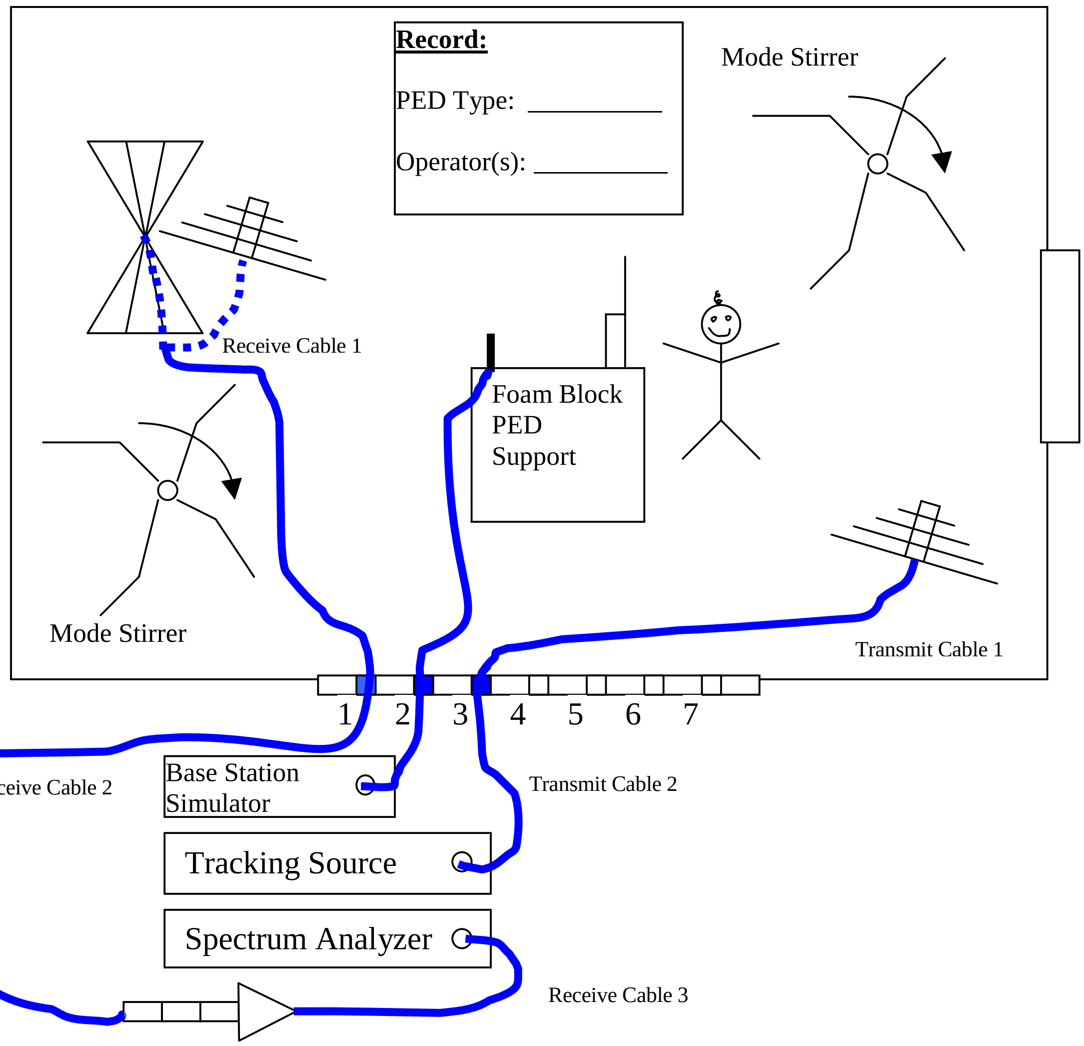
b) Source Output: RF OFF (or terminate into load). Turn PED OFF (if present). Turn Base Station Simulator ON (***if*** verified to be emission free in this band).

c) Setup PED Monitor program with the following parameters:

Filename = RCX Nfloor B1 (X= A, B, or C reverberation chamber.)
Frequency = 105 MHz to 120 MHz
RBW = 10 kHz
Sweep time = Default (375 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.1.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



(3) Mini Circuits NLP-550 550MHz LoPass Fltrs.
(1) Miteq AU-1291-N-1103-1179-WP 60dB preamp

b) Verify Source Output: RF OFF (or terminate into load). Turn PED ON. If required, command Base Station Simulator according to specified test protocol.

c) Setup PED Monitor program with the following parameters:

Filename = RCX Emeas ZZZA MB B1 (□= See File Notation Section.)
Frequency = 105 MHz to 120 MHz
RBW = 10 kHz
Sweep time = Default (375 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.2 Frequency Band 2 (325-340 MHz)

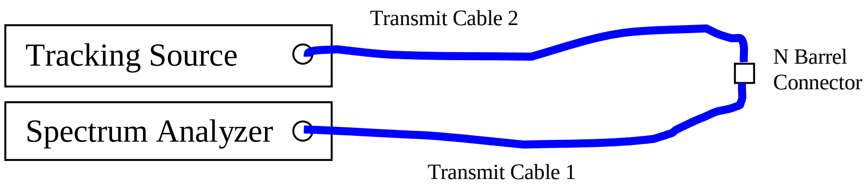
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	**Model Numbers**	**Serial Numbers**
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Transmit Antenna		
Receive Antenna		
Base Station Antenna		
Pre-Amplifier(s)		
Filters		
Feedthru Attenuators		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		
Receive Cable 3		

Table B.2.2: Equipment List for reverberation chamber __________ test.

B.3.2.1 Transmit Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

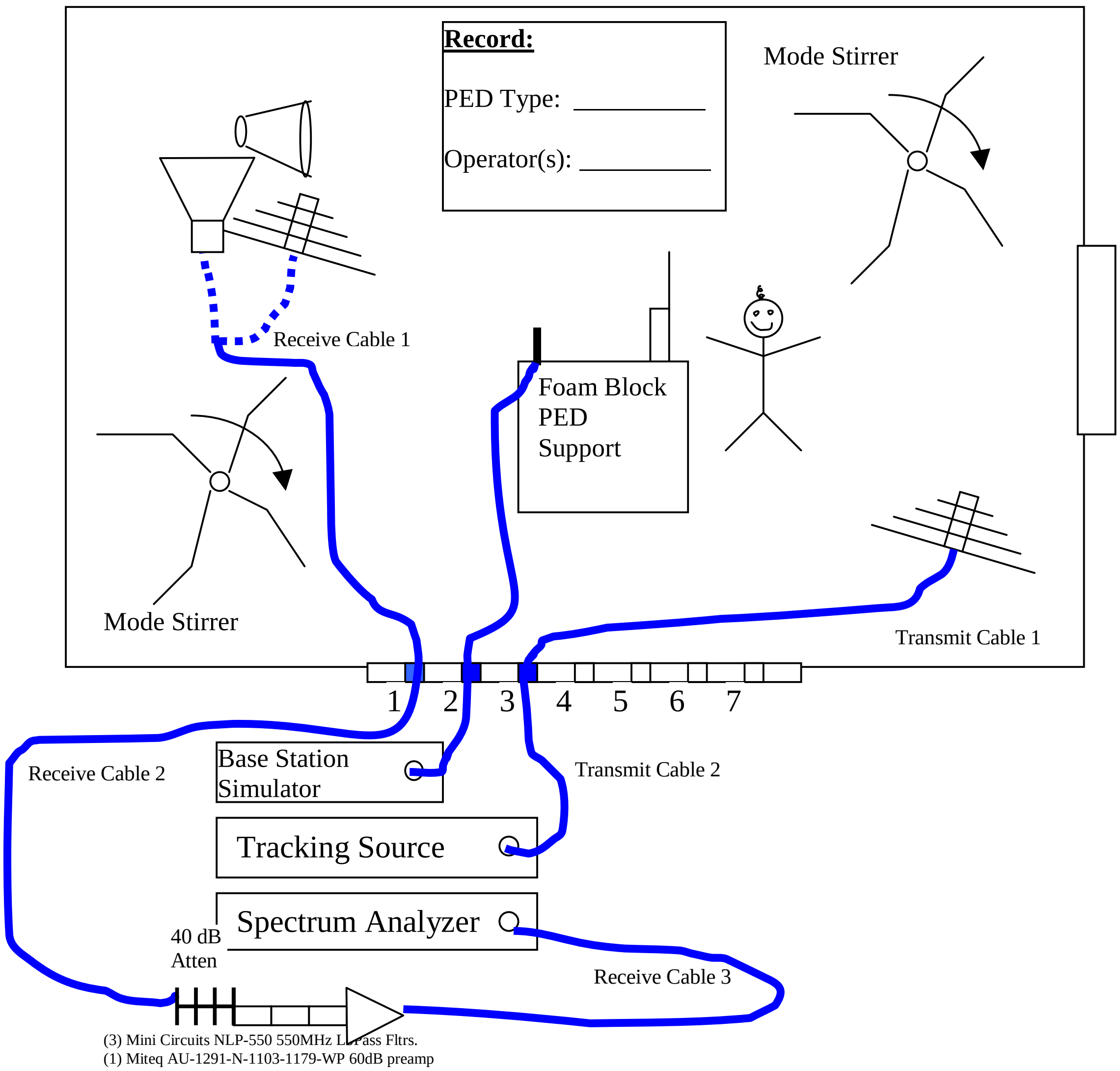
c) Setup PED Monitor program with the following parameters:

Filename = RCX CblCal B2 (X= A, B, or C reverberation chamber.)
Frequency = 325 MHz to 340 MHz
RBW = 10 kHz
Sweep time = Default (375 msec)
Ref Lvl = -10 dBm
Dwell Time = 2 Sec
SA Atten. Man. = 0 dB, Ext. Atten. = 0 dB

d) Allow data save. Exit.

B.3.2.2 Receive Path & Chamber Calibration

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. If base station antenna and/or human operator will be present for measurement, they should also be present for chamber calibration. Rotate Paddles at 5 Rev/minute, continuous.



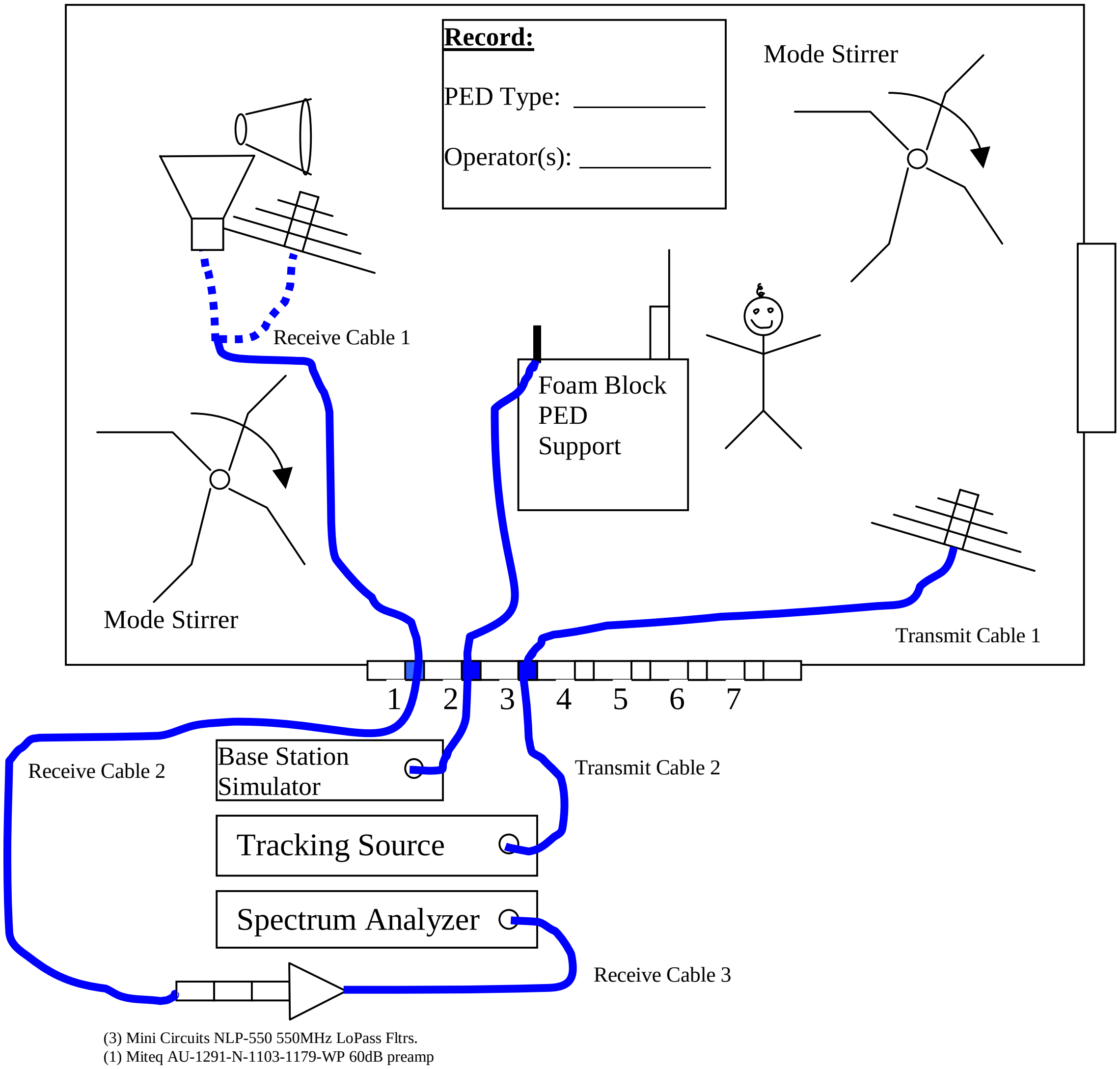
b) Source Output Power= -40dBm, RF ON. Turn PED OFF (if present). Turn Base Station Simulator OFF.

c) Setup PED Monitor program with the following parameters:

Filename	= RCX CbrCal B2 (X= A, B, or C reverberation chamber.)
Frequency	= 325 MHz to 340 MHz
RBW	= 10 kHz
Sweep time	= Default (375 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 120 Sec
SA Atten. Man.	= 0 dB, Ext. Atten. = 40 dB

B.3.2.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



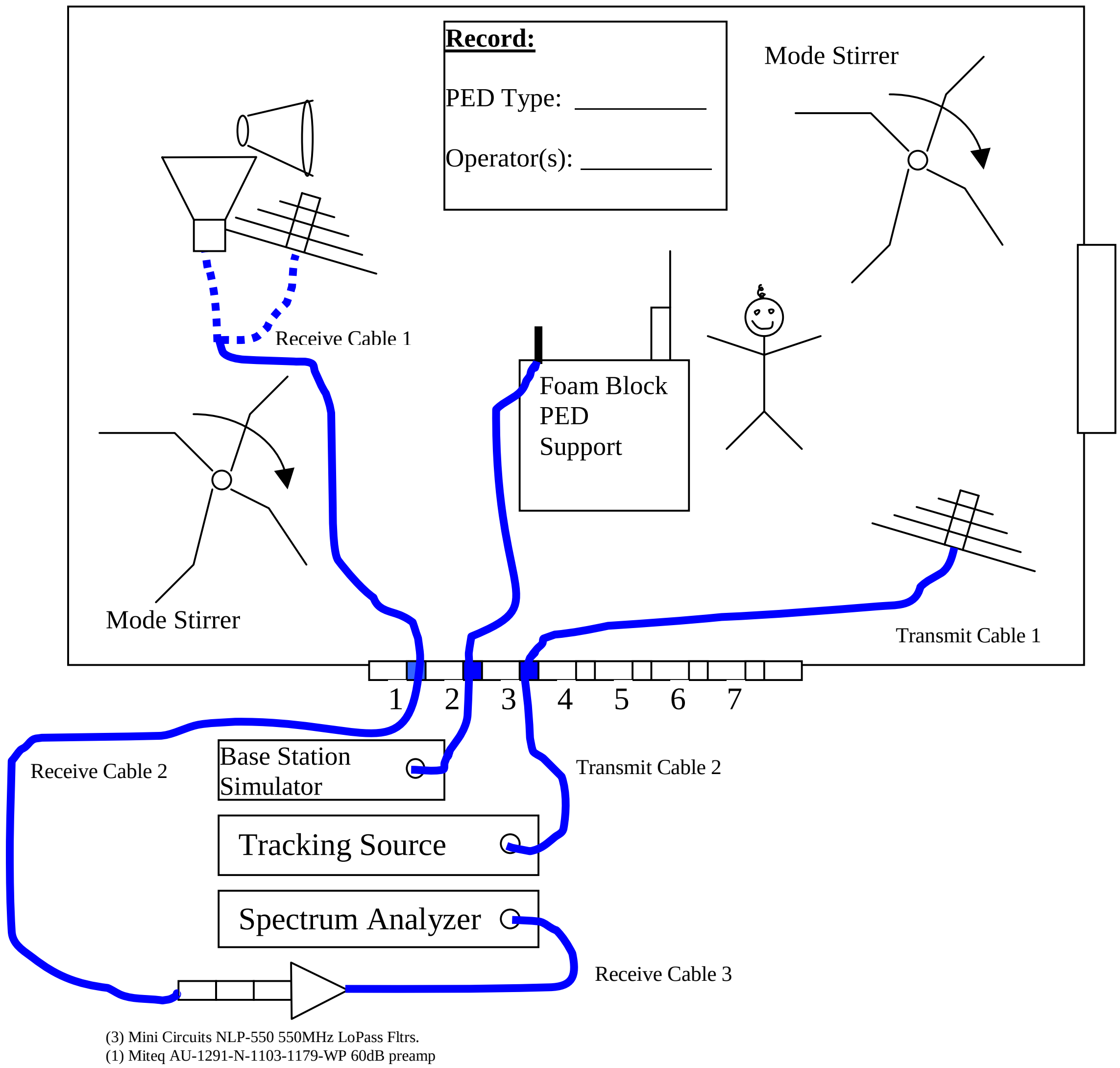
b) Source Output: RF OFF (or terminate into load). Turn PED OFF (if present). Turn Base Station Simulator ON (***if*** verified to be emission free in this band).

c) Setup PED Monitor program with the following parameters:

Filename = RCX Nfloor B2 (X= A, B, or C reverberation chamber.)
Frequency = 325 MHz to 340 MHz
RBW = 10 kHz
Sweep time = Default (375 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.2.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



b) Verify Source Output: RF OFF (or terminate into load). Turn PED ON. If required, command Base Station Simulator according to specified test protocol.

c) Setup PED Monitor program with the following parameters:

Filename = RCX Emeas ZZZA MB B2 (□= See File Notation Section.)
Frequency = 325 MHz to 340 MHz
RBW = 10 kHz
Sweep time = Default (375 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.3 Frequency Band 3 (960-1215 MHz)

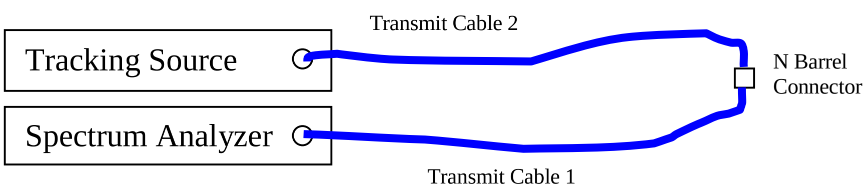
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	**Model Numbers**	**Serial Numbers**
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Transmit Antenna		
Receive Antenna		
Base Station Antenna		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		

Table B.2.3: Equipment List for reverberation chamber __________ test.

B.3.3.1 Transmit Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

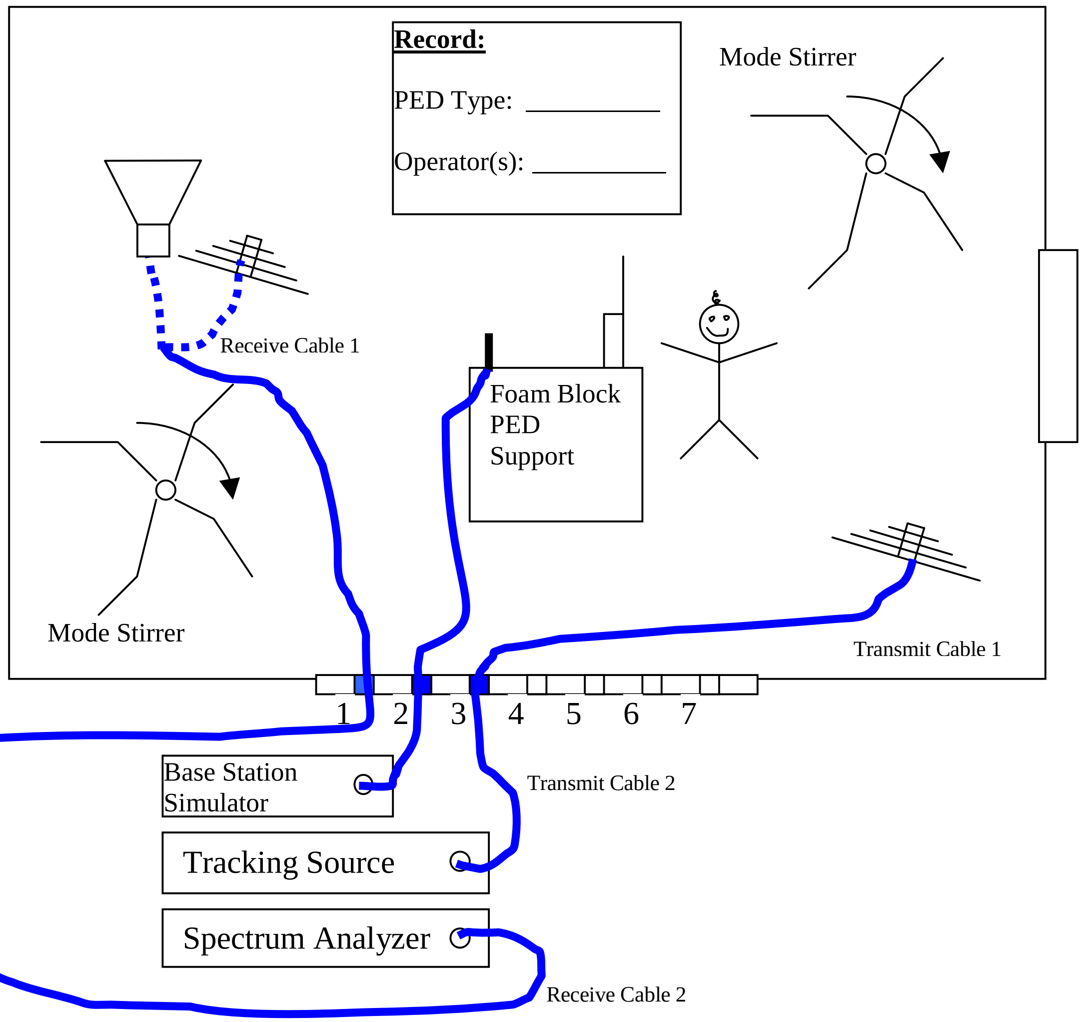
c) Setup PED Monitor program with the following parameters:

Filename = RCX CblCal B3 (X= A, B, or C reverberation chamber.)
Frequency = 960 MHz to 1215 MHz
RBW = 100 kHz
Sweep time = Default (64 msec)
Ref Lvl = -10 dBm
Dwell Time = 2 Sec
SA Atten. Man. = 0 dB, Ext. Atten. = 0 dB

d) Allow data save. Exit.

B.3.3.2 Receive Path & Chamber Calibration

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. If base station antenna and/or human operator will be present for measurement, they should also be present for chamber calibration. Rotate Paddles at 5 Rev/minute, continuous.



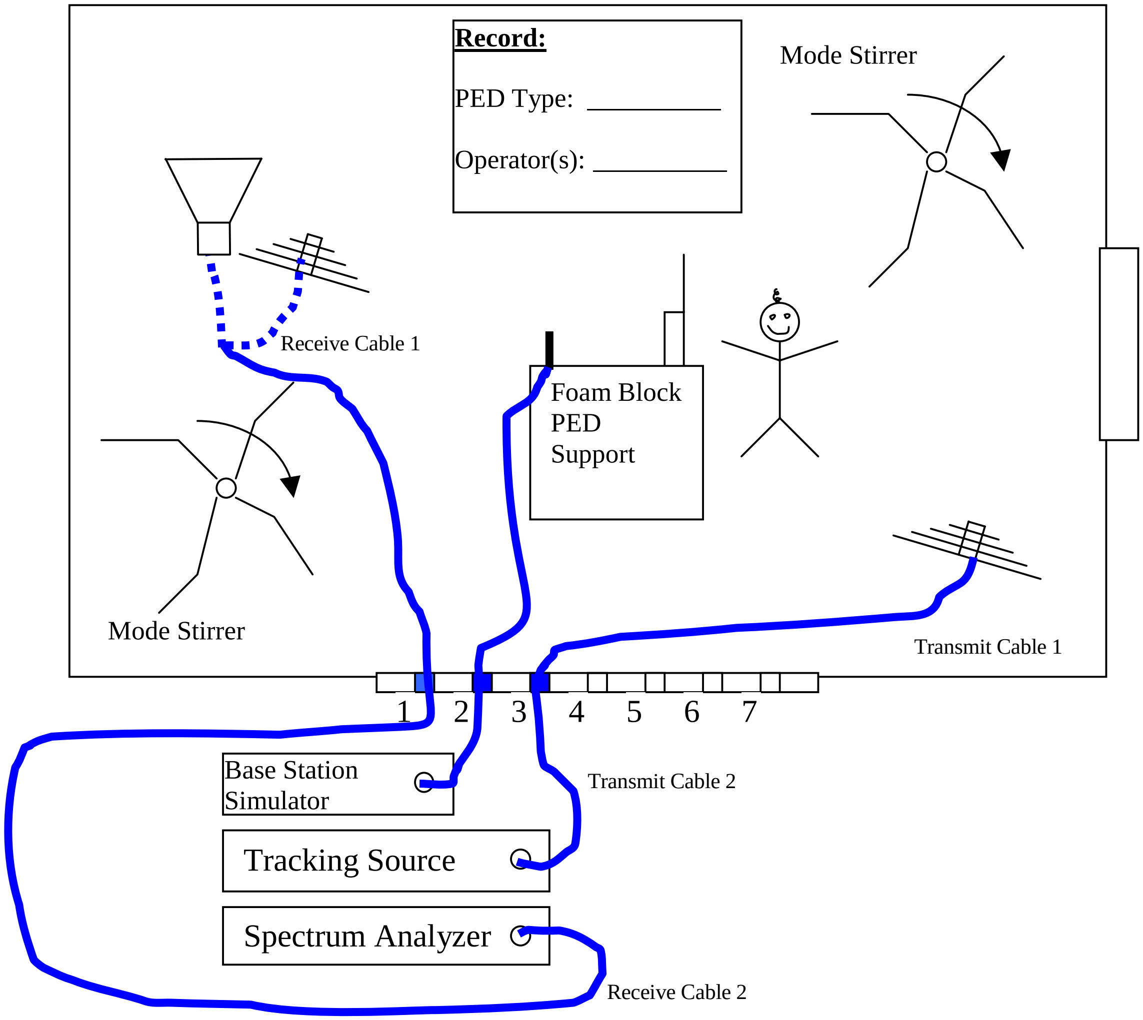
b) Source Output Power= 0dBm, RF ON. Turn PED OFF (if present). Turn Base Station Simulator OFF.

c) Setup PED Monitor program with the following parameters:

Filename	= RCX CbrCal B3 (X= A, B, or C reverberation chamber.)
Frequency	= 960 MHz to 1215 MHz
RBW	= 100 kHz
Sweep time	= Default (64 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 120 Sec
SA Atten. Man.	= 0 dB, Ext. Atten. = 0 dB

B.3.3.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



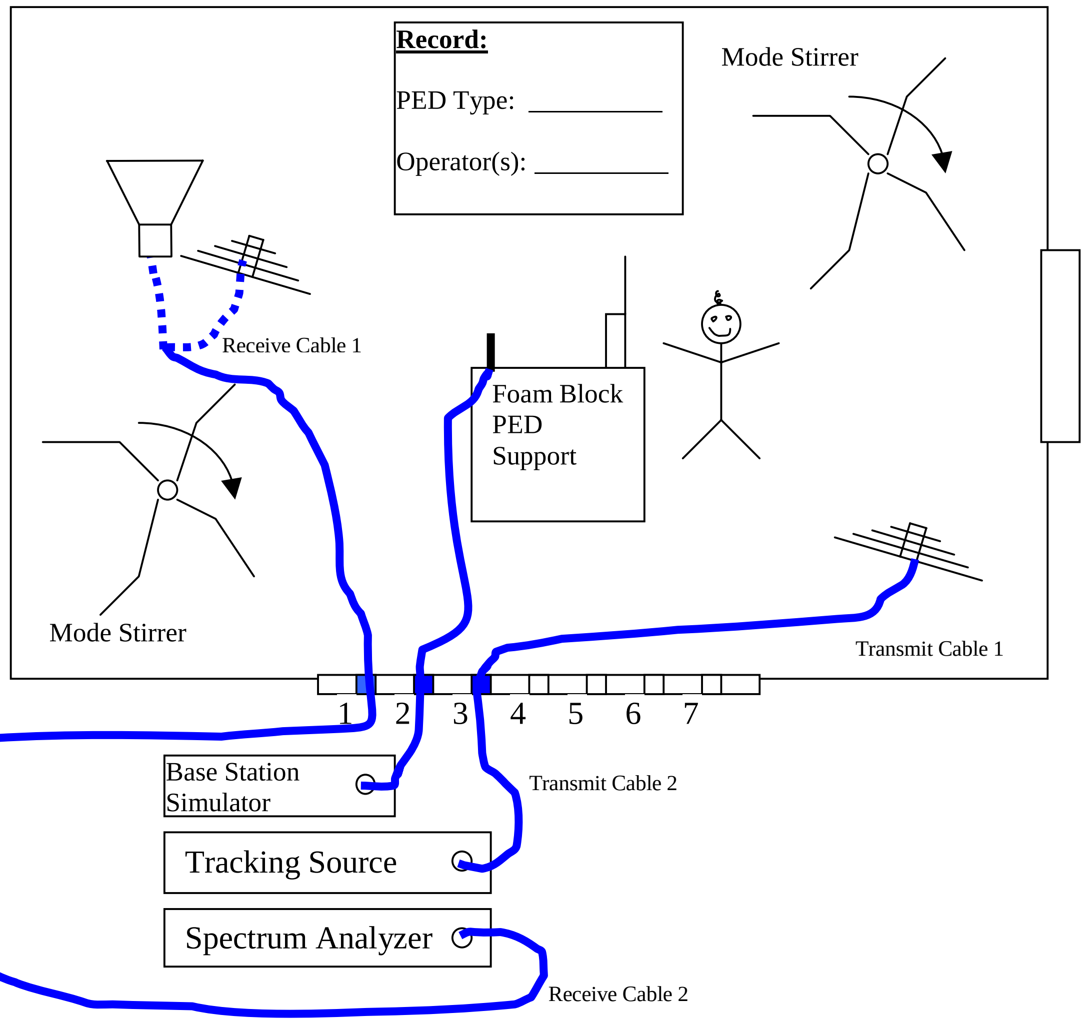
b) Source Output: RF OFF (or terminate into load). Turn PED OFF (if present). Turn Base Station Simulator ON (***if*** verified to be emission free in this band).

c) Setup PED Monitor program with the following parameters:

Filename = RCX Nfloor B3 (X= A, B, or C reverberation chamber.)
Frequency = 960 MHz to 1215 MHz
RBW = 100 kHz
Sweep time = Default (64 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.3.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



b) Verify Source Output: RF OFF (or terminate into load). Turn PED ON. If required, command Base Station Simulator according to specified test protocol.

c) Setup PED Monitor program with the following parameters:

Filename = RCX Emeas ZZZA MB B3 (□= See File Notation Section.)
Frequency = 960 MHz to 1215 MHz
RBW = 100 kHz
Sweep time = Default (64 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.4 Frequency Band 4 (1565-1585 MHz)

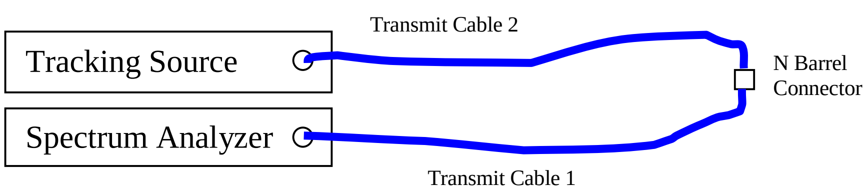
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	**Model Numbers**	**Serial Numbers**
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Reference Horn Antenna		
Receive Antenna		
Base Station Antenna		
Bias Tee		
12VDC Power Supply		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		

Table B.2.4: Equipment List for reverberation chamber __________ test.

B.3.4.1 Transmit Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

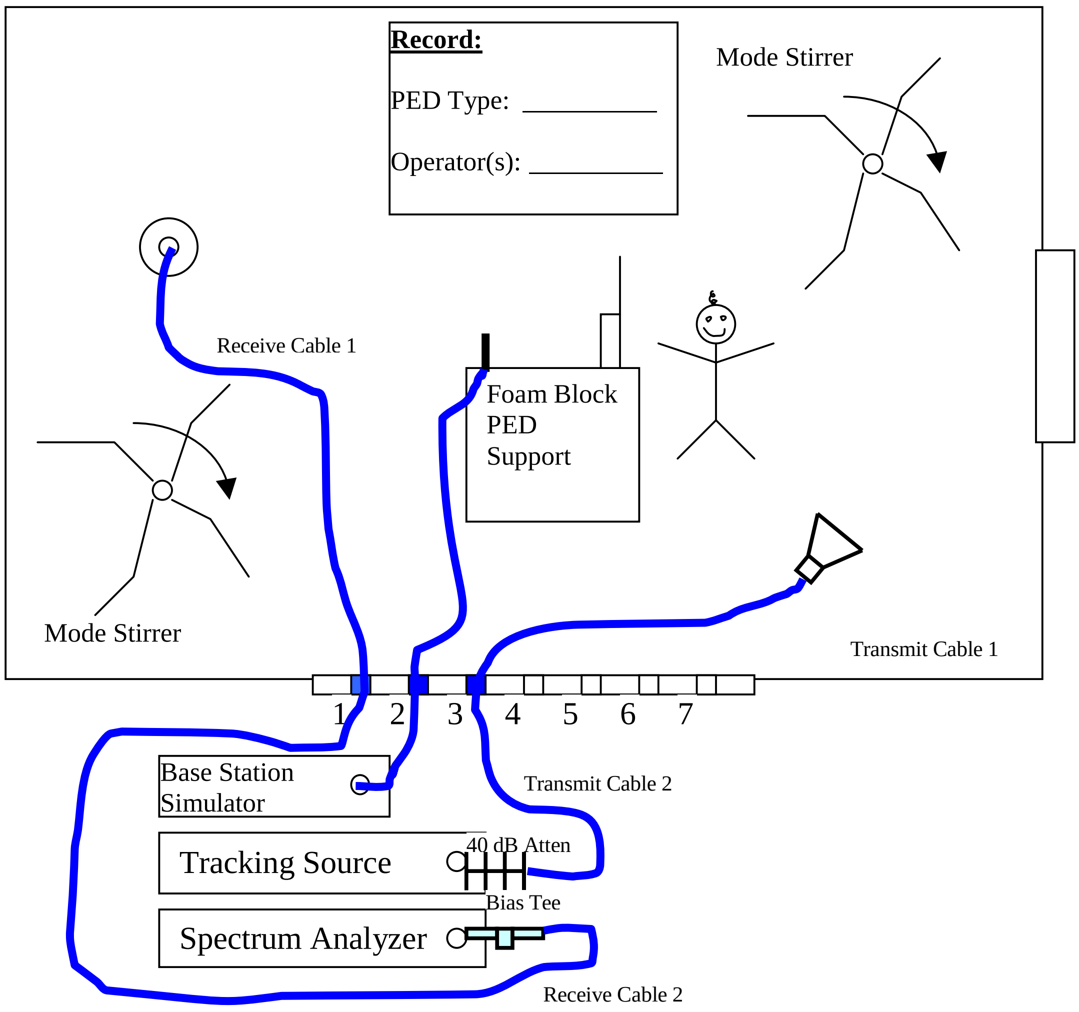
c) Setup PED Monitor program with the following parameters:

Filename = RCX CblCal B4 (X= A, B, or C reverberation chamber.)
Frequency = 1565 MHz to 1585 MHz
RBW = 10 kHz
Sweep time = Default (500 msec)
Ref Lvl = -10 dBm
Dwell Time = 2 Sec
SA Atten. Man. = 0 dB, Ext. Atten. = 0 dB

d) Allow data save. Exit.

B.3.4.2 Receive Path & Chamber Calibration

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. If base station antenna and/or human operator will be present for measurement, they should also be present for chamber calibration. Rotate Paddles at 5 Rev/minute, continuous.



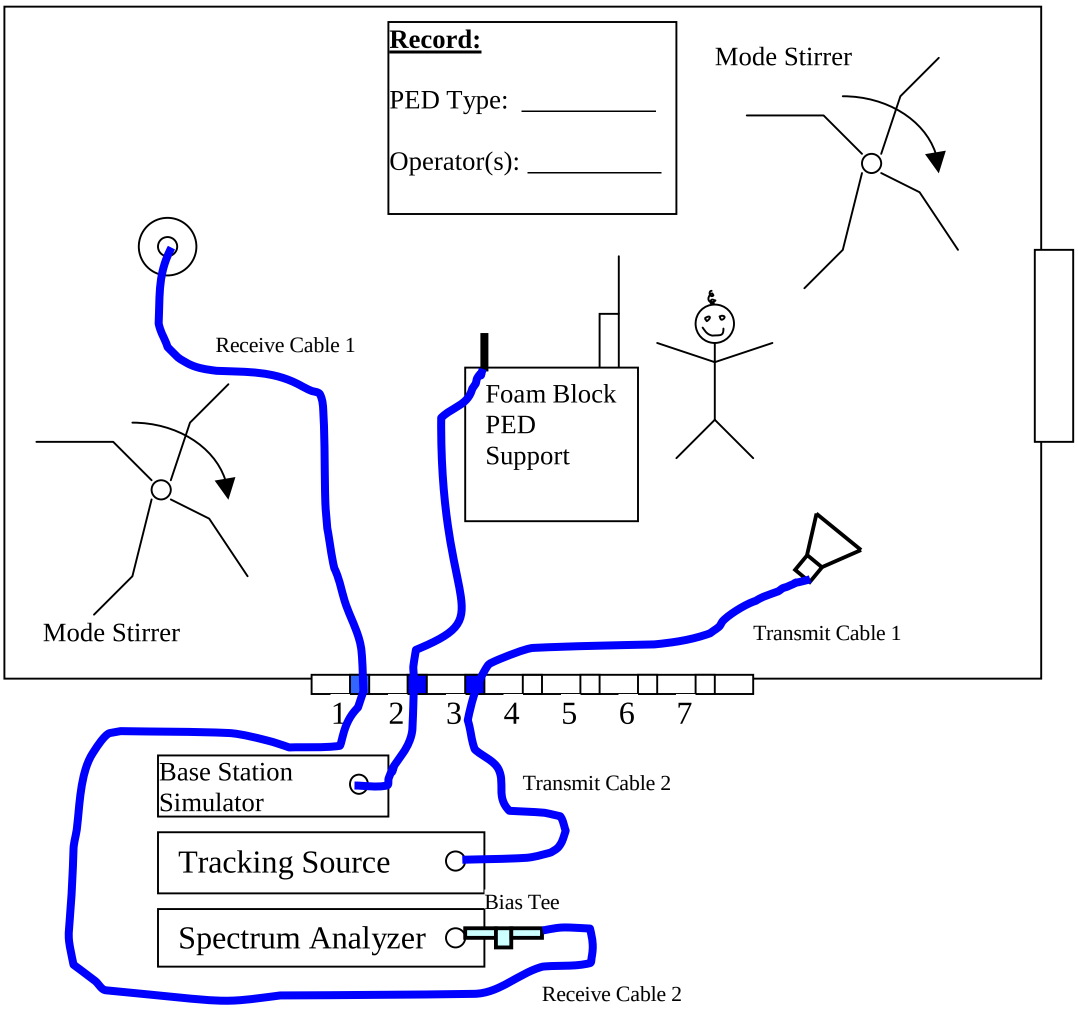
b) Source Output Power= -60dBm, RF ON. Apply 12VDC to Bias Tee. Turn PED OFF (if present). Turn Base Station Simulator OFF.

c) Setup PED Monitor program with the following parameters:

Filename	= RCX CbrCal B4 (X= A, B, or C reverberation chamber.)
Frequency	= 1565 MHz to 1585 MHz
RBW	= 10 kHz
Sweep time	= Default (500 msec)
Ref Lvl	= -10 dBm
Dwell Time	= 120 Sec
SA Atten. Man.	= 0 dB, Ext. Atten. = 40 dB

B.3.4.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



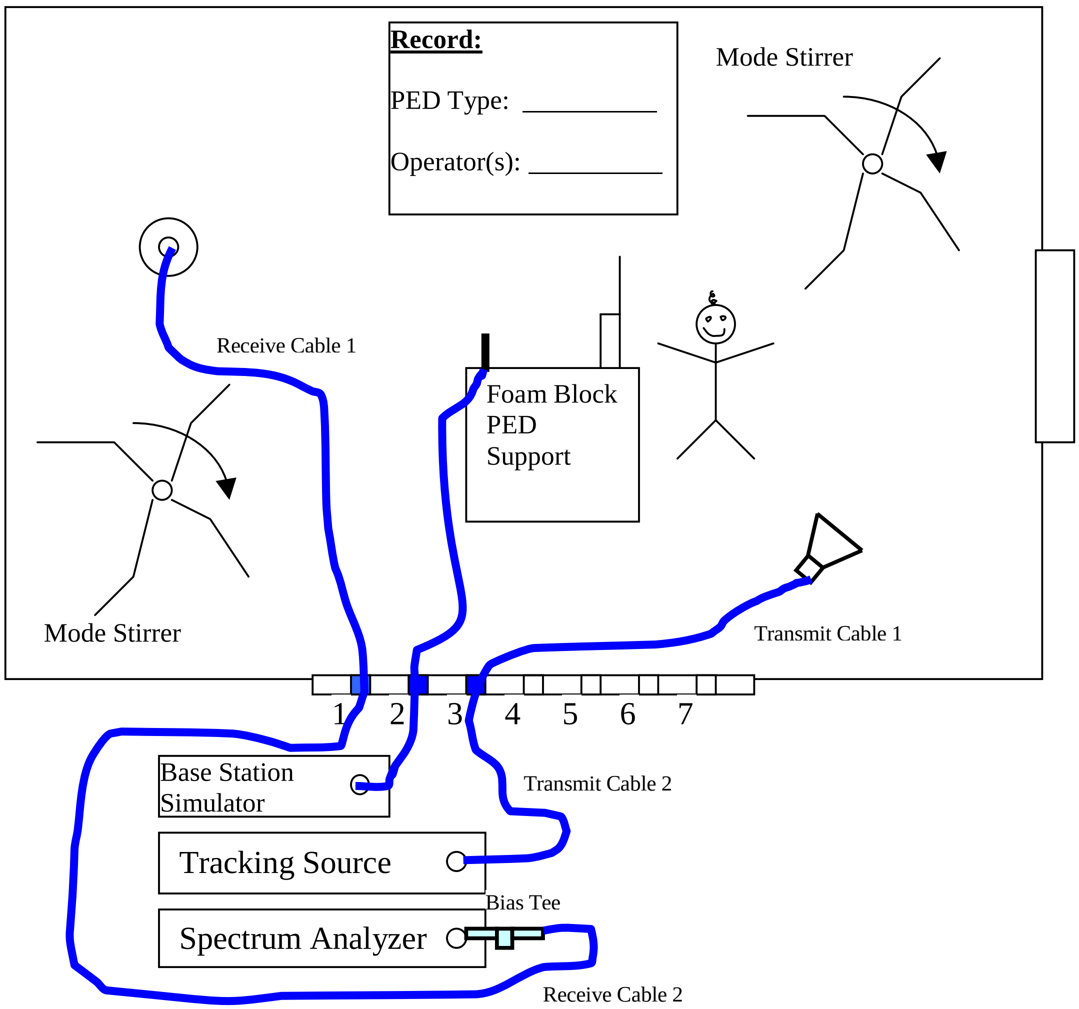
b) Source Output: RF OFF (or terminate into load). Turn PED OFF (if present). Turn Base Station Simulator ON (***if*** verified to be emission free in this band).

c) Setup PED Monitor program with the following parameters:

Filename = RCX Nfloor B4 (X= A, B, or C reverberation chamber.)
Frequency = 1565 MHz to 1585 MHz
RBW = 10 kHz
Sweep time = Default (500 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.4.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



b) Verify Source Output: RF OFF (or terminate into load). Turn PED ON. If required, command Base Station Simulator according to specified test protocol.

c) Setup PED Monitor program with the following parameters:

Filename = RCX Emeas ZZZA MB B4 (□= See File Notation Section.)
Frequency = 1565 MHz to 1585 MHz
RBW = 10 kHz
Sweep time = Default (500 msec)
Ref Lvl = -10 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 0 dB

B.3.5 Frequency Band 5 (820-960 MHz)

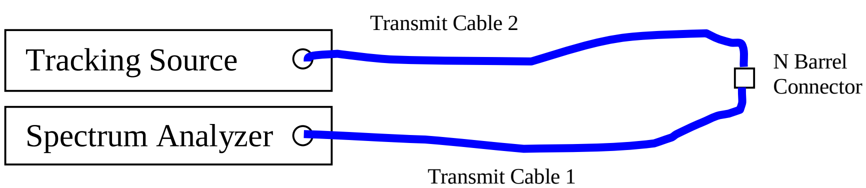
The following equipment will be used for this test. Any modifications must be clearly noted in the test matrix.

Item	Model Numbers	Serial Numbers
Test Control Computer		
Base Station Simulator		
Spectrum Analyzer		
Tracking Source		
Transmit Antenna		
Receive Antenna		
Base Station Antenna		
Transmit Cable 1		
Transmit Cable 2		
Receive Cable 1		
Receive Cable 2		

Table B.2.5: Equipment List for reverberation chamber __________ test.

B.3.5.1 Transmit Path Calibration

a) Setup Signal Source and Spectrum Analyzer in a Tracking configuration, as shown.



b) Set source to track spectrum analyzer, Output Power= -10 dBm, RF ON.

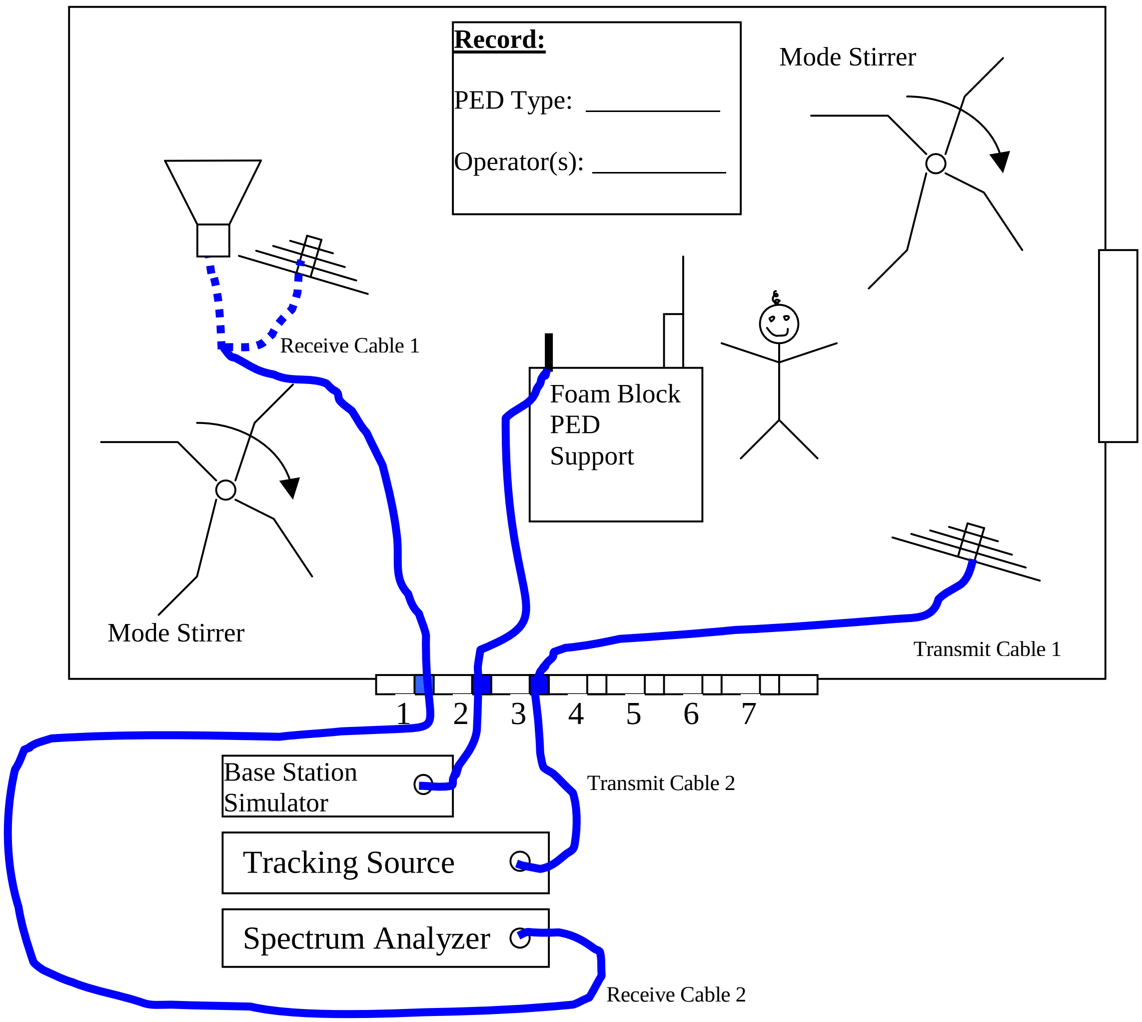
c) Setup PED Monitor program with the following parameters:

Filename = RCX CblCal B5 (X= A, B, or C reverberation chamber.)
Frequency = 820 MHz to 960 MHz
RBW = 100 kHz
Sweep time = Default (50 msec)
Ref Lvl = +20 dBm
Dwell Time = 2 Sec
SA Atten. Man. = 30 dB, Ext. Atten. = 0 dB

d) Allow data save. Exit.

B.3.5.2 Receive Path & Chamber Calibration

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. If base station antenna and/or human operator will be present for measurement, they should also be present for chamber calibration. Rotate Paddles at 5 Rev/minute, continuous.



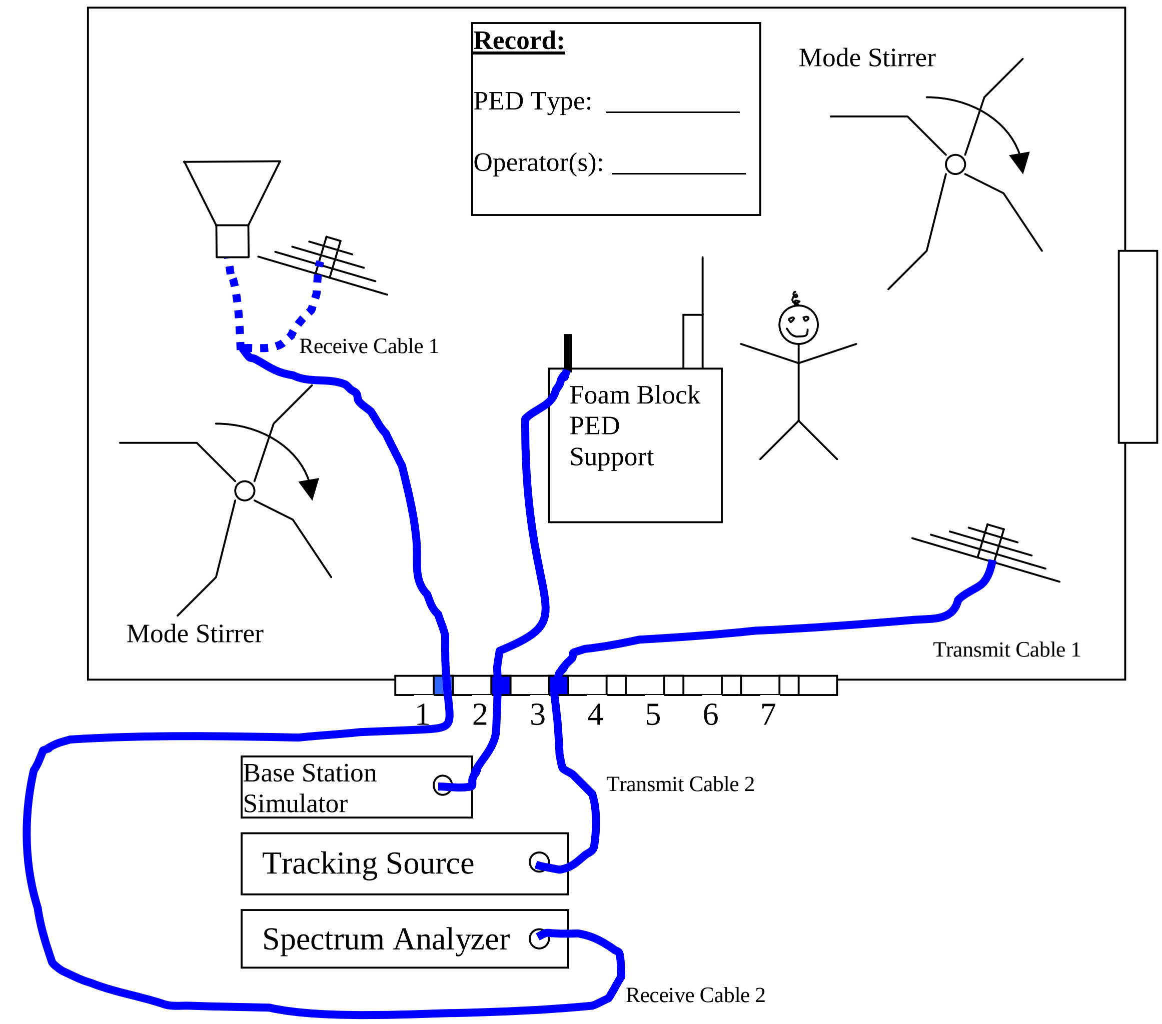
b) Source Output Power= 0dBm, RF ON. Turn PED OFF (if present). Turn Base Station Simulator OFF.

c) Setup PED Monitor program with the following parameters:

Filename	= RCX CbrCal B5 (X= A, B, or C reverberation chamber.)
Frequency	= 820 MHz to 960 MHz
RBW	= 100 kHz
Sweep time	= Default (50 msec)
Ref Lvl	= +20 dBm
Dwell Time	= 120 Sec
SA Atten. Man.	= 30 dB, Ext. Atten. = 0 dB

B.3.5.3 Noise Floor Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



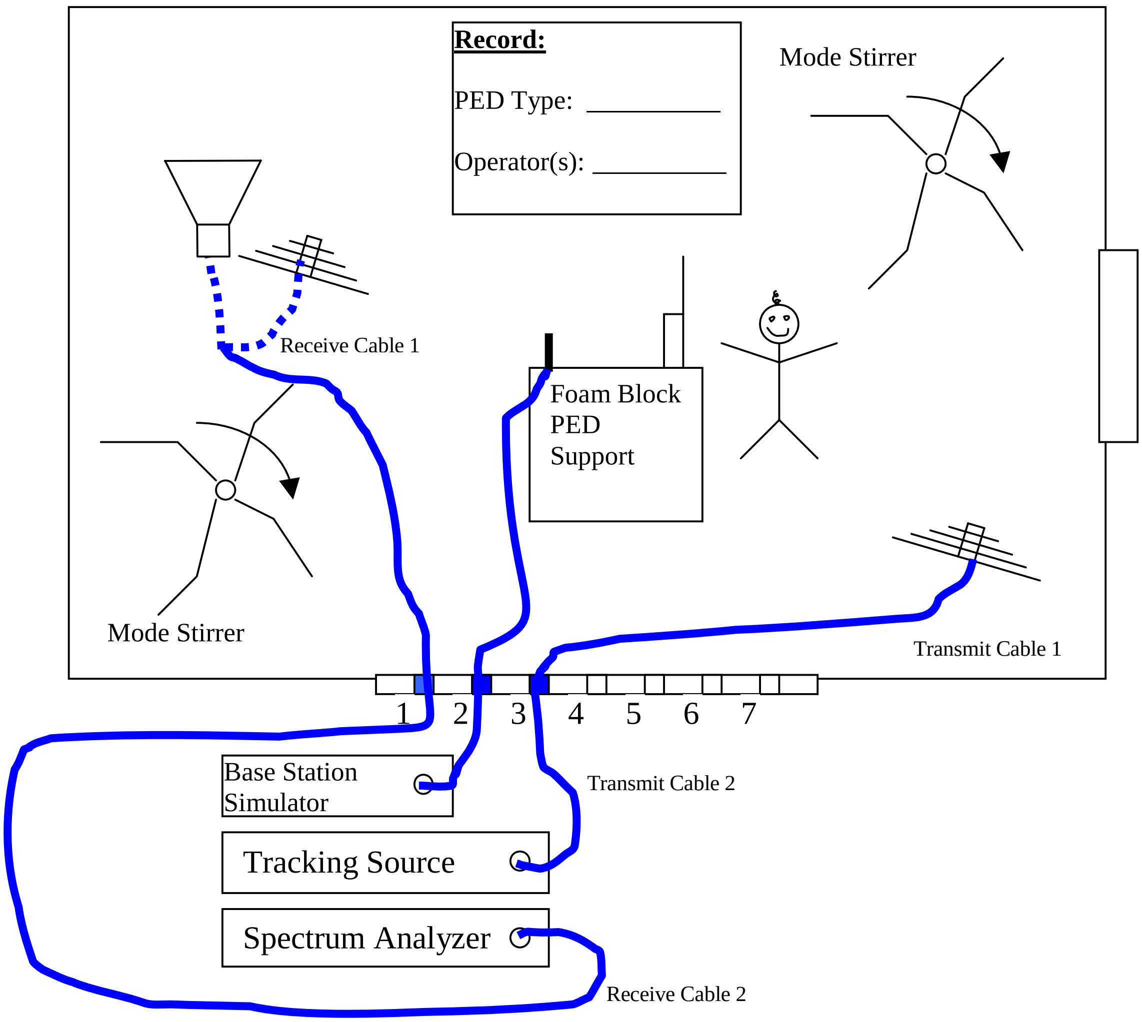
b) Source Output: RF OFF (or terminate into load). Turn PED OFF (if present). Turn Base Station Simulator ON (***if*** verified to be emission free in this band).

c) Setup PED Monitor program with the following parameters:

Filename = RCX Nfloor B5 (X= A, B, or C reverberation chamber.)
Frequency = 820 MHz to 960 MHz
RBW = 100 kHz
Sweep time = Default (50 msec)
Ref Lvl = +20 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 30 dB

B.3.5.4 Emission Measurement

a) Setup Signal Source, Spectrum Analyzer and Chamber, as shown. Rotate Paddles at 5 Rev/minute, continuous.



b) Verify Source Output: RF OFF (or terminate into load). Turn PED ON. If required, command Base Station Simulator according to specified test protocol.

c) Setup PED Monitor program with the following parameters:

Filename = RCX Emeas ZZZA MB B5 (□= See File Notation Section.)
Frequency = 820 MHz to 960 MHz
RBW = 100 kHz
Sweep time = Default (50 msec)
Ref Lvl = +20 dBm
Dwell Time = 120 Sec
SA Atten. Man. = 30 dB

B.4 Test Matrix: Modes Tests

Test #	Done ?	> -105 dBm ?	Cmd Type	RCA EMEAS	Phone	Mode	Band
1			BS	RCA Emeas M	CDM2	PClo-25 PREigh	1
2			BS	RCA Emeas M	CDM2	PClo-50 PREigh	1
3			BS	RCA Emeas M	CDM2	Pup PREigh	1
4			BS	RCA Emeas M	CDM2	Pup PREigh Call-End	1
5			BS	RCA Emeas M	CDM2	Pup PRFull	1
6			BS	RCA Emeas M	CDM2	Pup PRHalf	1
7			BS	RCA Emeas M	CDM2	Pup PRQuar	1
8			BS	RCA Emeas M	CDM3	PClo-25 PREigh	1
9			BS	RCA Emeas M	CDM3	PClo-50 PREigh	1
10			BS	RCA Emeas M	CDM3	Pup PREigh	1
11			BS	RCA Emeas M	CDM3	Pup PREigh Call-End	1
12			BS	RCA Emeas M	CDM3	Pup PRFull	1
13			BS	RCA Emeas M	CDM3	Pup PRHalf	1
14			BS	RCA Emeas M	CDM3	Pup PRQuar	1
15			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCFR CH62	1
16			BS	RCA Emeas M	GSM2	TXLVL1 DTOff DROn SCEFR CH62	1
17			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROff SCEFR CH62	1
18			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62 Org-End	1
19			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62	1
20			BS	RCA Emeas M	GSM2	TXLVL15 DTOn DROn SCEFR CH62	1
21			BS	RCA Emeas M	GSM2	TXLVL8 DTOn DROn SCEFR CH62	1
22			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCFR CH62	1
23			BS	RCA Emeas M	GSM3	TXLVL1 DTOff DROn SCEFR CH62	1
24			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROff SCEFR CH62	1
25			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62	1
26			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62 Org-End	1
27			BS	RCA Emeas M	GSM3	TXLVL15 DTOn DROn SCEFR CH62	1
28			BS	RCA Emeas M	GSM3	TXLVL8 DTOn DROn SCEFR CH62	1
29			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCFR CH62	1
30			BS	RCA Emeas M	GSM4	TXLVL1 DTOff DROn SCEFR CH62	1
31			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROff SCEFR CH62	1
32			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62	1
33			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62 Org-End	1
34			BS	RCA Emeas M	GSM4	TXLVL15 DTOn DROn SCEFR CH62	1
35			BS	RCA Emeas M	GSM4	TXLVL8 DTOn DROn SCEFR CH62	1
36			KPD	RCA Emeas M	CDM1	Pmax PRVar	1
37			KPD	RCA Emeas M	CDM1	Pnom PRVar	1
38			KPD	RCA Emeas M	CDM2	Pmax PRVar	1
39			KPD	RCA Emeas M	CDM2	Pnom PRVar	1
[redacted]							
42			KPD	RCA Emeas M	GSM1	PLvl33 DTOff CH62	1
43			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH1	1
44			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH100	1
45			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62	1
46			KPD	RCA Emeas M	GSM1	PLvl13 DTOn CH62	1
47			KPD	RCA Emeas M	GSM2	TXLvl0 CH1	1
48			KPD	RCA Emeas M	GSM2	TXLvl0 CH100	1
49			KPD	RCA Emeas M	GSM2	TXLvl0 CH62	1
50			KPD	RCA Emeas M	GSM2	TXLvl15 CH62	1

Notes:
PClo-25 = “Sector A Pwr” = 25
Puncture rate = “Data Rate”
SCFR = “FS”, SCEFR = “EFS”

51			KPD	RCA Emeas M	GSM3	TXLvl0 CH1	1
52			KPD	RCA Emeas M	GSM3	TXLvl0 CH100	1
53			KPD	RCA Emeas M	GSM3	TXLvl0 CH62	1
54			KPD	RCA Emeas M	GSM3	TXLvl15 CH62	1
55			KPD	RCA Emeas M	GSM4	TXLvl0 CH1	1
56			KPD	RCA Emeas M	GSM4	TXLvl0 CH100	1
57			KPD	RCA Emeas M	GSM4	TXLvl0 CH62	1
58			KPD	RCA Emeas M	GSM4	TXLvl15 CH62	1
59			SW	RCA Emeas M	CDM4	TXAGC225 PREigh VR13k	1
60			SW	RCA Emeas M	CDM4	TXAGC280 PREigh VR13k	1
61			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k	1
62			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR8k	1
63			SW	RCA Emeas M	CDM4	TXAGC511 PRFull VR13k	1
64			SW	RCA Emeas M	CDM4	TXAGC511 PRHalf VR13k	1
65			SW	RCA Emeas M	CDM4	TXAGC511 PRQuar VR13k	1
66			SW	RCA Emeas M	CDM5	TXAGC225 PREigh VR13k	1
67			SW	RCA Emeas M	CDM5	TXAGC280 PREigh VR13k	1
68			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR13k	1
69			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR8k	1
70			SW	RCA Emeas M	CDM5	TXAGC511 PRFull VR13k	1
71			SW	RCA Emeas M	CDM5	TXAGC511 PRHalf VR13k	1
72			SW	RCA Emeas M	CDM5	TXAGC511 PRQuar VR13k	1

Notes:
PClo-25 = “Sector A Pwr” = 25
Puncture rate = “Data Rate”
SCFR = “FS”, SCEFR = “EFS”

1			BS	RCA Emeas M	CDM2	PClo-25 PREigh	2
2			BS	RCA Emeas M	CDM2	PClo-50 PREigh	2
3			BS	RCA Emeas M	CDM2	Pup PREigh	2
4			BS	RCA Emeas M	CDM2	Pup PREigh Call-End	2
5			BS	RCA Emeas M	CDM2	Pup PRFull	2
6			BS	RCA Emeas M	CDM2	Pup PRHalf	2
7			BS	RCA Emeas M	CDM2	Pup PRQuar	2
8			BS	RCA Emeas M	CDM3	PClo-25 PREigh	2
9			BS	RCA Emeas M	CDM3	PClo-50 PREigh	2
10			BS	RCA Emeas M	CDM3	Pup PREigh	2
11			BS	RCA Emeas M	CDM3	Pup PREigh Call-End	2
12			BS	RCA Emeas M	CDM3	Pup PRFull	2
13			BS	RCA Emeas M	CDM3	Pup PRHalf	2
14			BS	RCA Emeas M	CDM3	Pup PRQuar	2
15			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCFR CH62	2
16			BS	RCA Emeas M	GSM2	TXLVL1 DTOff DROn SCEFR CH62	2
17			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROff SCEFR CH62	2
18			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62 Org-End	2
19			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62	2
20			BS	RCA Emeas M	GSM2	TXLVL15 DTOn DROn SCEFR CH62	2
21			BS	RCA Emeas M	GSM2	TXLVL8 DTOn DROn SCEFR CH62	2
22			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCFR CH62	2
23			BS	RCA Emeas M	GSM3	TXLVL1 DTOff DROn SCEFR CH62	2
24			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROff SCEFR CH62	2
25			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62	2
26			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62 Org-End	2
27			BS	RCA Emeas M	GSM3	TXLVL15 DTOn DROn SCEFR CH62	2
28			BS	RCA Emeas M	GSM3	TXLVL8 DTOn DROn SCEFR CH62	2
29			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCFR CH62	2
30			BS	RCA Emeas M	GSM4	TXLVL1 DTOff DROn SCEFR CH62	2
31			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROff SCEFR CH62	2
32			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62	2
33			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62 Org-End	2
34			BS	RCA Emeas M	GSM4	TXLVL15 DTOn DROn SCEFR CH62	2
35			BS	RCA Emeas M	GSM4	TXLVL8 DTOn DROn SCEFR CH62	2
36			KPD	RCA Emeas M	CDM1	Pmax PRVar	2
37			KPD	RCA Emeas M	CDM1	Pnom PRVar	2
38			KPD	RCA Emeas M	CDM2	Pmax PRVar	2
39			KPD	RCA Emeas M	CDM2	Pnom PRVar	2
[redacted]							
42			KPD	RCA Emeas M	GSM1	PLvl33 DTOff CH62	2
43			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH1	2
44			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH100	2
45			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62	2
46			KPD	RCA Emeas M	GSM1	PLvl13 DTOn CH62	2
47			KPD	RCA Emeas M	GSM2	TXLvl0 CH1	2
48			KPD	RCA Emeas M	GSM2	TXLvl0 CH100	2
49			KPD	RCA Emeas M	GSM2	TXLvl0 CH62	2
50			KPD	RCA Emeas M	GSM2	TXLvl15 CH62	2

Notes:
PClo-25 = “Sector A Pwr” = 25
Puncture rate = “Data Rate”
SCFR = “FS”, SCEFR = “EFS”

51			KPD	RCA Emeas M	GSM3	TXLvl0 CH1	2
52			KPD	RCA Emeas M	GSM3	TXLvl0 CH100	2
53			KPD	RCA Emeas M	GSM3	TXLvl0 CH62	2
54			KPD	RCA Emeas M	GSM3	TXLvl15 CH62	2
55			KPD	RCA Emeas M	GSM4	TXLvl0 CH1	2
56			KPD	RCA Emeas M	GSM4	TXLvl0 CH100	2
57			KPD	RCA Emeas M	GSM4	TXLvl0 CH62	2
58			KPD	RCA Emeas M	GSM4	TXLvl15 CH62	2
59			SW	RCA Emeas M	CDM4	TXAGC225 PREigh VR13k	2
60			SW	RCA Emeas M	CDM4	TXAGC280 PREigh VR13k	2
61			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k	2
62			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR8k	2
63			SW	RCA Emeas M	CDM4	TXAGC511 PRFull VR13k	2
64			SW	RCA Emeas M	CDM4	TXAGC511 PRHalf VR13k	2
65			SW	RCA Emeas M	CDM4	TXAGC511 PRQuar VR13k	2
66			SW	RCA Emeas M	CDM5	TXAGC225 PREigh VR13k	2
67			SW	RCA Emeas M	CDM5	TXAGC280 PREigh VR13k	2
68			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR13k	2
69			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR8k	2
70			SW	RCA Emeas M	CDM5	TXAGC511 PRFull VR13k	2
71			SW	RCA Emeas M	CDM5	TXAGC511 PRHalf VR13k	2
72			SW	RCA Emeas M	CDM5	TXAGC511 PRQuar VR13k	2

Notes:
PClo-25 = “Sector A Pwr” = 25
Puncture rate = “Data Rate”
SCFR = “FS”, SCEFR = “EFS”

1			BS	RCA Emeas M	CDM2	PClo-25 PREigh	3
2			BS	RCA Emeas M	CDM2	PClo-50 PREigh	3
3			BS	RCA Emeas M	CDM2	Pup PREigh	3
4			BS	RCA Emeas M	CDM2	Pup PREigh Call-End	3
5			BS	RCA Emeas M	CDM2	Pup PRFull	3
6			BS	RCA Emeas M	CDM2	Pup PRHalf	3
7			BS	RCA Emeas M	CDM2	Pup PRQuar	3
8			BS	RCA Emeas M	CDM3	PClo-25 PREigh	3
9			BS	RCA Emeas M	CDM3	PClo-50 PREigh	3
10			BS	RCA Emeas M	CDM3	Pup PREigh	3
11			BS	RCA Emeas M	CDM3	Pup PREigh Call-End	3
12			BS	RCA Emeas M	CDM3	Pup PRFull	3
13			BS	RCA Emeas M	CDM3	Pup PRHalf	3
14			BS	RCA Emeas M	CDM3	Pup PRQuar	3
15			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCFR CH62	3
16			BS	RCA Emeas M	GSM2	TXLVL1 DTOff DROn SCEFR CH62	3
17			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROff SCEFR CH62	3
18			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62 Org-End	3
19			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62	3
20			BS	RCA Emeas M	GSM2	TXLVL15 DTOn DROn SCEFR CH62	3
21			BS	RCA Emeas M	GSM2	TXLVL8 DTOn DROn SCEFR CH62	3
22			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCFR CH62	3
23			BS	RCA Emeas M	GSM3	TXLVL1 DTOff DROn SCEFR CH62	3
24			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROff SCEFR CH62	3
25			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62	3
26			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62 Org-End	3
27			BS	RCA Emeas M	GSM3	TXLVL15 DTOn DROn SCEFR CH62	3
28			BS	RCA Emeas M	GSM3	TXLVL8 DTOn DROn SCEFR CH62	3
29			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCFR CH62	3
30			BS	RCA Emeas M	GSM4	TXLVL1 DTOff DROn SCEFR CH62	3
31			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROff SCEFR CH62	3
32			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62	3
33			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62 Org-End	3
34			BS	RCA Emeas M	GSM4	TXLVL15 DTOn DROn SCEFR CH62	3
35			BS	RCA Emeas M	GSM4	TXLVL8 DTOn DROn SCEFR CH62	3
36			KPD	RCA Emeas M	CDM1	Pmax PRVar	3
37			KPD	RCA Emeas M	CDM1	Pnom PRVar	3
38			KPD	RCA Emeas M	CDM2	Pmax PRVar	3
39			KPD	RCA Emeas M	CDM2	Pnom PRVar	3
[redacted]							
42			KPD	RCA Emeas M	GSM1	PLvl33 DTOff CH62	3
43			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH1	3
44			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH100	3
45			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62	3
46			KPD	RCA Emeas M	GSM1	PLvl13 DTOn CH62	3
47			KPD	RCA Emeas M	GSM2	TXLvl0 CH1	3
48			KPD	RCA Emeas M	GSM2	TXLvl0 CH100	3
49			KPD	RCA Emeas M	GSM2	TXLvl0 CH62	3
50			KPD	RCA Emeas M	GSM2	TXLvl15 CH62	3
51			KPD	RCA Emeas M	GSM3	TXLvl0 CH1	3

Notes:
PClo-25 = "Sector A Pwr" = 25
Puncture rate = "Data Rate"
SCFR = "FS", SCEFR = "EFS"

52			KPD	RCA Emeas M	GSM3	TXLvl0 CH100	3
53			KPD	RCA Emeas M	GSM3	TXLvl0 CH62	3
54			KPD	RCA Emeas M	GSM3	TXLvl15 CH62	3
55			KPD	RCA Emeas M	GSM4	TXLvl0 CH1	3
56			KPD	RCA Emeas M	GSM4	TXLvl0 CH100	3
57			KPD	RCA Emeas M	GSM4	TXLvl0 CH62	3
58			KPD	RCA Emeas M	GSM4	TXLvl15 CH62	3
59			SW	RCA Emeas M	CDM4	TXAGC225 PREigh VR13k	3
60			SW	RCA Emeas M	CDM4	TXAGC280 PREigh VR13k	3
61			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k	3
62			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR8k	3
63			SW	RCA Emeas M	CDM4	TXAGC511 PRFull VR13k	3
64			SW	RCA Emeas M	CDM4	TXAGC511 PRHalf VR13k	3
65			SW	RCA Emeas M	CDM4	TXAGC511 PRQuar VR13k	3
66			SW	RCA Emeas M	CDM5	TXAGC225 PREigh VR13k	3
67			SW	RCA Emeas M	CDM5	TXAGC280 PREigh VR13k	3
68			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR13k	3
69			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR8k	3
70			SW	RCA Emeas M	CDM5	TXAGC511 PRFull VR13k	3
71			SW	RCA Emeas M	CDM5	TXAGC511 PRHalf VR13k	3
72			SW	RCA Emeas M	CDM5	TXAGC511 PRQuar VR13k	3

Notes:
PClo-25 = “Sector A Pwr” = 25
Puncture rate = “Data Rate”
SCFR = “FS”, SCEFR = “EFS”

1			BS	RCA Emeas M	CDM2	PClo-25 PREigh	4
2			BS	RCA Emeas M	CDM2	PClo-50 PREigh	4
3			BS	RCA Emeas M	CDM2	Pup PREigh	4
4			BS	RCA Emeas M	CDM2	Pup PREigh Call-End	4
5			BS	RCA Emeas M	CDM2	Pup PRFull	4
6			BS	RCA Emeas M	CDM2	Pup PRHalf	4
7			BS	RCA Emeas M	CDM2	Pup PRQuar	4
8			BS	RCA Emeas M	CDM3	PClo-25 PREigh	4
9			BS	RCA Emeas M	CDM3	PClo-50 PREigh	4
10			BS	RCA Emeas M	CDM3	Pup PREigh	4
11			BS	RCA Emeas M	CDM3	Pup PREigh Call-End	4
12			BS	RCA Emeas M	CDM3	Pup PRFull	4
13			BS	RCA Emeas M	CDM3	Pup PRHalf	4
14			BS	RCA Emeas M	CDM3	Pup PRQuar	4
15			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCFR CH62	4
16			BS	RCA Emeas M	GSM2	TXLVL1 DTOff DROn SCEFR CH62	4
17			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROff SCEFR CH62	4
18			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62 Org-End	4
19			BS	RCA Emeas M	GSM2	TXLVL1 DTOn DROn SCEFR CH62	4
20			BS	RCA Emeas M	GSM2	TXLVL15 DTOn DROn SCEFR CH62	4
21			BS	RCA Emeas M	GSM2	TXLVL8 DTOn DROn SCEFR CH62	4
22			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCFR CH62	4
23			BS	RCA Emeas M	GSM3	TXLVL1 DTOff DROn SCEFR CH62	4
24			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROff SCEFR CH62	4
25			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62	4
26			BS	RCA Emeas M	GSM3	TXLVL1 DTOn DROn SCEFR CH62 Org-End	4
27			BS	RCA Emeas M	GSM3	TXLVL15 DTOn DROn SCEFR CH62	4
28			BS	RCA Emeas M	GSM3	TXLVL8 DTOn DROn SCEFR CH62	4
29			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCFR CH62	4
30			BS	RCA Emeas M	GSM4	TXLVL1 DTOff DROn SCEFR CH62	4
31			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROff SCEFR CH62	4
32			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62	4
33			BS	RCA Emeas M	GSM4	TXLVL1 DTOn DROn SCEFR CH62 Org-End	4
34			BS	RCA Emeas M	GSM4	TXLVL15 DTOn DROn SCEFR CH62	4
35			BS	RCA Emeas M	GSM4	TXLVL8 DTOn DROn SCEFR CH62	4
36			KPD	RCA Emeas M	CDM1	Pmax PRVar	4
37			KPD	RCA Emeas M	CDM1	Pnom PRVar	4
38			KPD	RCA Emeas M	CDM2	Pmax PRVar	4
39			KPD	RCA Emeas M	CDM2	Pnom PRVar	4
[redacted]							
42			KPD	RCA Emeas M	GSM1	PLvl33 DTOff CH62	4
43			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH1	4
44			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH100	4
45			KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62	4
46			KPD	RCA Emeas M	GSM1	PLvl13 DTOn CH62	4
47			KPD	RCA Emeas M	GSM2	TXLvl0 CH1	4
48			KPD	RCA Emeas M	GSM2	TXLvl0 CH100	4
49			KPD	RCA Emeas M	GSM2	TXLvl0 CH62	4
50			KPD	RCA Emeas M	GSM2	TXLvl15 CH62	4

Notes:
PClo-25 = “Sector A Pwr” = 25
Puncture rate = “Data Rate”
SCFR = “FS”, SCEFR = “EFS”

51			KPD	RCA Emeas M	GSM3	TXLvl0 CH1	4
52			KPD	RCA Emeas M	GSM3	TXLvl0 CH100	4
53			KPD	RCA Emeas M	GSM3	TXLvl0 CH62	4
54			KPD	RCA Emeas M	GSM3	TXLvl15 CH62	4
55			KPD	RCA Emeas M	GSM4	TXLvl0 CH1	4
56			KPD	RCA Emeas M	GSM4	TXLvl0 CH100	4
57			KPD	RCA Emeas M	GSM4	TXLvl0 CH62	4
58			KPD	RCA Emeas M	GSM4	TXLvl15 CH62	4
59			SW	RCA Emeas M	CDM4	TXAGC225 PREigh VR13k	4
60			SW	RCA Emeas M	CDM4	TXAGC280 PREigh VR13k	4
61			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k	4
62			SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR8k	4
63			SW	RCA Emeas M	CDM4	TXAGC511 PRFull VR13k	4
64			SW	RCA Emeas M	CDM4	TXAGC511 PRHalf VR13k	4
65			SW	RCA Emeas M	CDM4	TXAGC511 PRQuar VR13k	4
66			SW	RCA Emeas M	CDM5	TXAGC225 PREigh VR13k	4
67			SW	RCA Emeas M	CDM5	TXAGC280 PREigh VR13k	4
68			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR13k	4
69			SW	RCA Emeas M	CDM5	TXAGC511 PREigh VR8k	4
70			SW	RCA Emeas M	CDM5	TXAGC511 PRFull VR13k	4
71			SW	RCA Emeas M	CDM5	TXAGC511 PRHalf VR13k	4
72			SW	RCA Emeas M	CDM5	TXAGC511 PRQuar VR13k	4

Notes:
PClo-25 = “Sector A Pwr” = 25
Puncture rate = “Data Rate”
SCFR = “FS”, SCEFR = “EFS”

B.5 Test Matrix: Extra Tests

Test #	Done ?	Cmd Type	RCA EMEAS	Phone	Mode	Band	Notes
1		KPD	RCA Emeas M	CDM1	Pmax PRVar Manipulate	1	Handle and Manipultate phone
2		KPD	RCA Emeas M	CDM1	Pmax PRVar Free Rtrctd	1	Free standing on platform, Antenna Retracted
3		KPD	RCA Emeas M	CDM2	Pmax PRVar Manipulate	1	Handle and Manipultate phone
4		KPD	RCA Emeas M	CDM2	Pmax PRVar Free Rtrctd	1	Free standing on platform, Antenna Retracted
5		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Manipulate	1	Handle and Manipultate phone
6		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Free Rtrctd	1	Free standing on platform, Antenna Retracted
7		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Manipulate	1	Handle and Manipultate phone
8		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Free Rtrctd	1	Free standing on platform, Antenna Retracted
9		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Manipulate	1	Handle and Manipultate phone
10		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Free Rtrctd	1	Free standing on platform, Antenna Retracted
11		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Manipulate	1	Handle and Manipultate phone
12		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Free Rtrctd	1	Free standing on platform, Antenna Retracted
13		BS	RCA Emeas M	CDM3	Pup PREigh Manipulate	1	Handle and Manipultate phone
14		BS	RCA Emeas M	CDM3	Pup PREigh Free Rtrctd	1	Free standing on platform, Antenna Retracted
15		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Manipulate	1	Handle and Manipultate phone
16		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Free Rtrctd	1	Free standing on platform, Antenna Retracted
17		---	RCA Emeas M	All On& Max	KPD-BS-SW Worst Case	1	Leave Chamber, All phones transmitting
18		KPD	RCA Emeas M	CDM1	Pmax PRVar Manipulate	2	Handle and Manipultate phone
19		KPD	RCA Emeas M	CDM1	Pmax PRVar Free Rtrctd	2	Free standing on platform, Antenna Retracted
20		KPD	RCA Emeas M	CDM2	Pmax PRVar Manipulate	2	Handle and Manipultate phone
21		KPD	RCA Emeas M	CDM2	Pmax PRVar Free Rtrctd	2	Free standing on platform, Antenna Retracted
22		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Manipulate	2	Handle and Manipultate phone
23		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Free Rtrctd	2	Free standing on platform, Antenna Retracted
24		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Manipulate	2	Handle and Manipultate phone
25		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Free Rtrctd	2	Free standing on platform, Antenna Retracted
26		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Manipulate	2	Handle and Manipultate phone
27		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Free Rtrctd	2	Free standing on platform, Antenna Retracted
28		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Manipulate	2	Handle and Manipultate phone
29		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Free Rtrctd	2	Free standing on platform, Antenna Retracted
30		BS	RCA Emeas M	CDM3	Pup PREigh Manipulate	2	Handle and Manipultate phone
31		BS	RCA Emeas M	CDM3	Pup PREigh Free Rtrctd	2	Free standing on platform, Antenna Retracted
32		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Manipulate	2	Handle and Manipultate phone
33		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k On-Off	2	On-Off-On-Off Test
34		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Free Rtrctd	2	Free standing on platform, Antenna Retracted
35		---	RCA Emeas M	All On& Max	KPD-BS-SW Worst Case	2	Leave Chamber, All phones transmitting

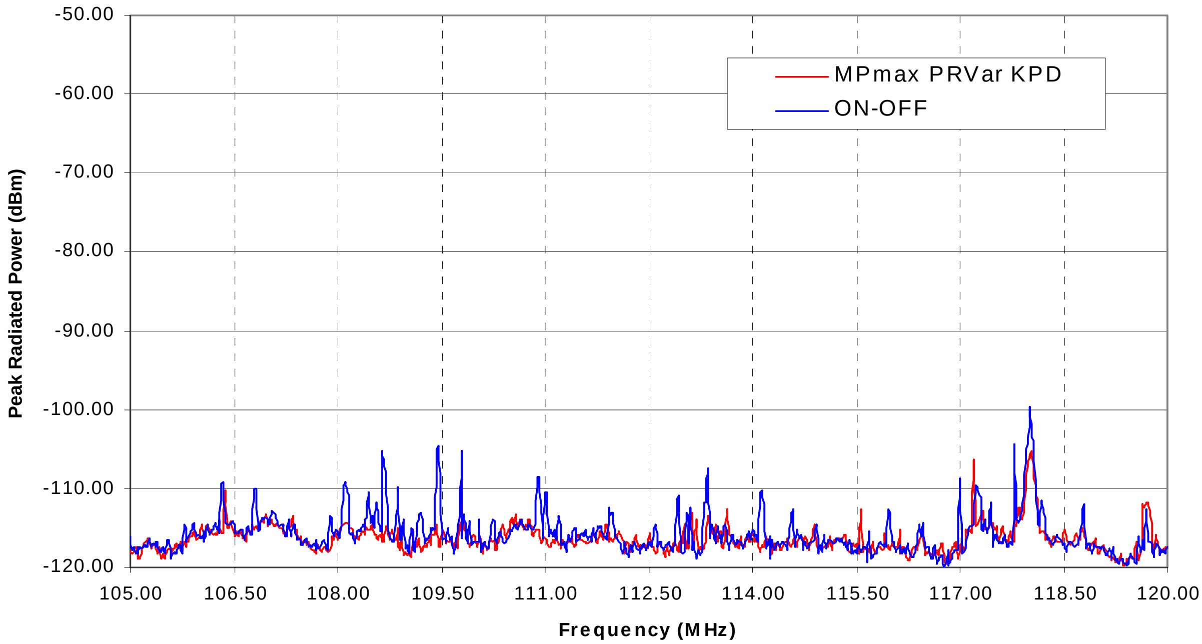
36		KPD	RCA Emeas M	CDM1	Pmax PRVar Manipulate	3	Handle and Manipultate phone
37		KPD	RCA Emeas M	CDM1	Pmax PRVar Free Rtrctd	3	Free standing on platform, Antenna Retracted
38		KPD	RCA Emeas M	CDM2	Pmax PRVar Manipulate	3	Handle and Manipultate phone
39		KPD	RCA Emeas M	CDM2	Pmax PRVar Free Rtrctd	3	Free standing on platform, Antenna Retracted
40		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Manipulate	3	Handle and Manipultate phone
41		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Free Rtrctd	3	Free standing on platform, Antenna Retracted
42		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Manipulate	3	Handle and Manipultate phone
43		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Free Rtrctd	3	Free standing on platform, Antenna Retracted
44		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Manipulate	3	Handle and Manipultate phone
45		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Free Rtrctd	3	Free standing on platform, Antenna Retracted
46		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Manipulate	3	Handle and Manipultate phone
47		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Free Rtrctd	3	Free standing on platform, Antenna Retracted
48		BS	RCA Emeas M	CDM3	Pup PREigh Manipulate	3	Handle and Manipultate phone
49		BS	RCA Emeas M	CDM3	Pup PREigh Free Rtrctd	3	Free standing on platform, Antenna Retracted
50		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Manipulate	3	Handle and Manipultate phone
51		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k On-Off	3	On-Off-On-Off Test
52		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Free Rtrctd	3	Free standing on platform, Antenna Retracted
53		---	RCA Emeas M	All On& Max	KPD-BS-SW Worst Case	3	Leave Chamber, All phones transmitting
54		KPD	RCA Emeas M	CDM1	Pmax PRVar Manipulate	4	Handle and Manipultate phone
55		KPD	RCA Emeas M	CDM1	Pmax PRVar Free Rtrctd	4	Free standing on platform, Antenna Retracted
56		KPD	RCA Emeas M	CDM2	Pmax PRVar Manipulate	4	Handle and Manipultate phone
57		KPD	RCA Emeas M	CDM2	Pmax PRVar Free Rtrctd	4	Free standing on platform, Antenna Retracted
58		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Manipulate	4	Handle and Manipultate phone
59		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Free Rtrctd	4	Free standing on platform, Antenna Retracted
60		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Manipulate	4	Handle and Manipultate phone
61		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Free Rtrctd	4	Free standing on platform, Antenna Retracted
62		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Manipulate	4	Handle and Manipultate phone
63		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Free Rtrctd	4	Free standing on platform, Antenna Retracted
64		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Manipulate	4	Handle and Manipultate phone
65		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Free Rtrctd	4	Free standing on platform, Antenna Retracted
66		BS	RCA Emeas M	CDM3	Pup PREigh Manipulate	4	Handle and Manipultate phone
67		BS	RCA Emeas M	CDM3	Pup PREigh Free Rtrctd	4	Free standing on platform, Antenna Retracted
68		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Manipulate	4	Handle and Manipultate phone
69		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Free Rtrctd	4	Free standing on platform, Antenna Retracted
70		---	RCA Emeas M	All On& Max	KPD-BS-SW Worst Case	4	Leave Chamber, All phones transmitting

1		KPD	RCA Emeas M	CDM1	Pmax PRVar Head Extnd	5	Measure next to head, Ant. Extended
2		KPD	RCA Emeas M	CDM1	Pmax PRVar Free Extnd	5	Measure free-standing on platform, Ant. Extended
3		KPD	RCA Emeas M	CDM1	Pmax PRVar Head Rtrctd	5	Measure next to head, Ant. Retracted
4		KPD	RCA Emeas M	CDM1	Pmax PRVar Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted
5		KPD	RCA Emeas M	CDM2	Pmax PRVar Head Extnd	5	Measure next to head, Ant. Extended
6		KPD	RCA Emeas M	CDM2	Pmax PRVar Free Extnd	5	Measure free-standing on platform, Ant. Extended
7		KPD	RCA Emeas M	CDM2	Pmax PRVar Head Rtrctd	5	Measure next to head, Ant. Retracted
8		KPD	RCA Emeas M	CDM2	Pmax PRVar Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted
9		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Head Extnd	5	Measure next to head, Ant. Extended
10		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Free Extnd	5	Measure free-standing on platform, Ant. Extended
11		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Head Rtrctd	5	Measure next to head, Ant. Retracted
12		KPD	RCA Emeas M	GSM1	PLvl33 DTOn CH62 Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted
13		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Head Extnd	5	Measure next to head, Ant. Extended
14		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Free Extnd	5	Measure free-standing on platform, Ant. Extended
15		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Head Rtrctd	5	Measure next to head, Ant. Retracted
16		KPD	RCA Emeas M	GSM2	PLvl33 CH62 Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted
17		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Head Extnd	5	Measure next to head, Ant. Extended
18		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Free Extnd	5	Measure free-standing on platform, Ant. Extended
19		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Head Rtrctd	5	Measure next to head, Ant. Retracted
20		KPD	RCA Emeas M	GSM3	PLvl33 CH62 Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted
21		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Head Extnd	5	Measure next to head, Ant. Extended
22		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Free Extnd	5	Measure free-standing on platform, Ant. Extended
23		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Head Rtrctd	5	Measure next to head, Ant. Retracted
24		KPD	RCA Emeas M	GSM4	PLvl33 CH62 Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted
25		BS	RCA Emeas M	CDM3	Pup PREigh Head Extnd	5	Measure next to head, Ant. Extended
26		BS	RCA Emeas M	CDM3	Pup PREigh Free Extnd	5	Measure free-standing on platform, Ant. Extended
27		BS	RCA Emeas M	CDM3	Pup PREigh Head Rtrctd	5	Measure next to head, Ant. Retracted
28		BS	RCA Emeas M	CDM3	Pup PREigh Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted
29		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Head Extnd	5	Measure next to head, Ant. Extended
30		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Free Extnd	5	Measure free-standing on platform, Ant. Extended
31		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Head Rtrctd	5	Measure next to head, Ant. Retracted
32		SW	RCA Emeas M	CDM4	TXAGC511 PREigh VR13k Free Rtrctd	5	Measure free-standing on platform, Ant. Retracted

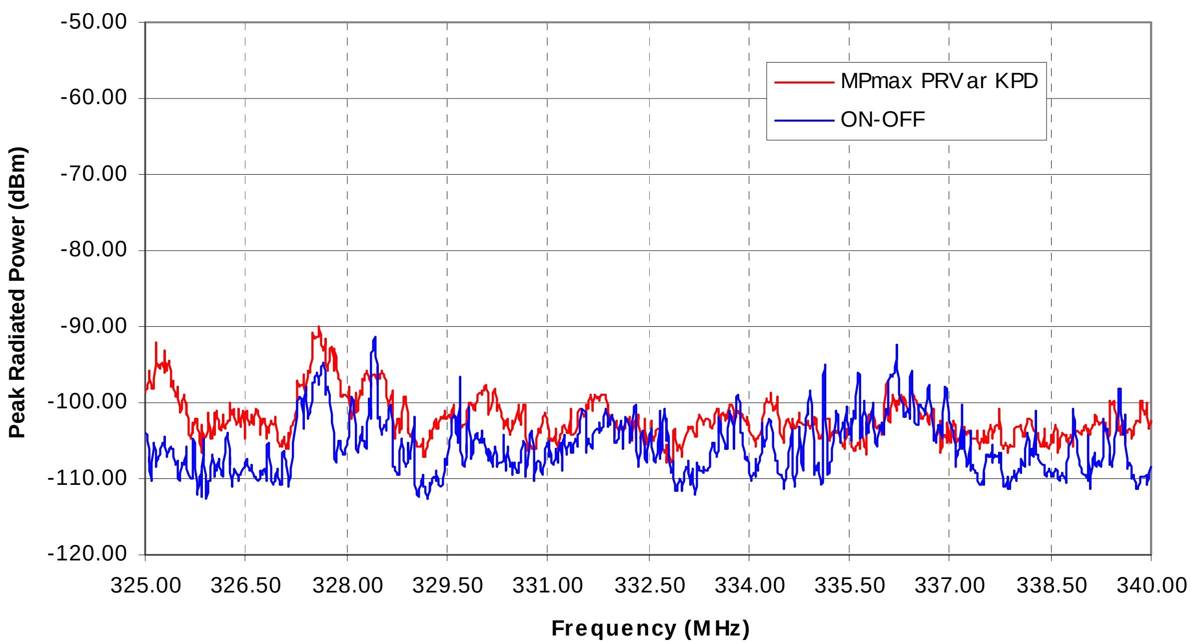
1		KPD	RCA	UO GSM	RCA GSM B1	1a	
2		KPD	RCA	UO TDMA50PC	RCA TDMA50PCS B1	1a	
3		KPD	RCA	UO TDMA50Cel	RCA TDMA50Cell B1	1a	
4		KPD	RCA	UO CDMAIS95	RCA CDMAIS95 B1	1a	
5		KPD	RCA	UO DCS	RCA DCS B1	1a	
6		KPD	RCA	UO TDMA11	RCA TDMA11 B1	1a	
7		KPD	RCA	UO GSM	RCA GSM B2	2	
8		KPD	RCA	UO TDMA50PC	RCA TDMA50PCS B2	2	
9		KPD	RCA	UO TDMA50Cel	RCA TDMA50Cell B2	2	
10		KPD	RCA	UO CDMAIS95	RCA CDMAIS95 B2	2	
11		KPD	RCA	UO DCS	RCA DCS B2	2	
12		KPD	RCA	UO TDMA11	RCA TDMA11 B2	2	
13		KPD	RCA	UO GSM	RCA GSM B3	4	
14		KPD	RCA	UO TDMA50PC	RCA TDMA50PCS B3	4	
15		KPD	RCA	UO TDMA50Cel	RCA TDMA50Cell B3	4	
16		KPD	RCA	UO CDMAIS95	RCA CDMAIS95 B3	4	
17		KPD	RCA	UO DCS	RCA DCS B3	4	
18		KPD	RCA	UO TDMA11	RCA TDMA11 B3	4	

Appendix C: Spurious Radiated Emissions Data

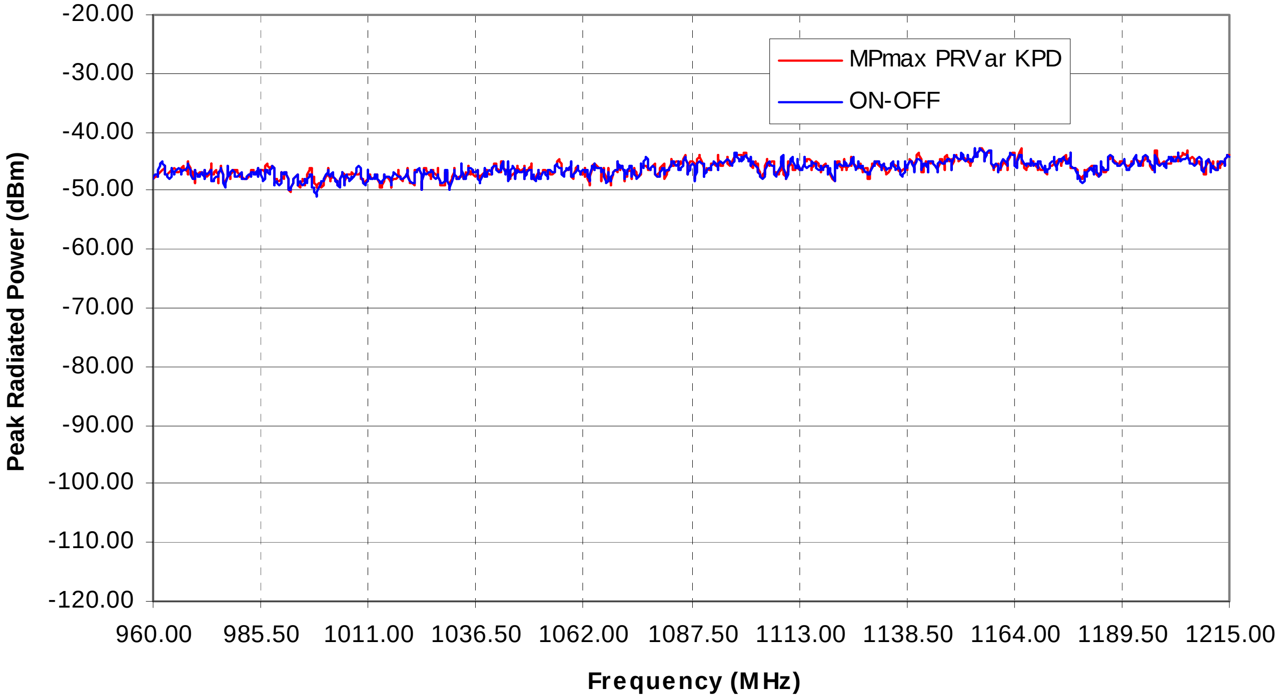
C.1 Mode Comparison: CDM1 Band 1



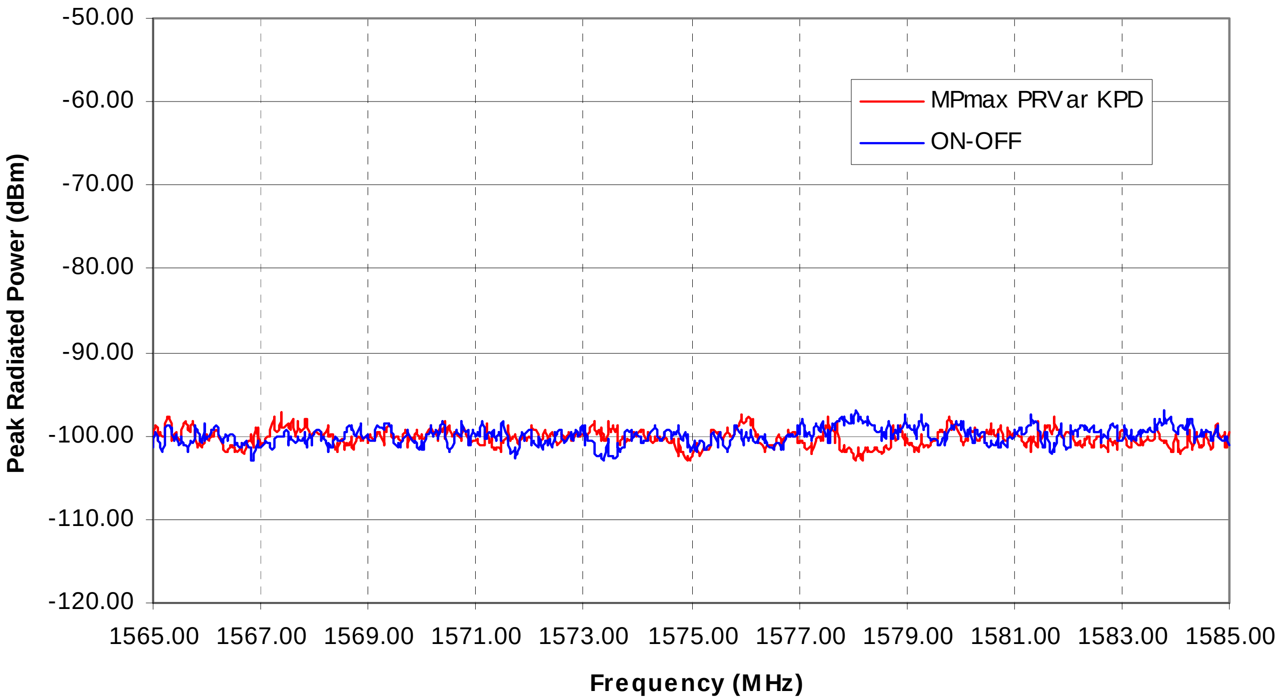
C.2 Mode Comparison: CDM1 Band 2



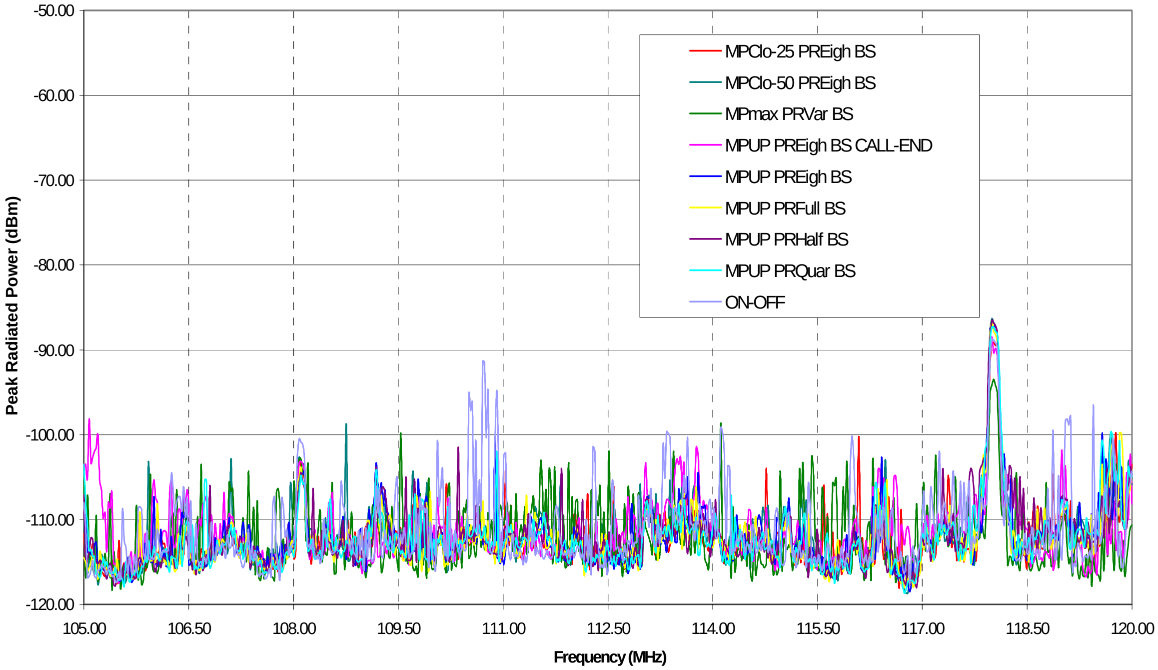
C.3 Mode Comparison: CDM1 Band 3



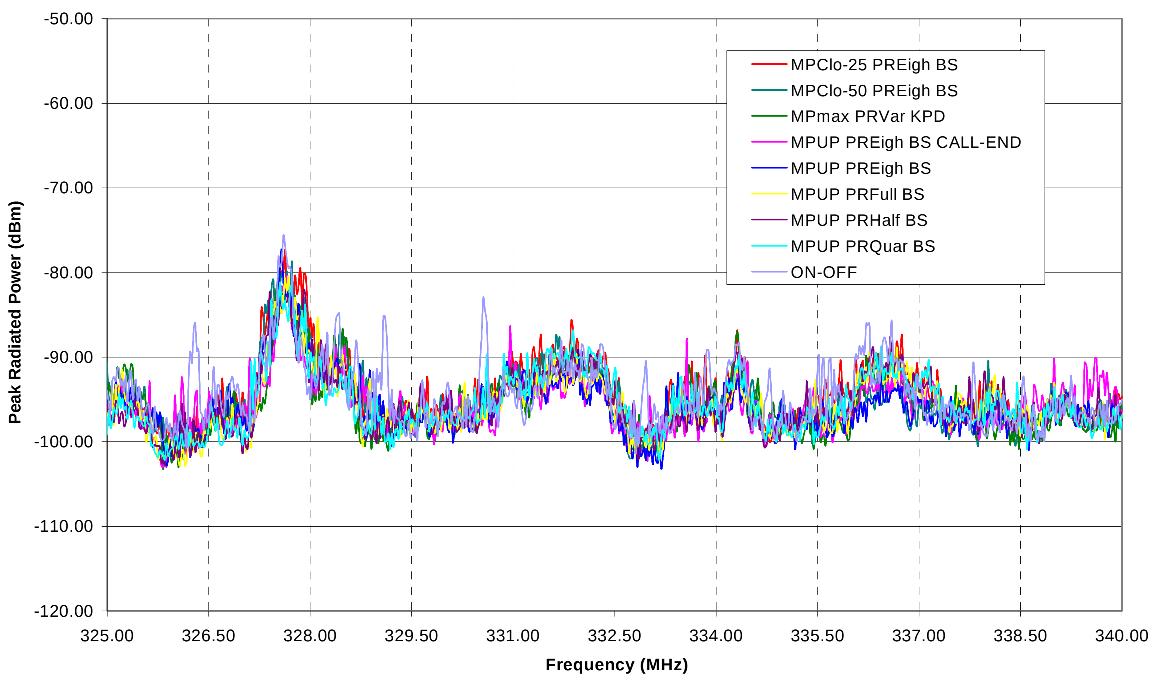
C.4 Mode Comparison: CDM1 Band4



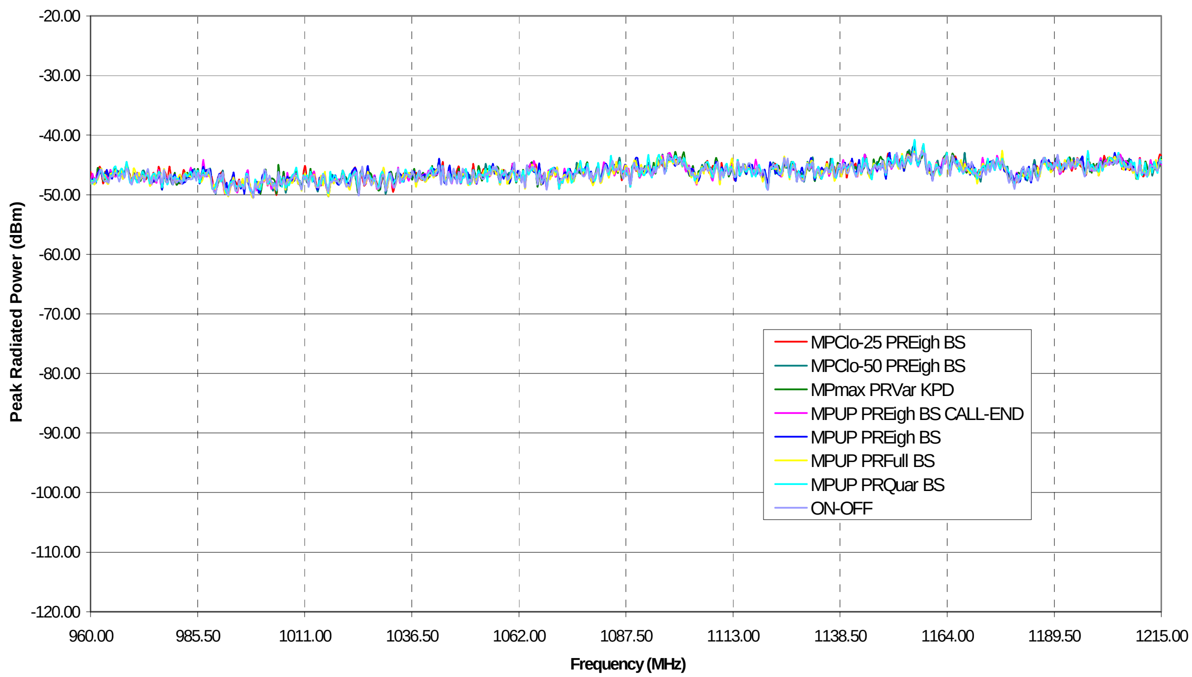
C.5 Mode Comparison: CDM2 Band 1



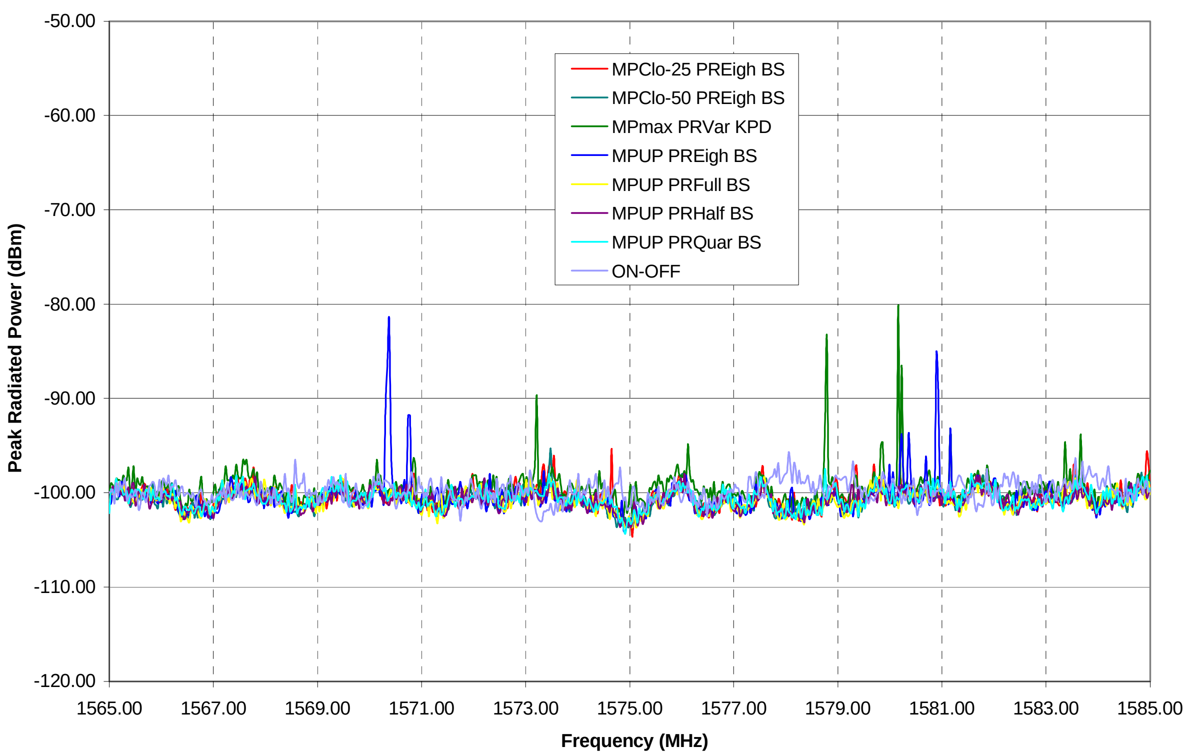
C.6 Mode Comparison: CDM2 Band 2



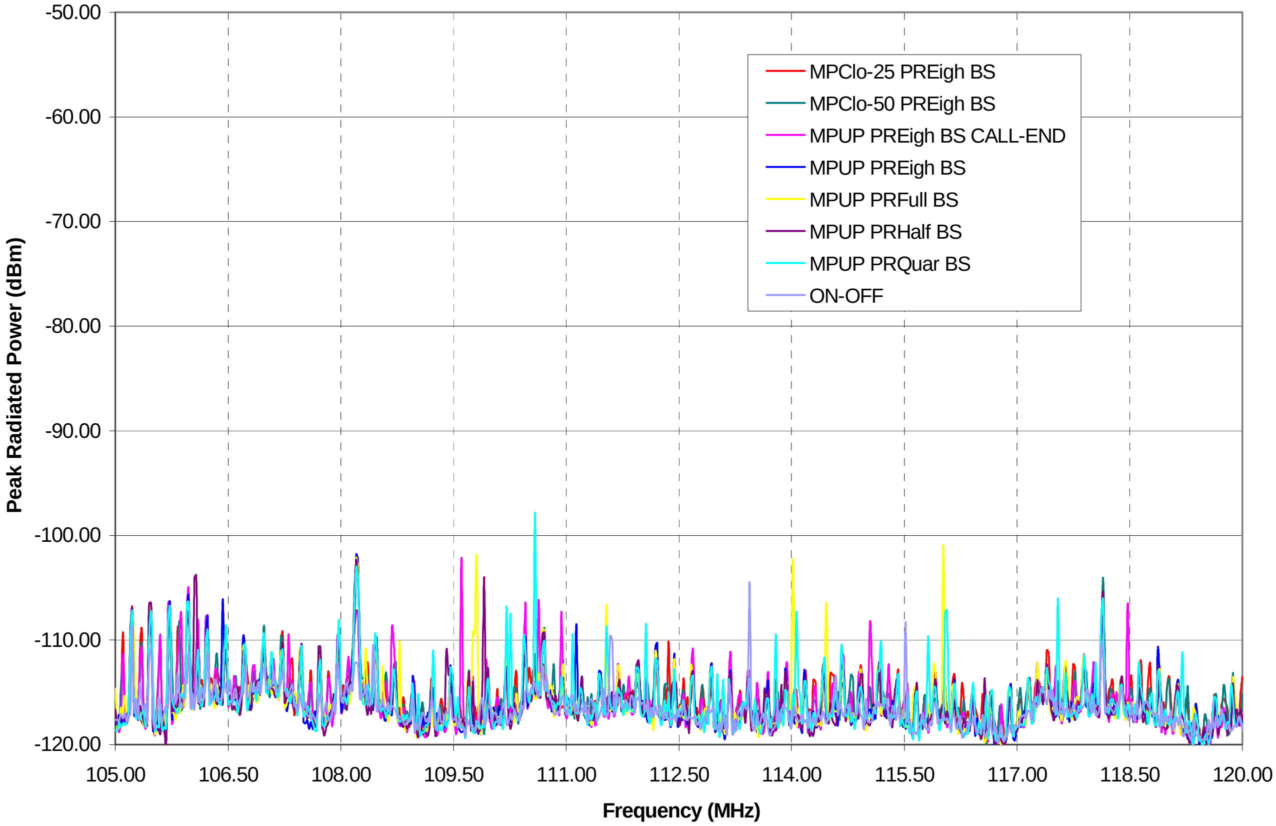
C.7 Mode Comparison: CDM2 Band 3



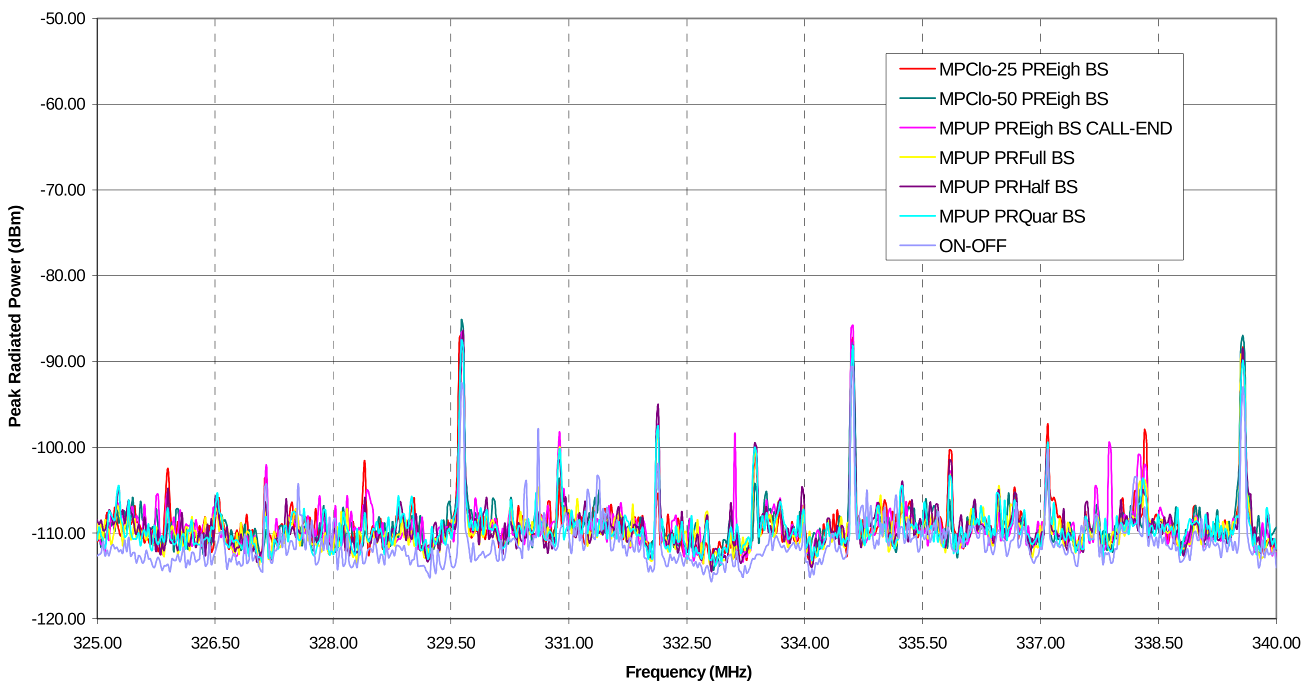
C.8 Mode Comparison: CDM2 Band4



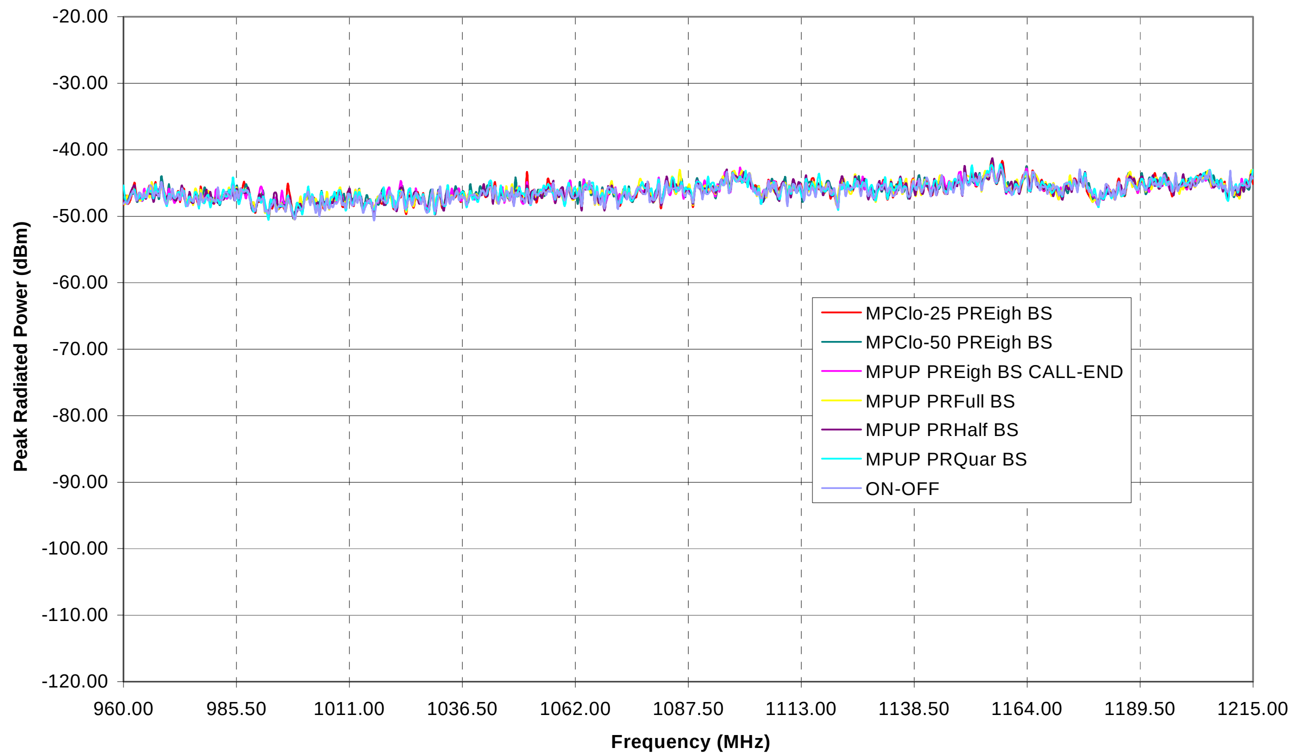
C.9 Mode Comparison: CDM3 Band 1



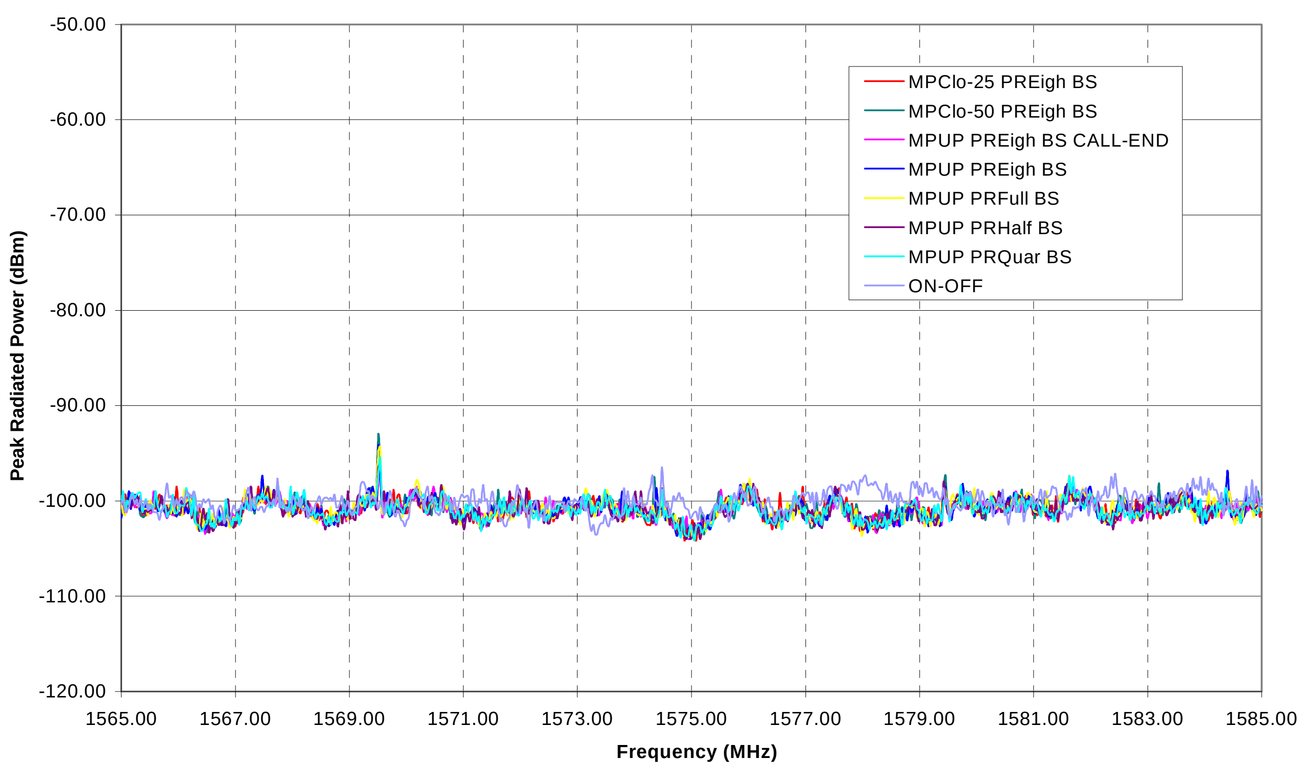
C.10 Mode Comparison: CDM3 Band 2



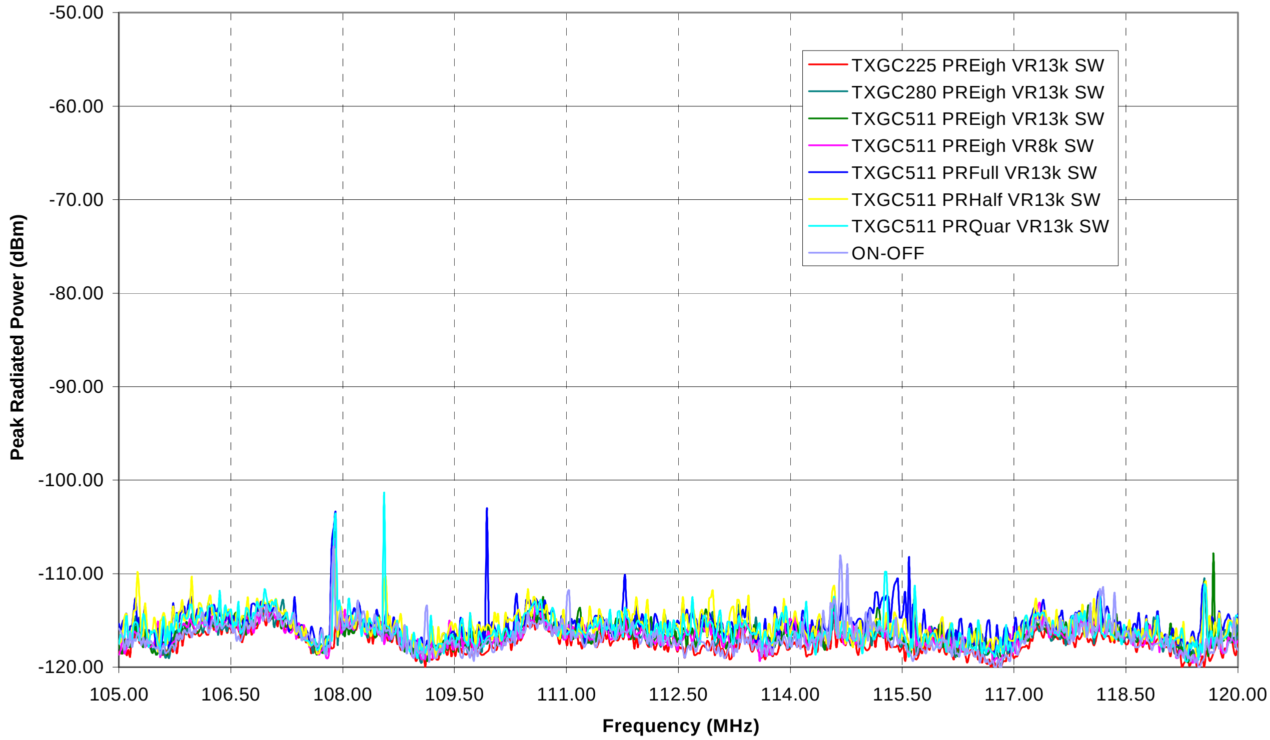
C.11 Mode Comparison: CDM3 Band 3



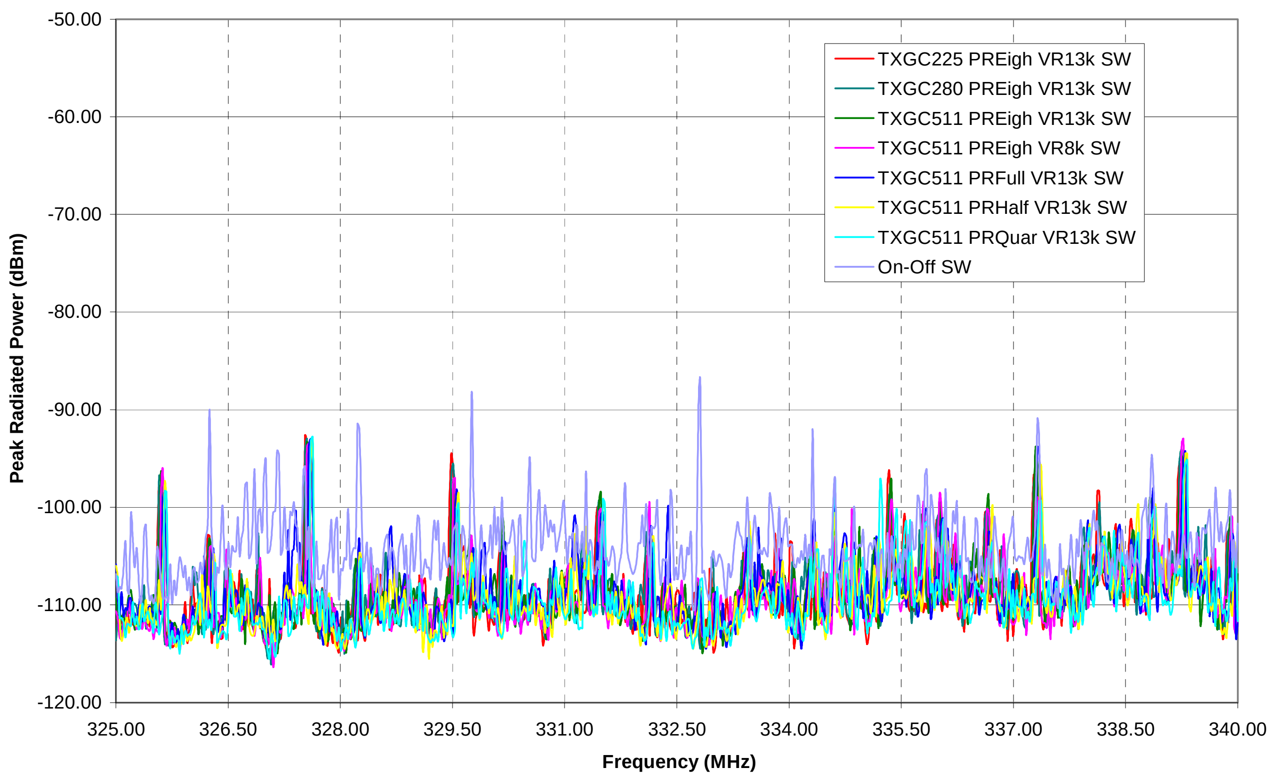
C.12 Mode Comparison: CDM3 Band 4



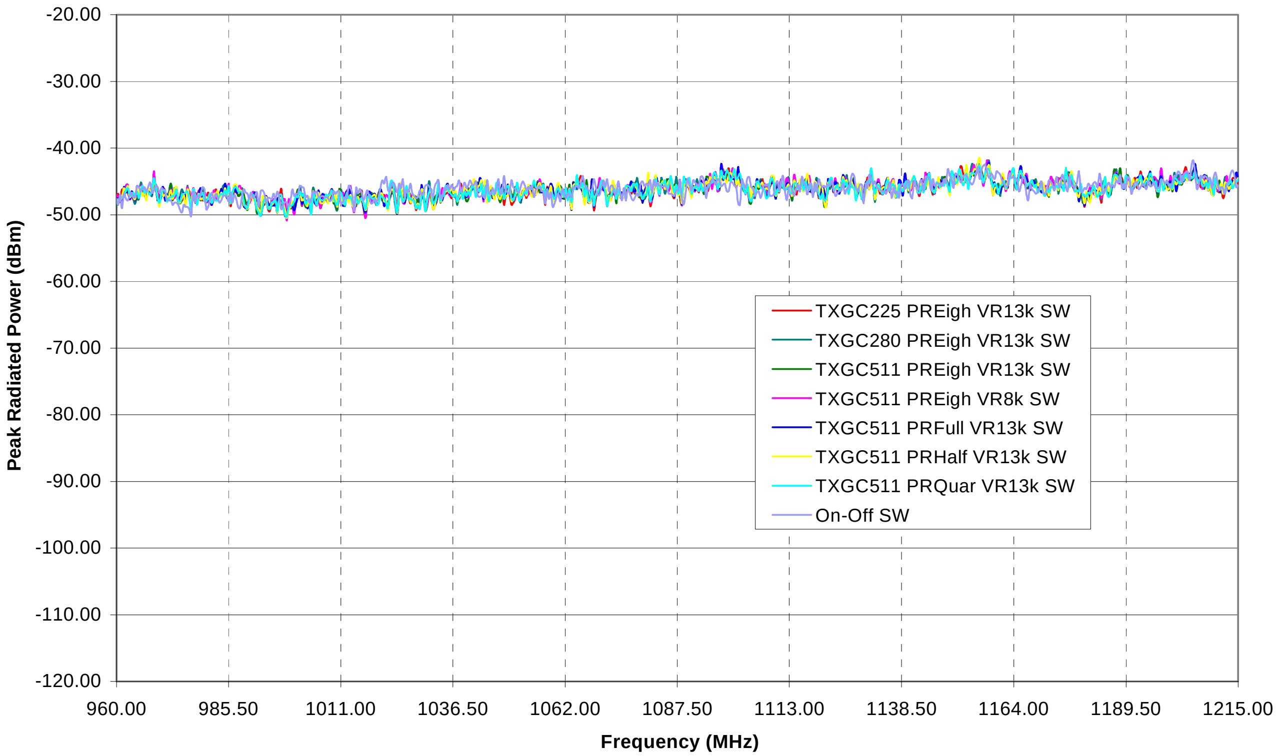
C.13 Mode Comparison: CDM4 Band 1



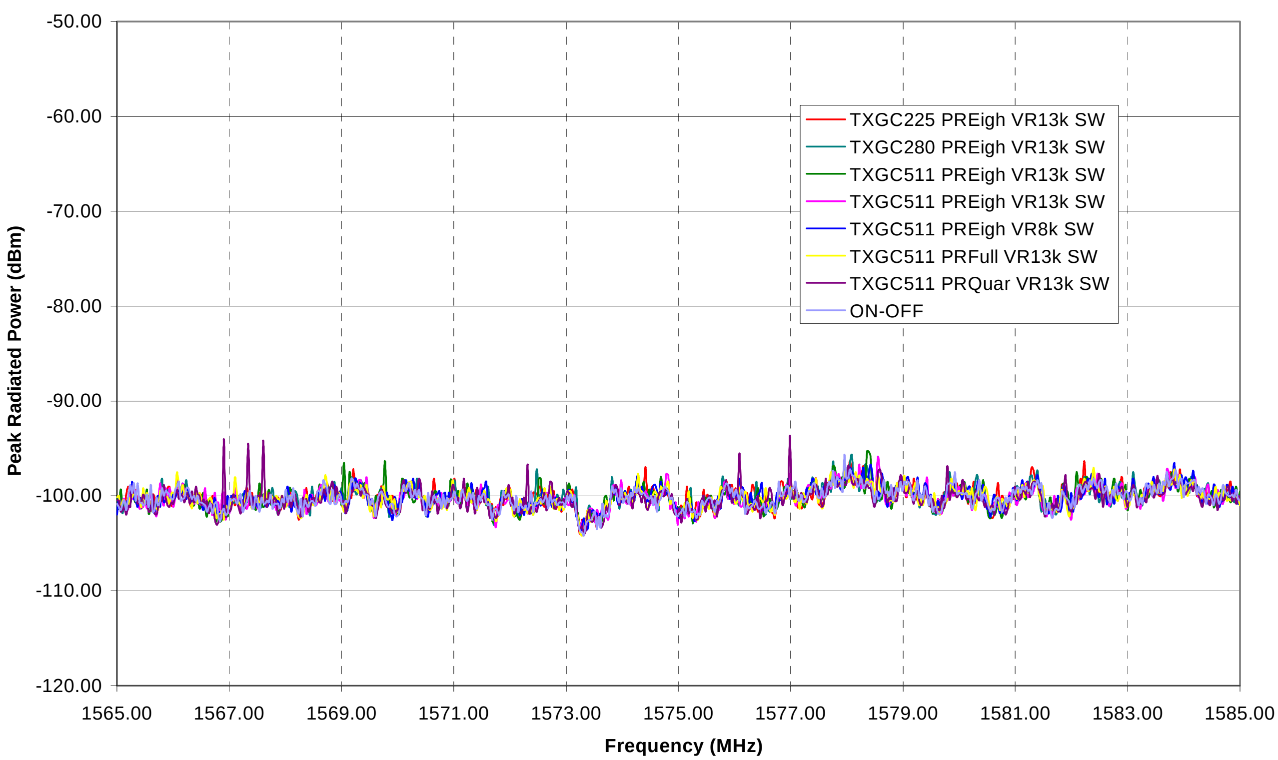
C.14 Mode Comparison: CDM4 Band 2



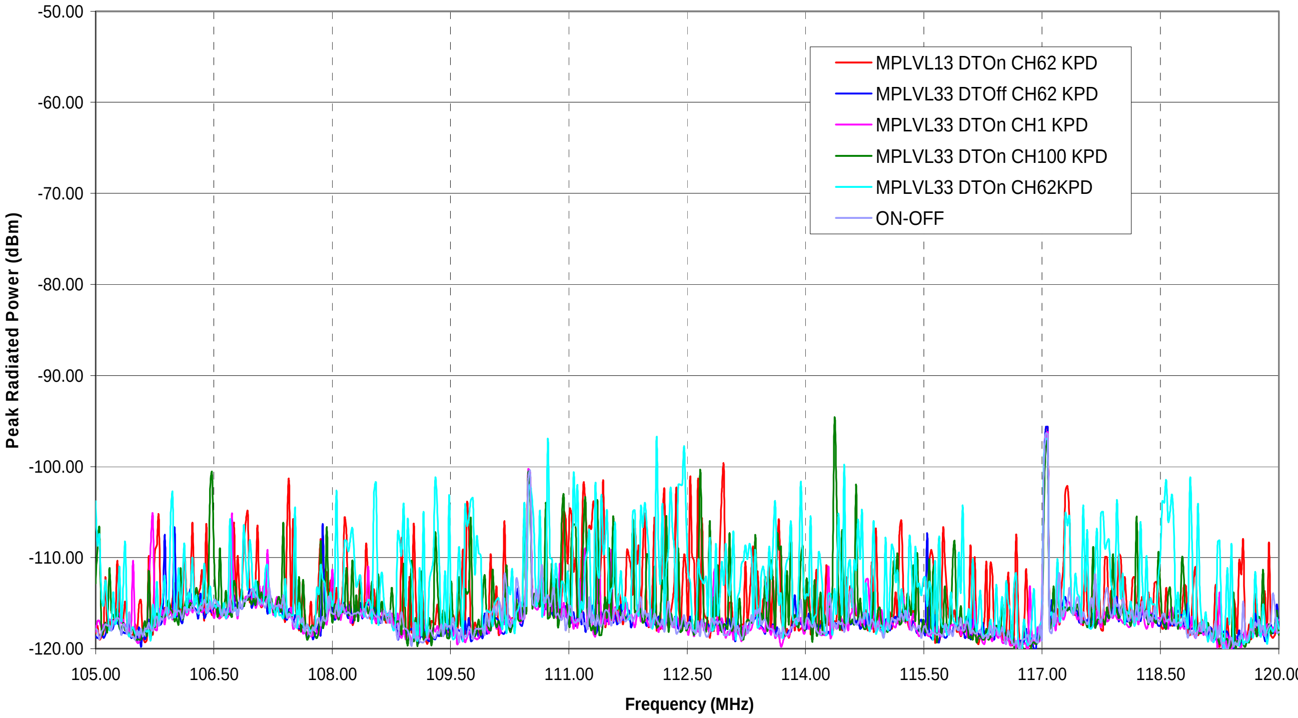
C.15 **Mode Comparison: CDM4 Band 3**



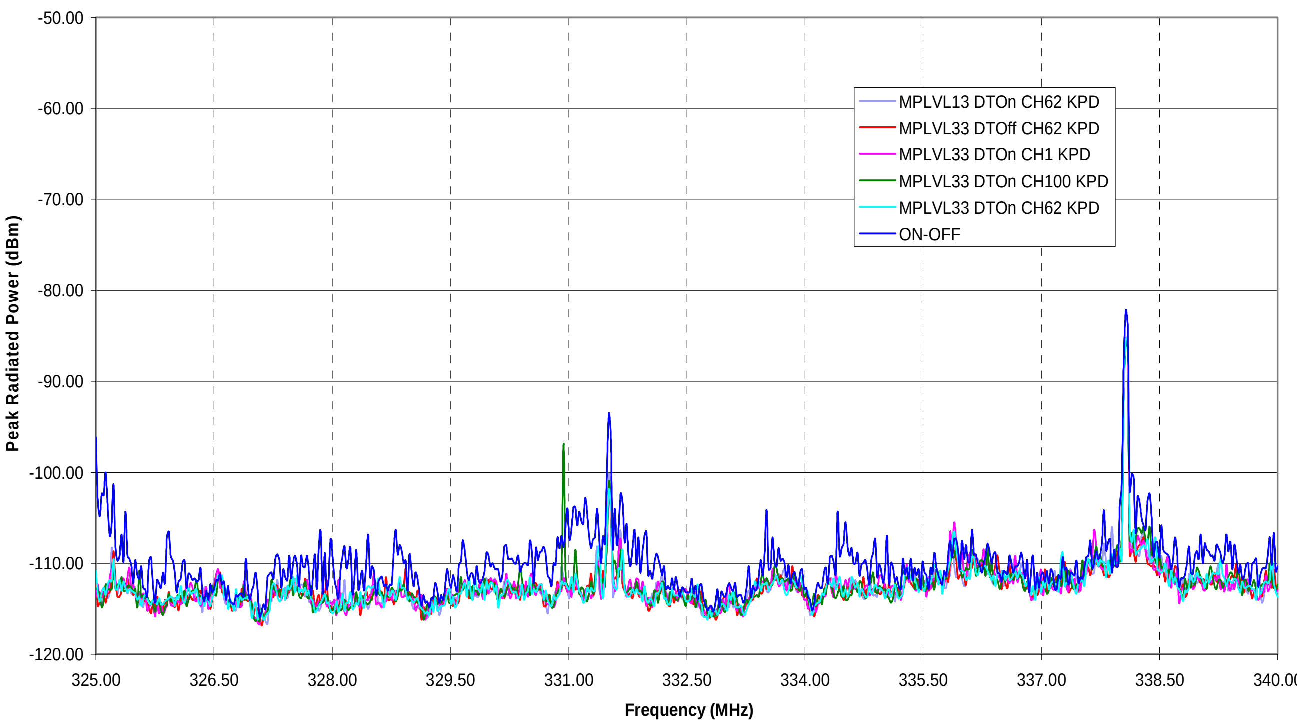
C.16 **Mode Comparison: CDM4 Band 4**



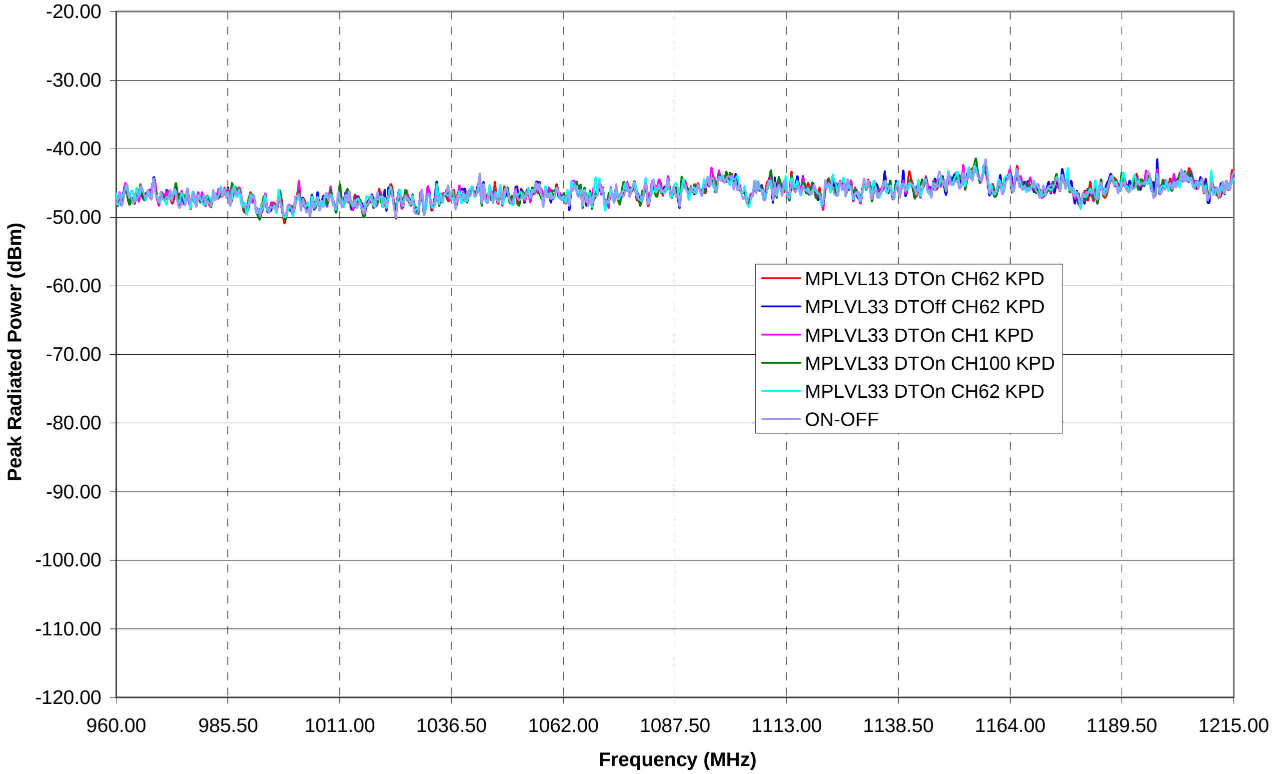
C.17 **Mode Comparison: GSM1 Band 1**



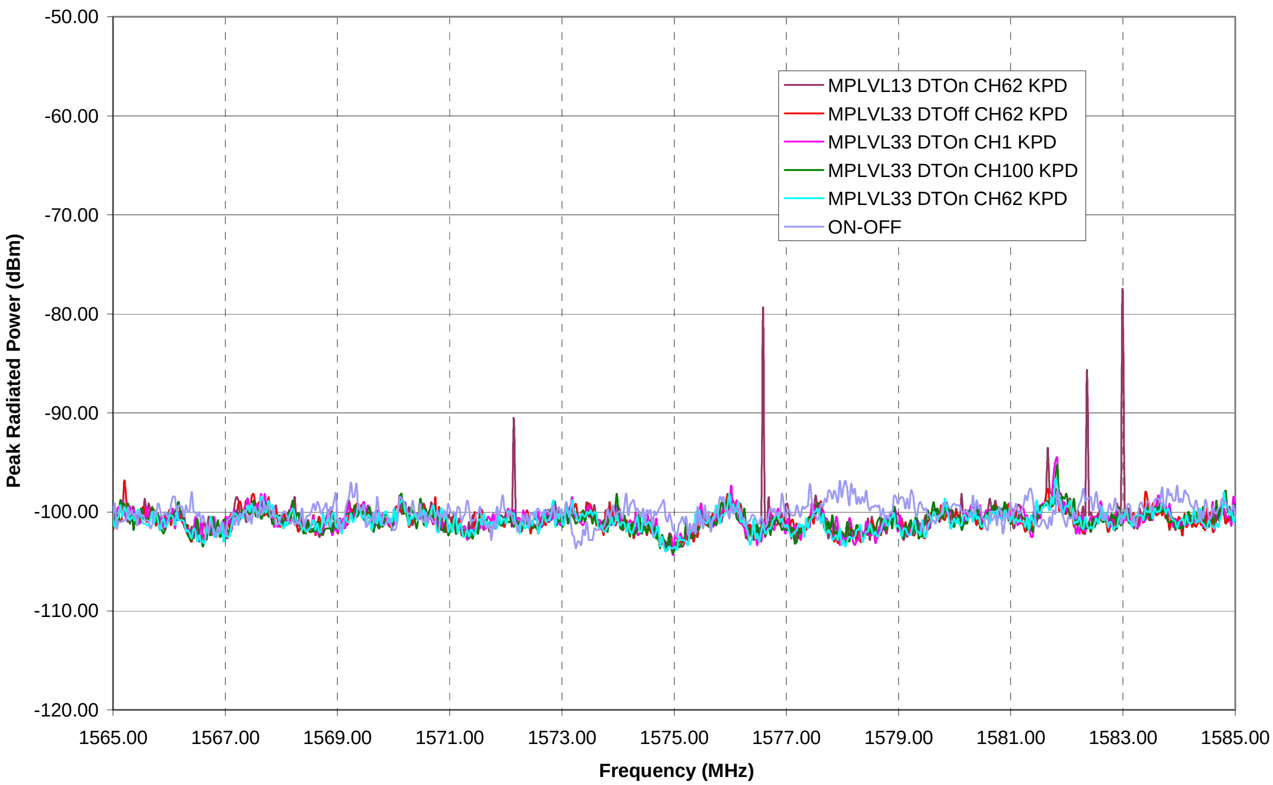
C.18 **Mode Comparison: GSM1 Band 2**



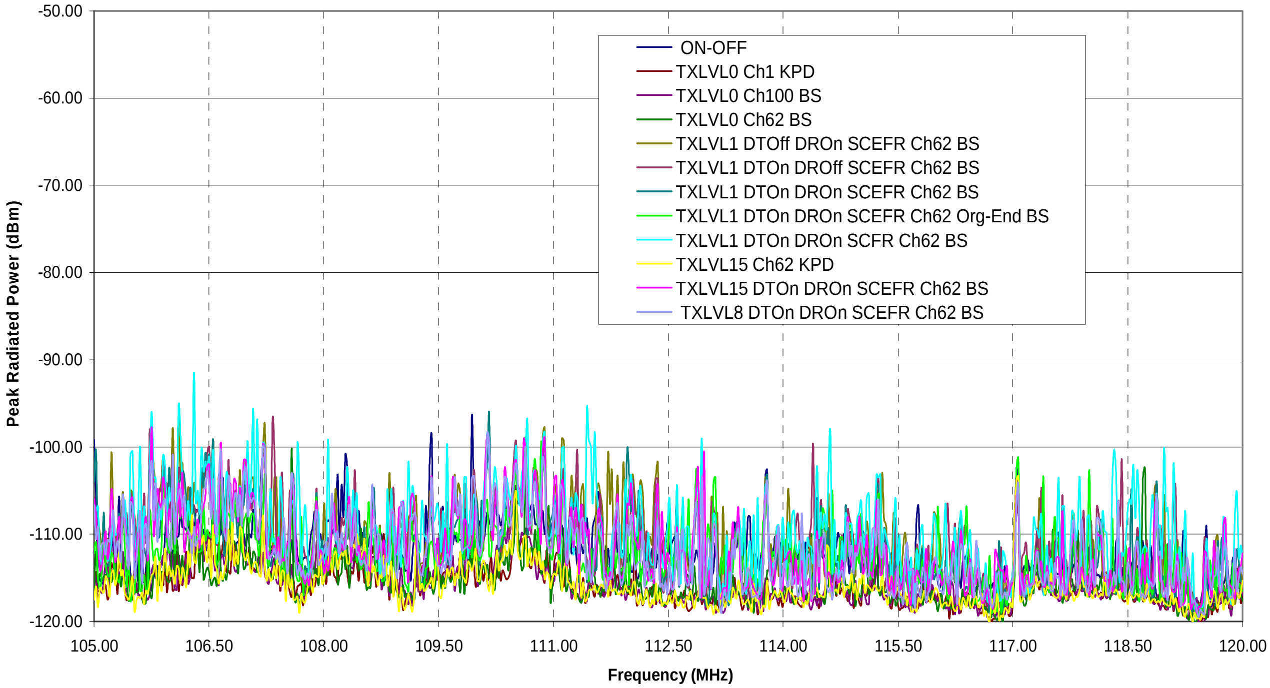
C.19 Mode Comparison: GSM1 Band 3



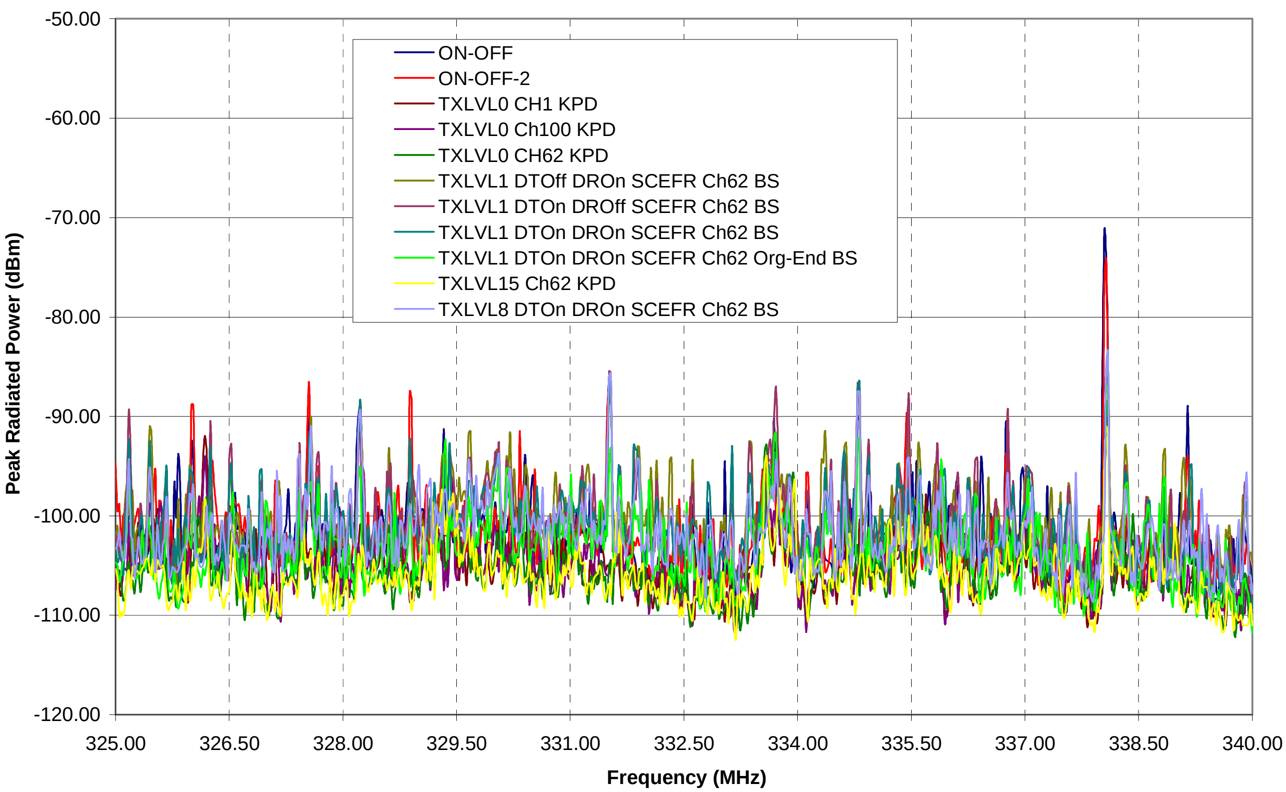
C.20 Mode Comparison: GSM1 Band 4



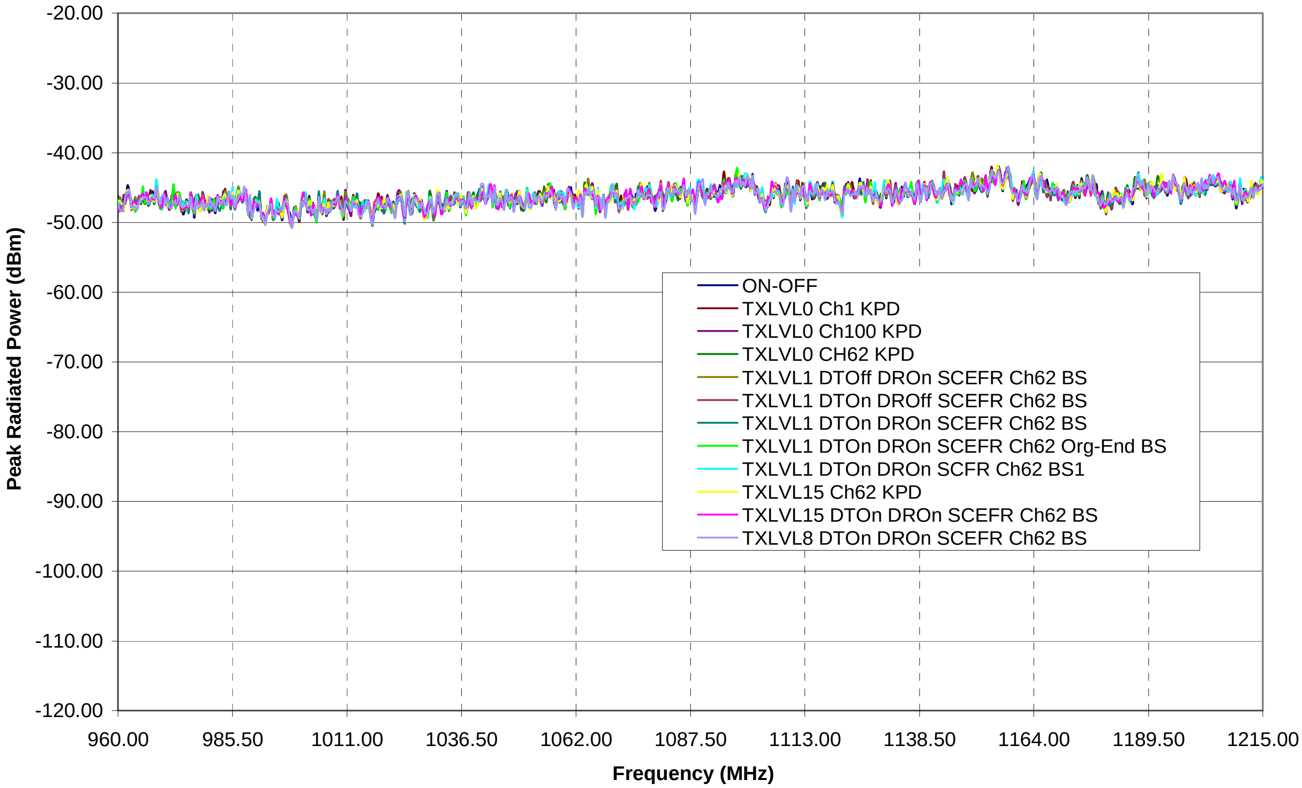
C.21 **Mode Comparison: GSM2 Band1**



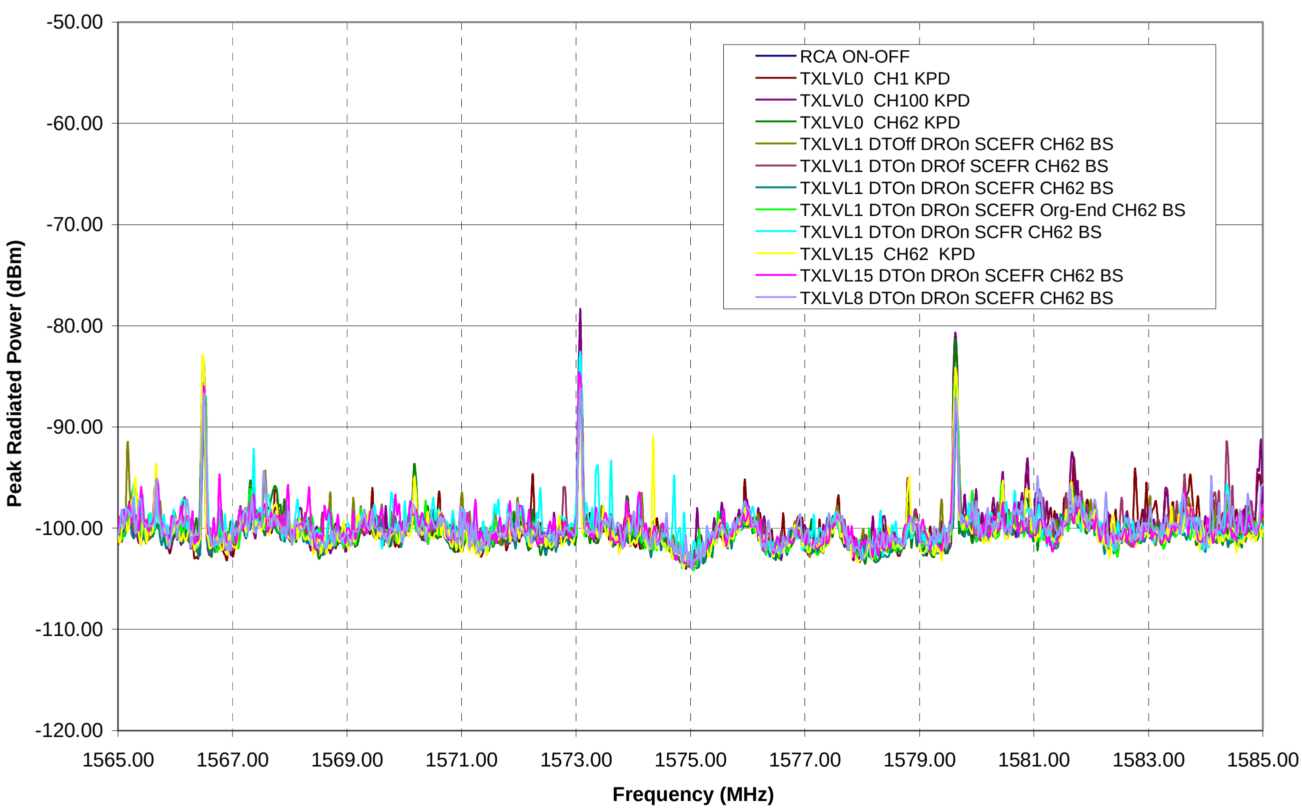
C.22 **Mode Comparison: GSM2 Band 2**



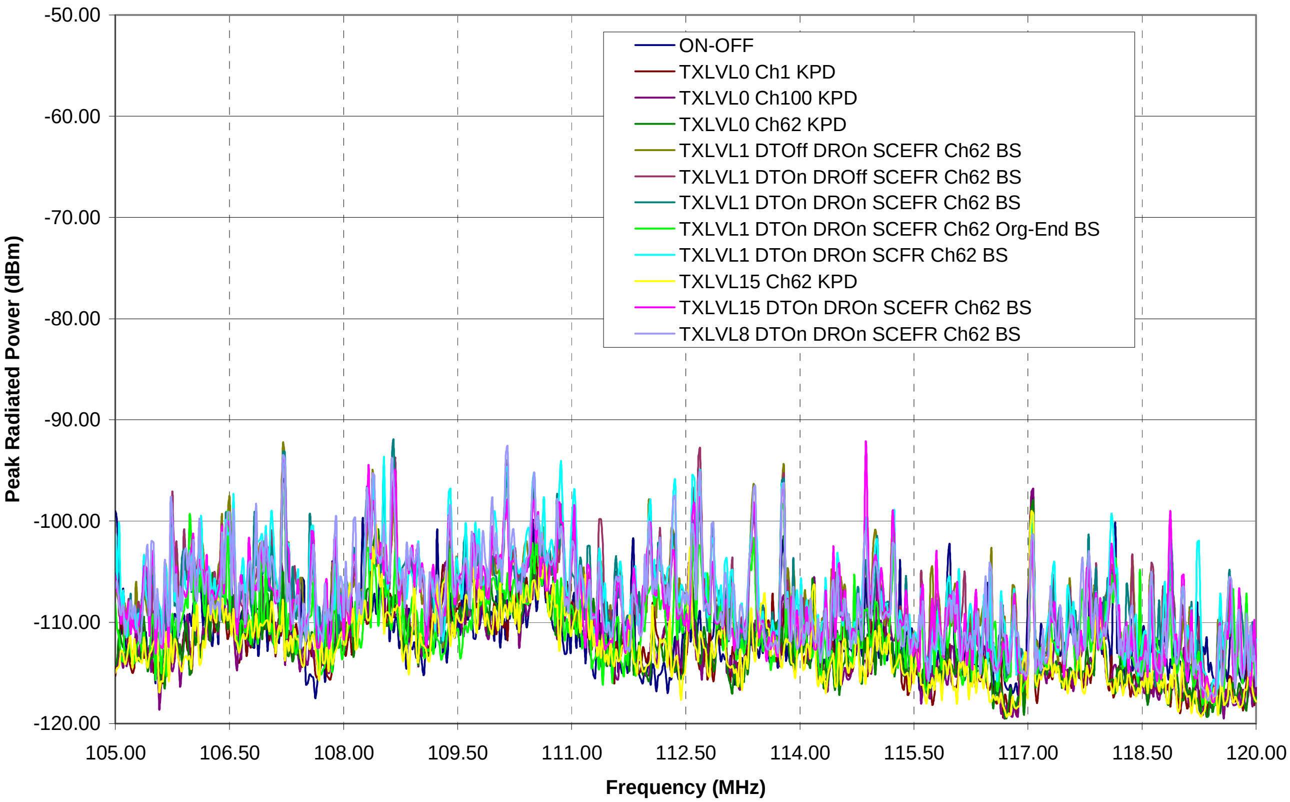
C.23 Mode Comparison: GSM2 Band 3



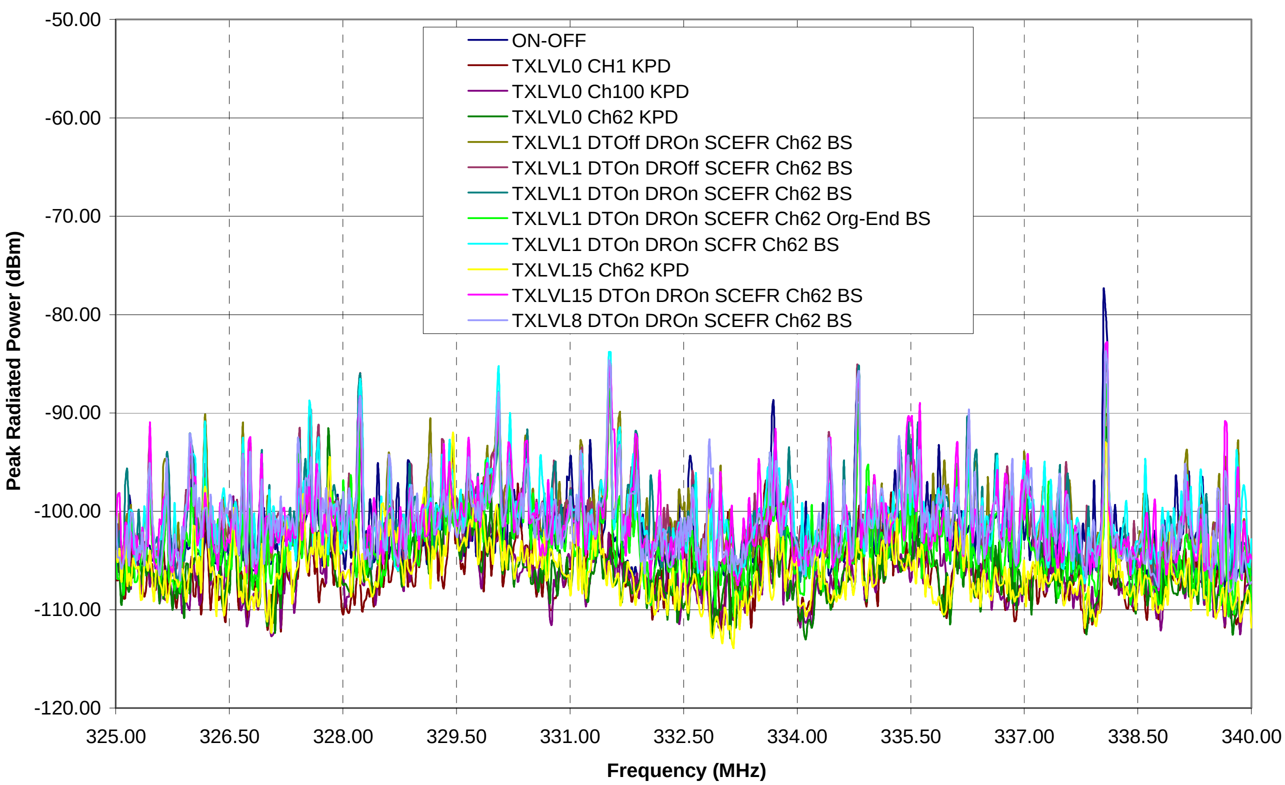
C.24 Mode Comparison: GSM2 Band 4



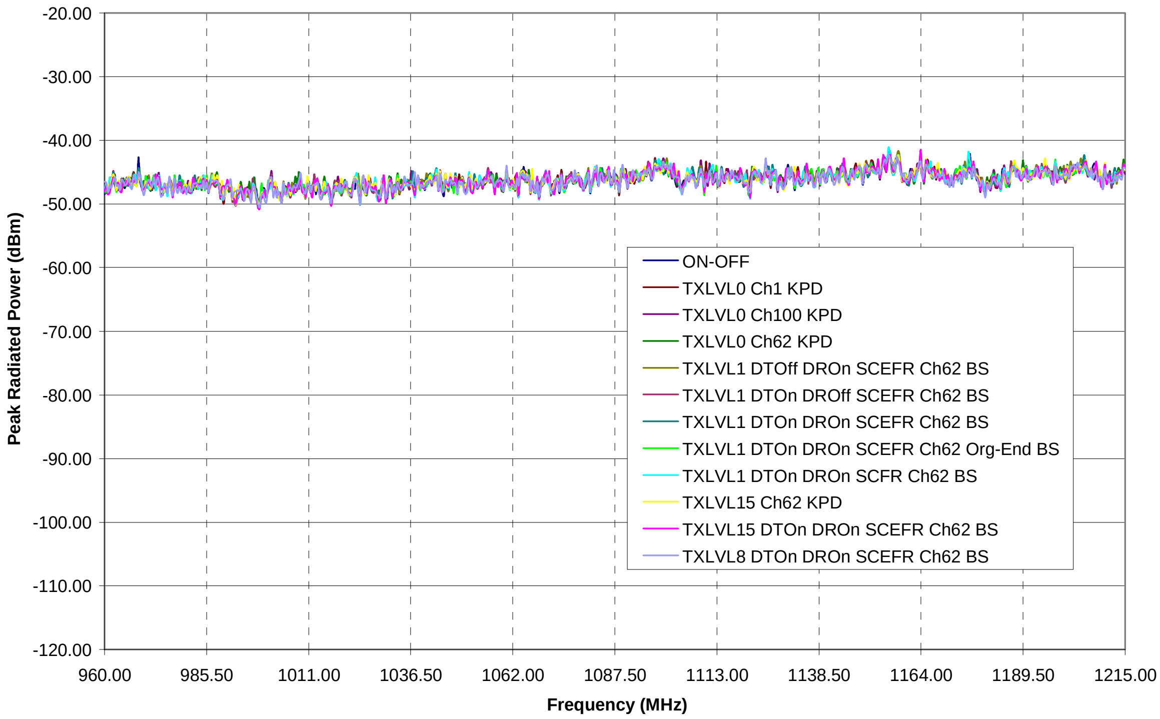
C.25 Mode Comparison: GSM3 Band1



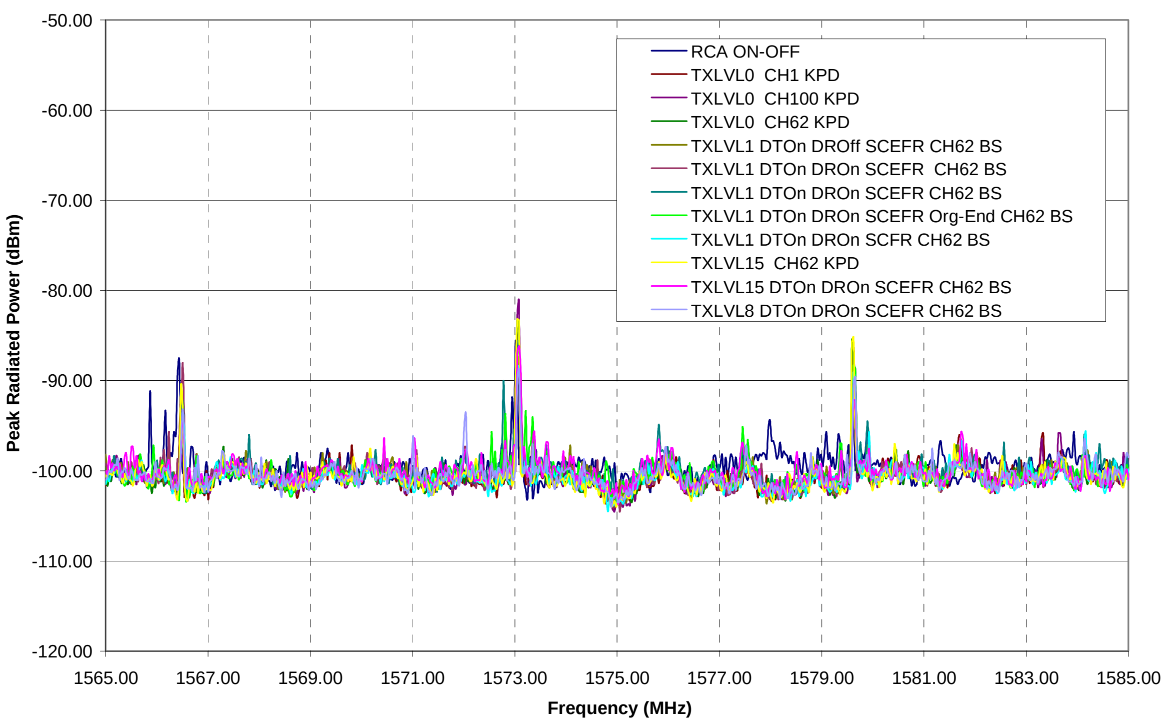
C.26 Mode Comparison: GSM3 Band 2



C.27 **Mode Comparison: GSM3 Band 3**



C.28 **Mode Comparison: GSM3 Band 4**



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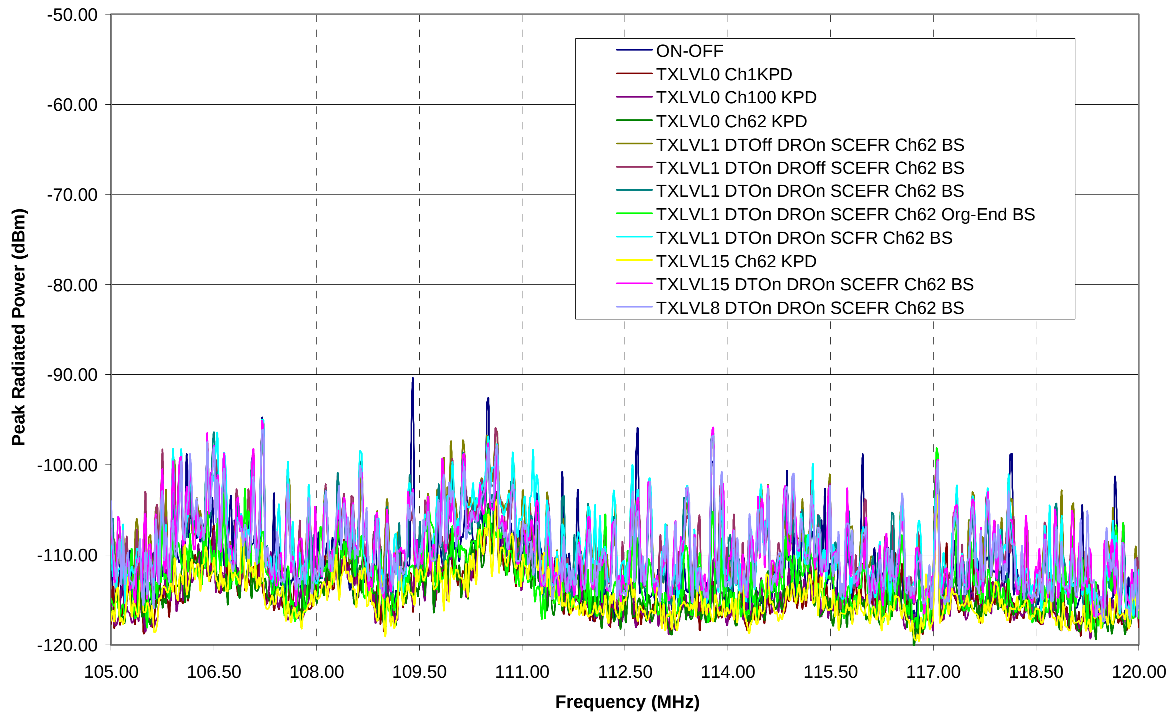

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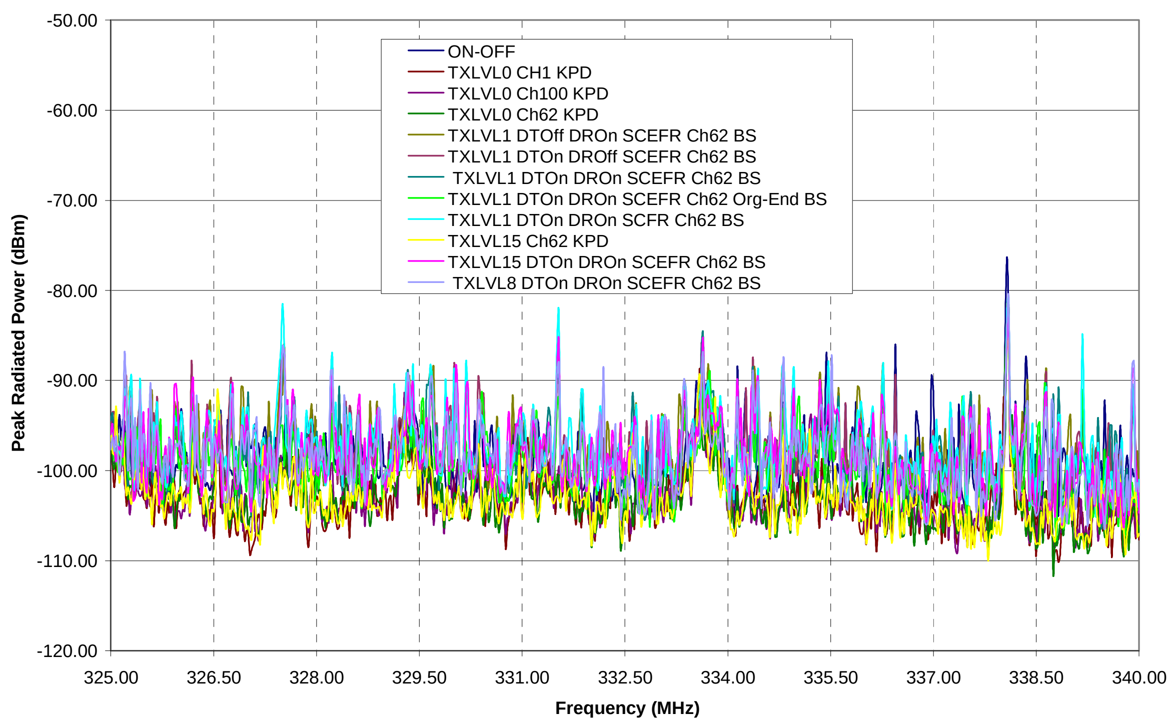

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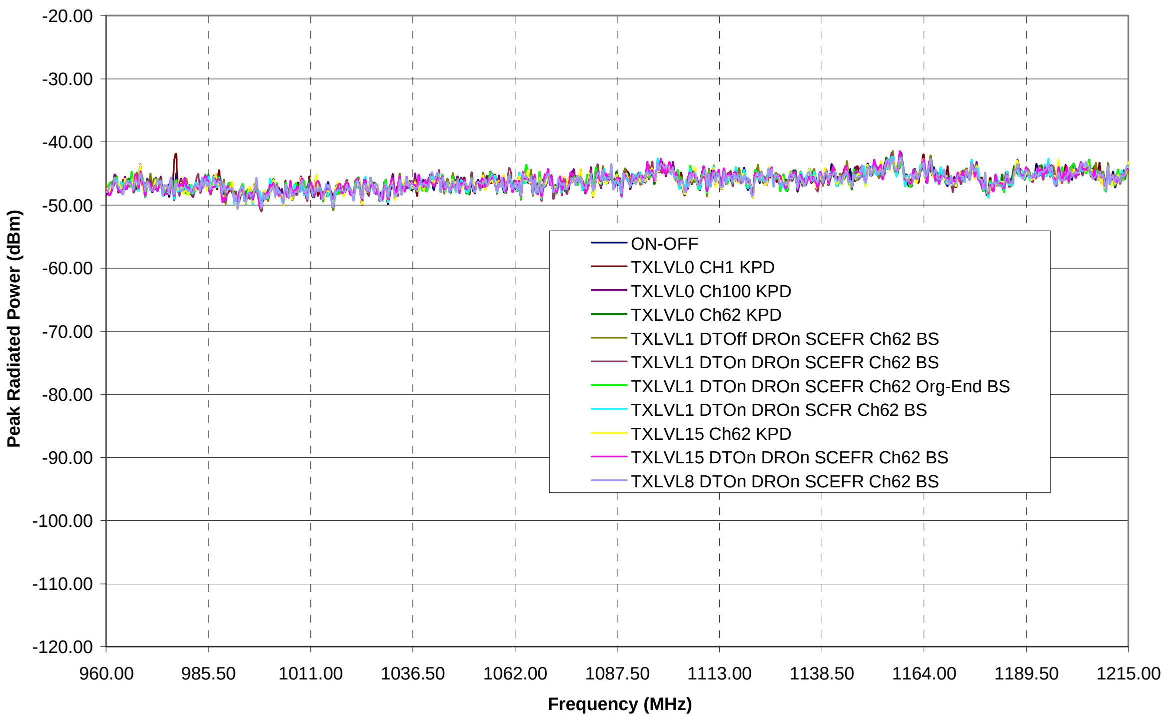
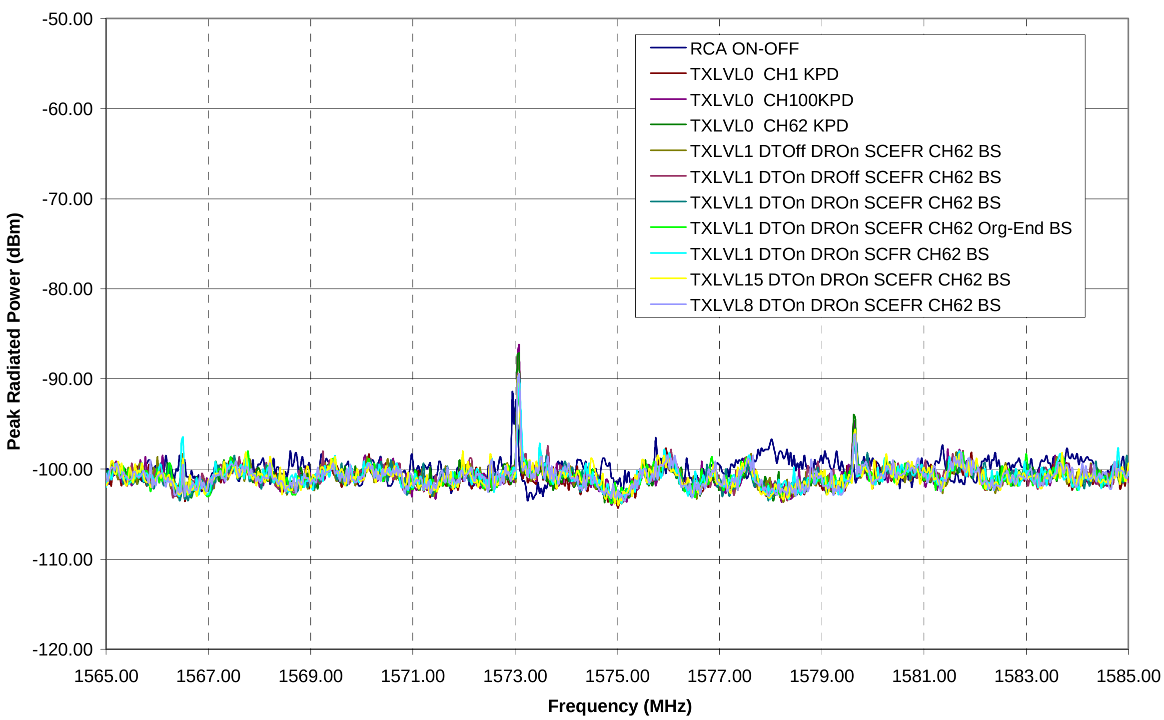
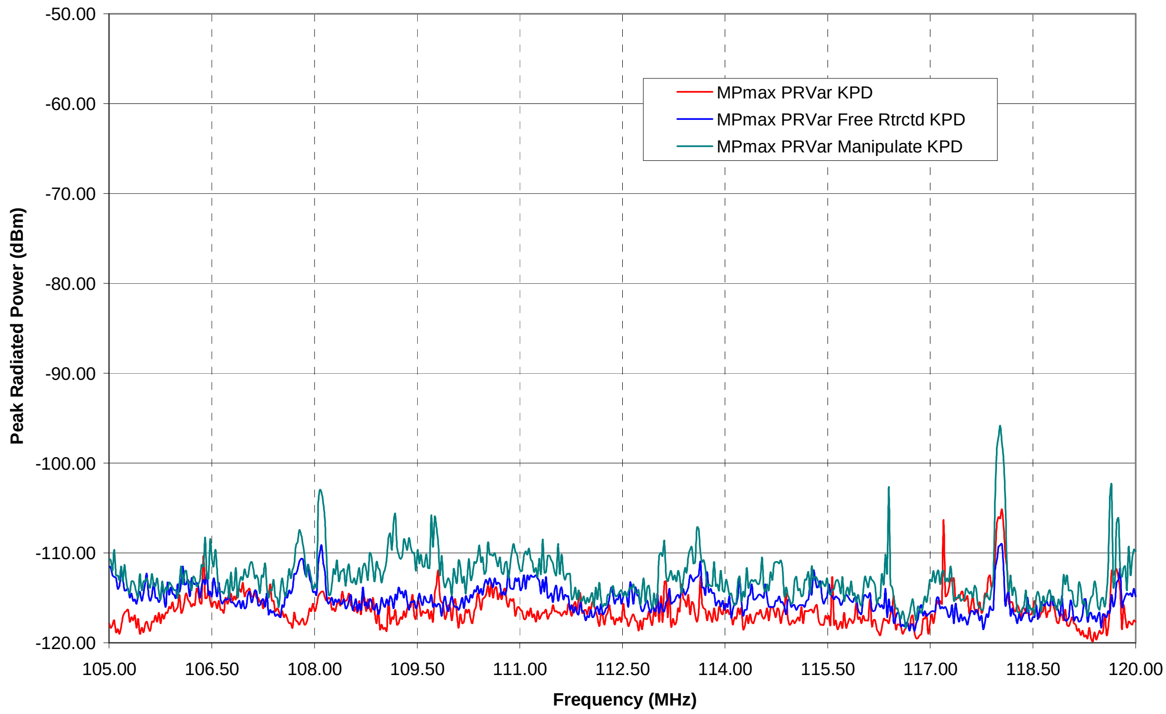


C.32 Mode Comparison: GSM4 Band 4



C.33 Phone Handling and Anteena Position: CDM1 Band 1



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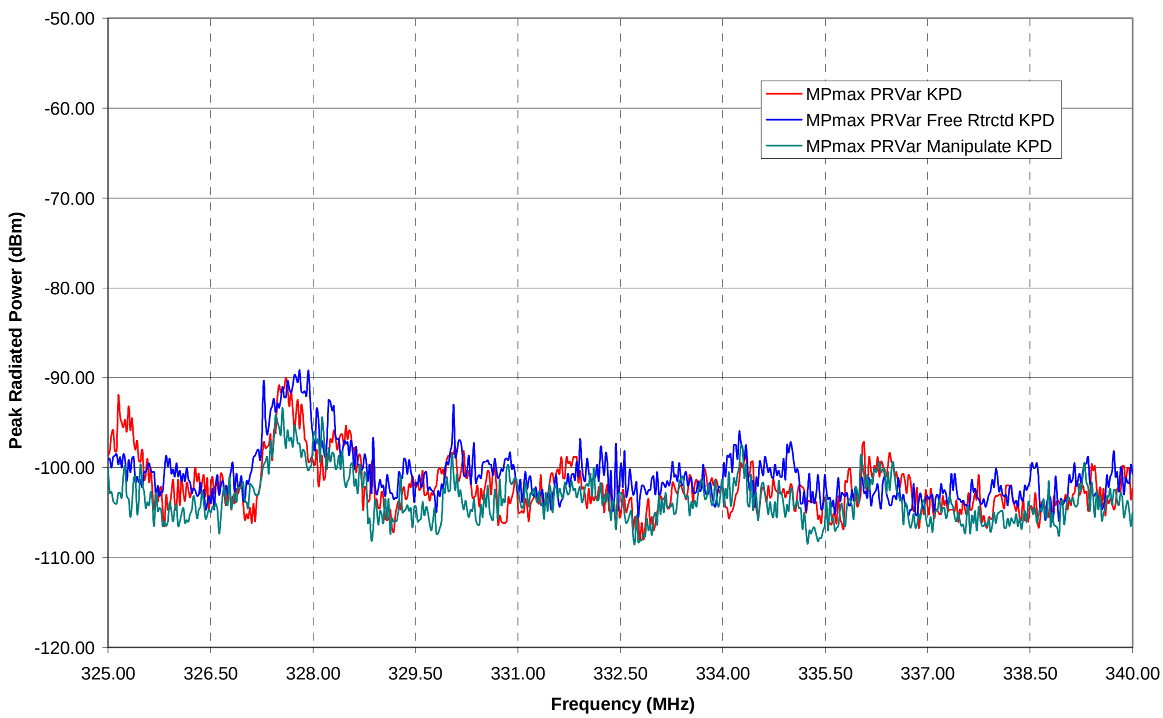

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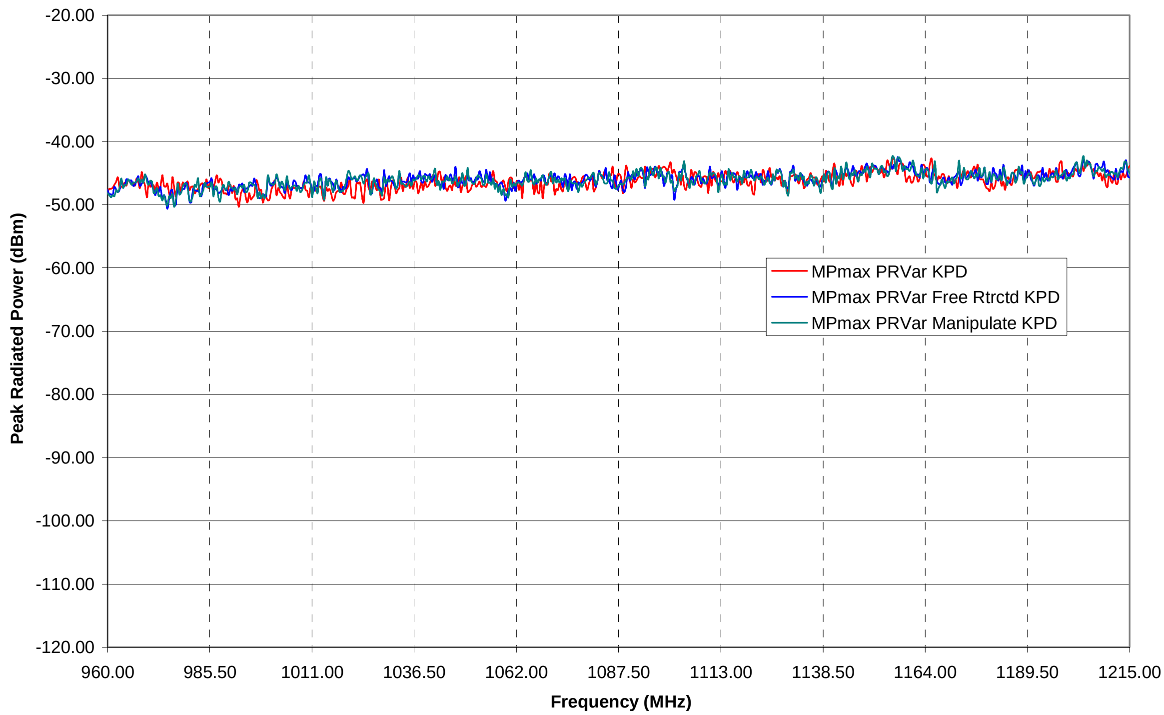

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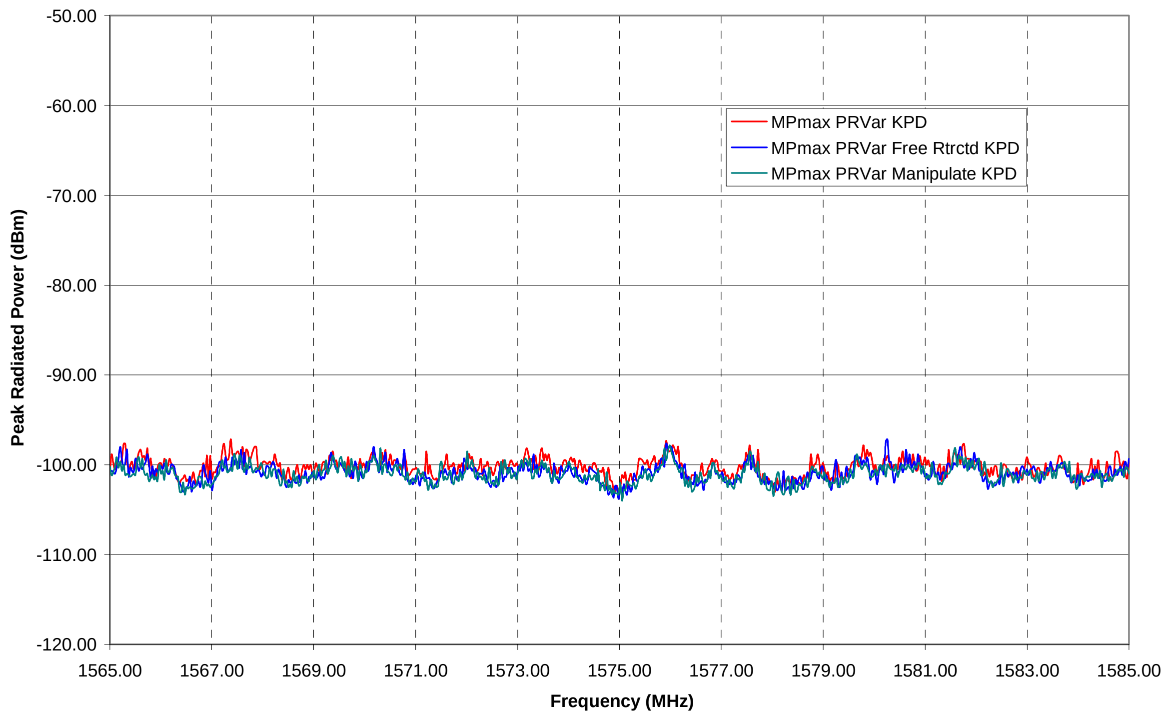

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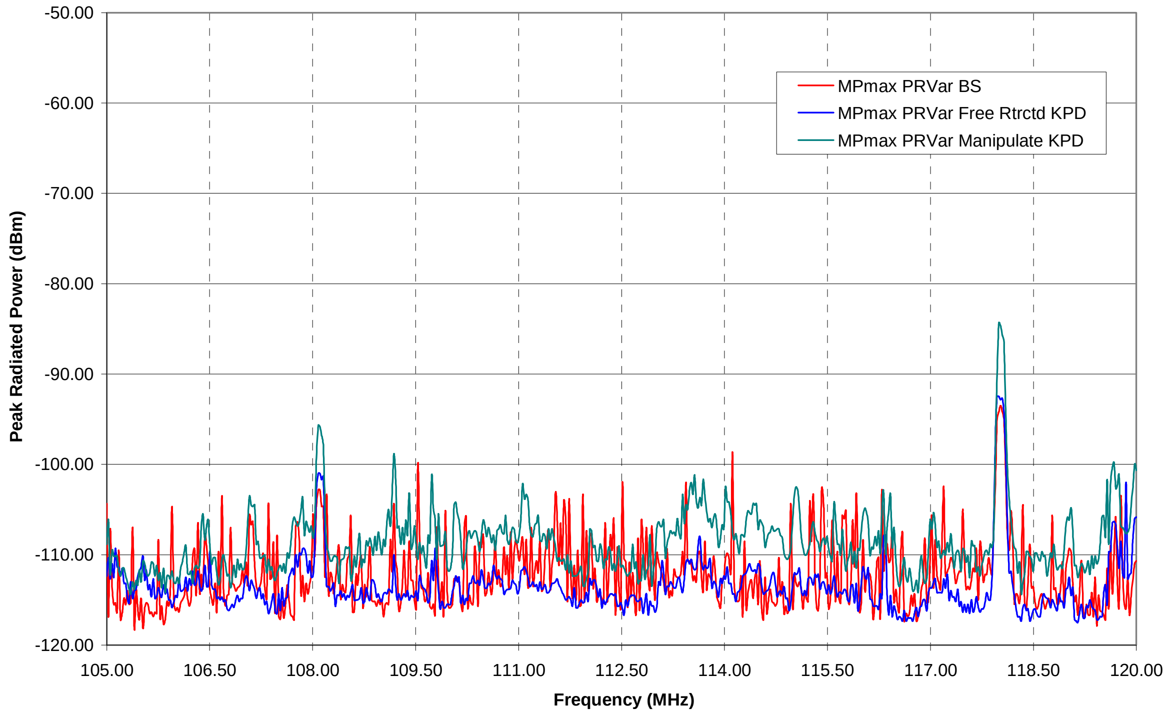

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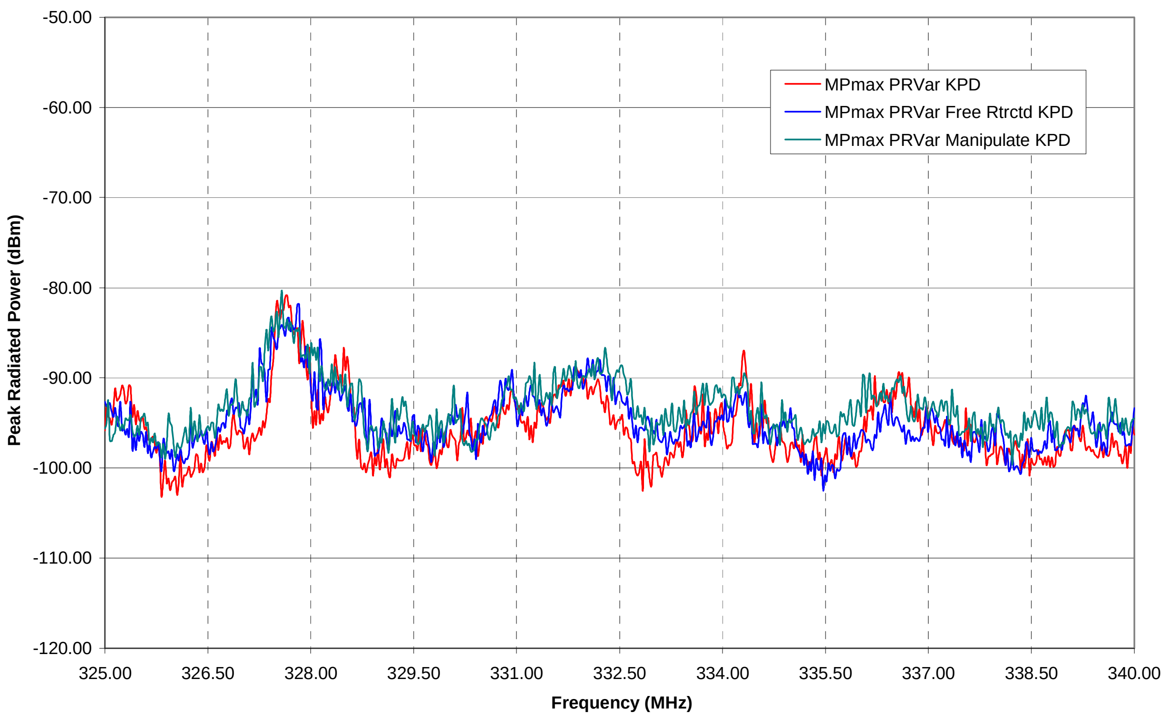

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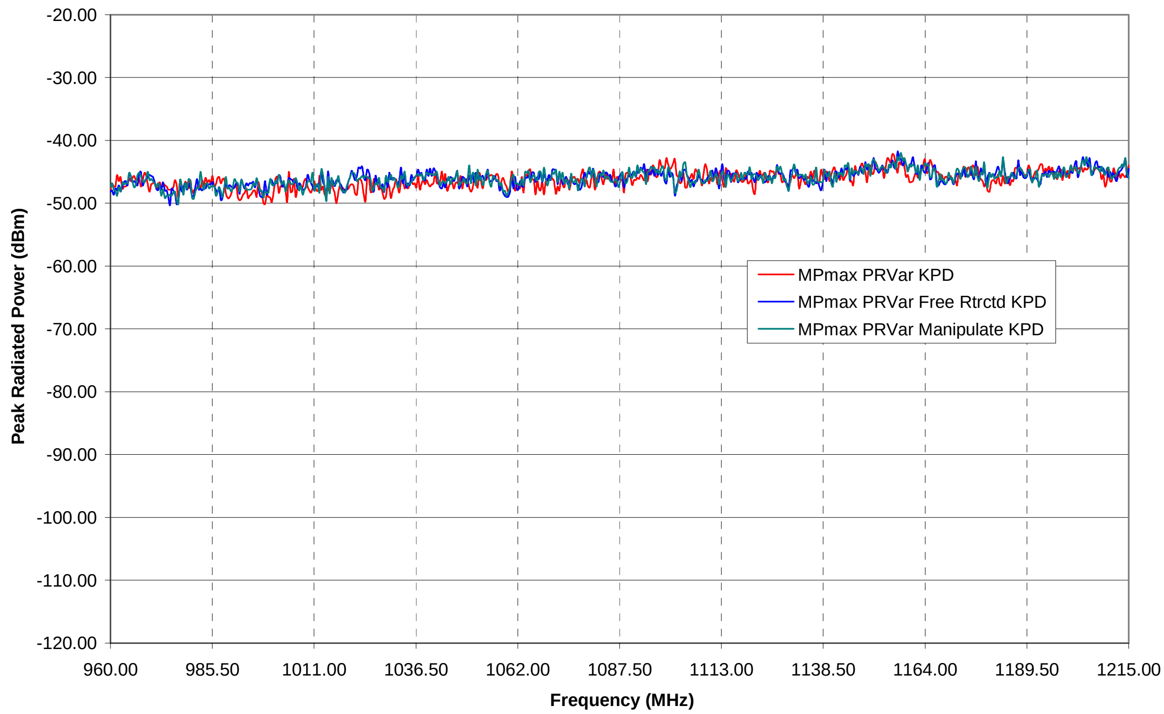

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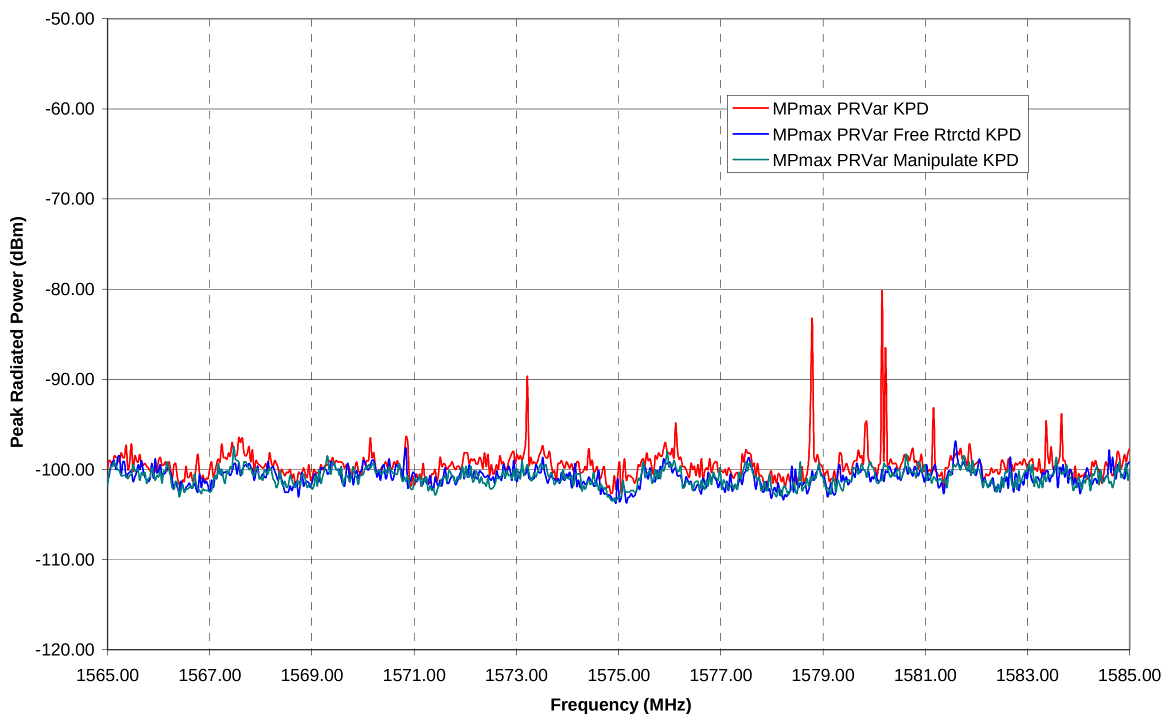

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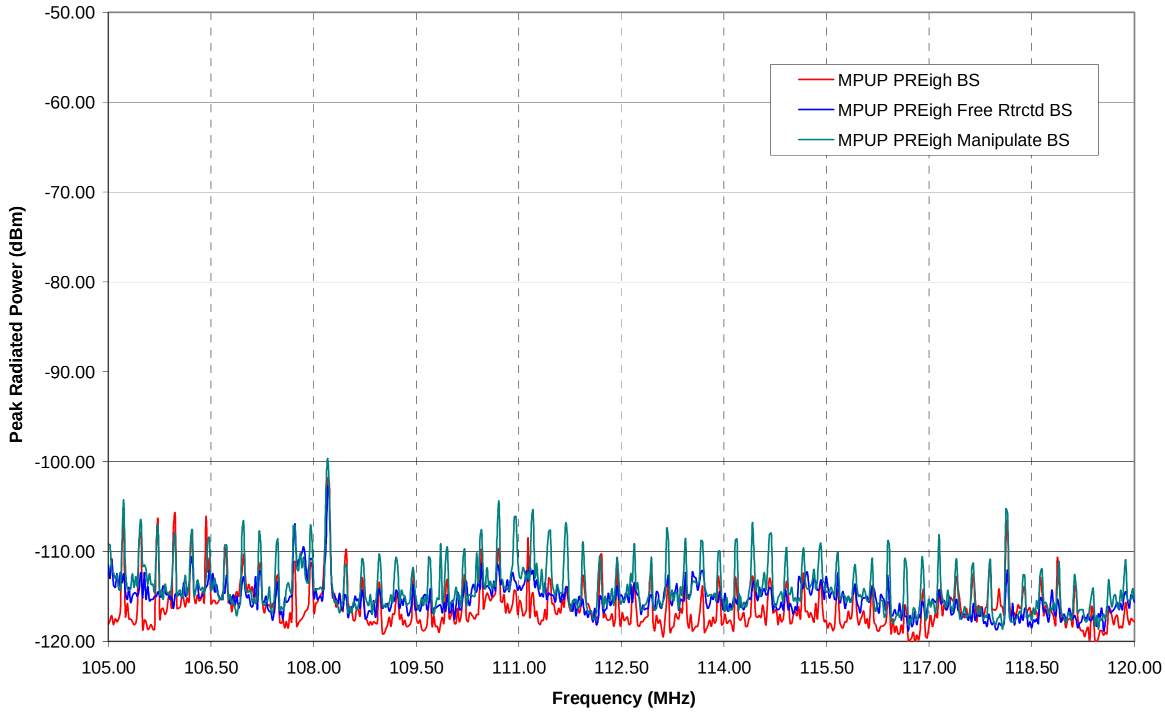

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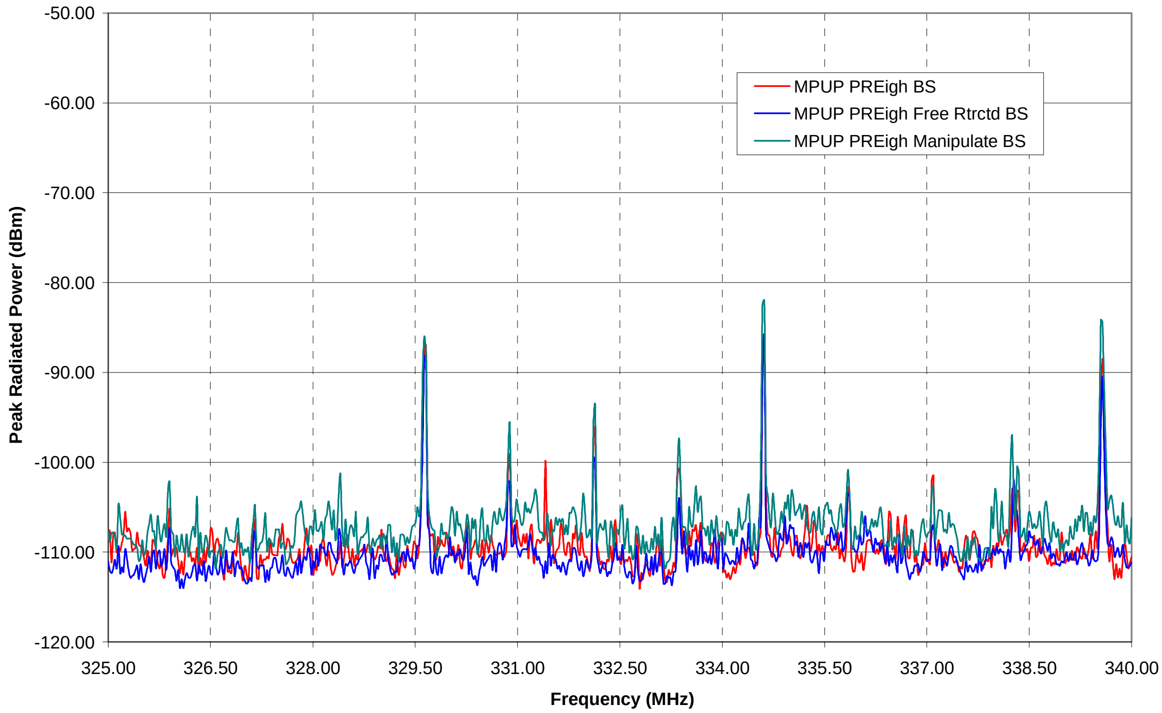

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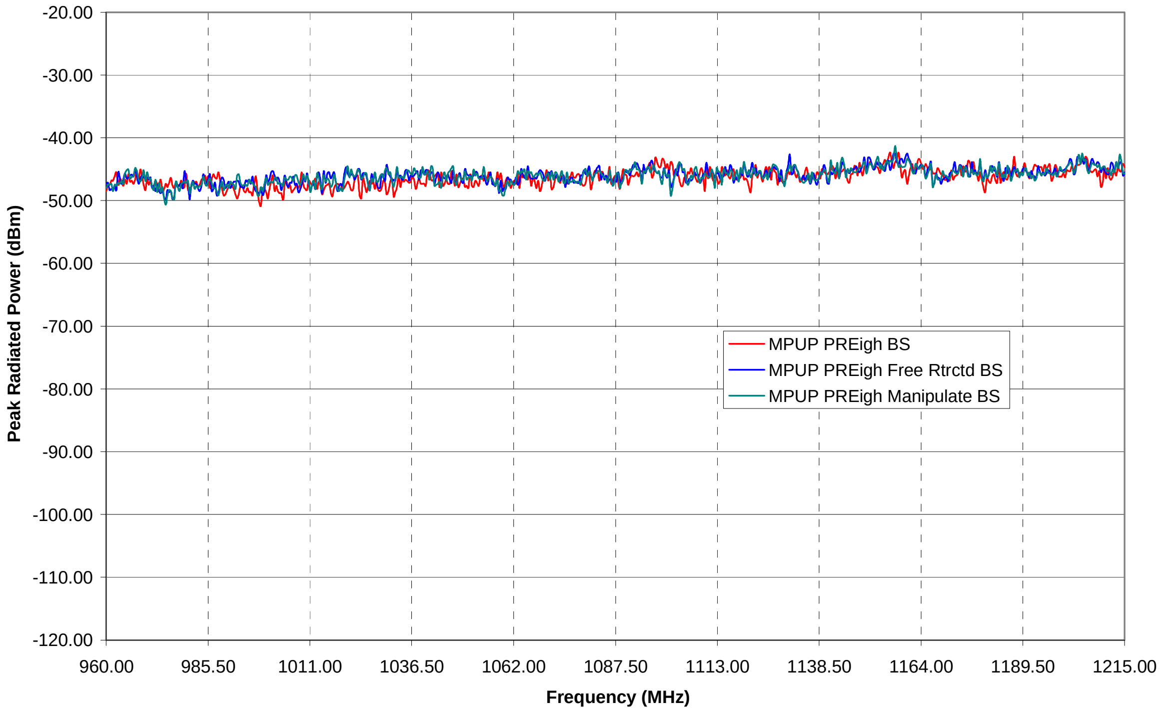

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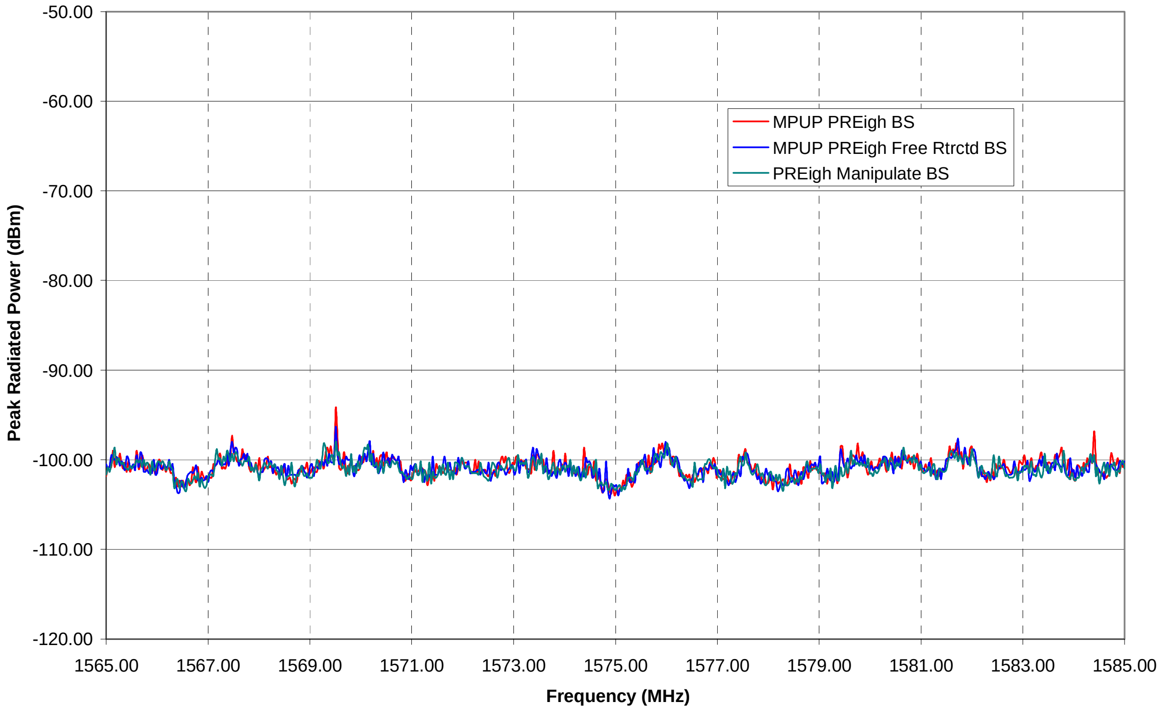

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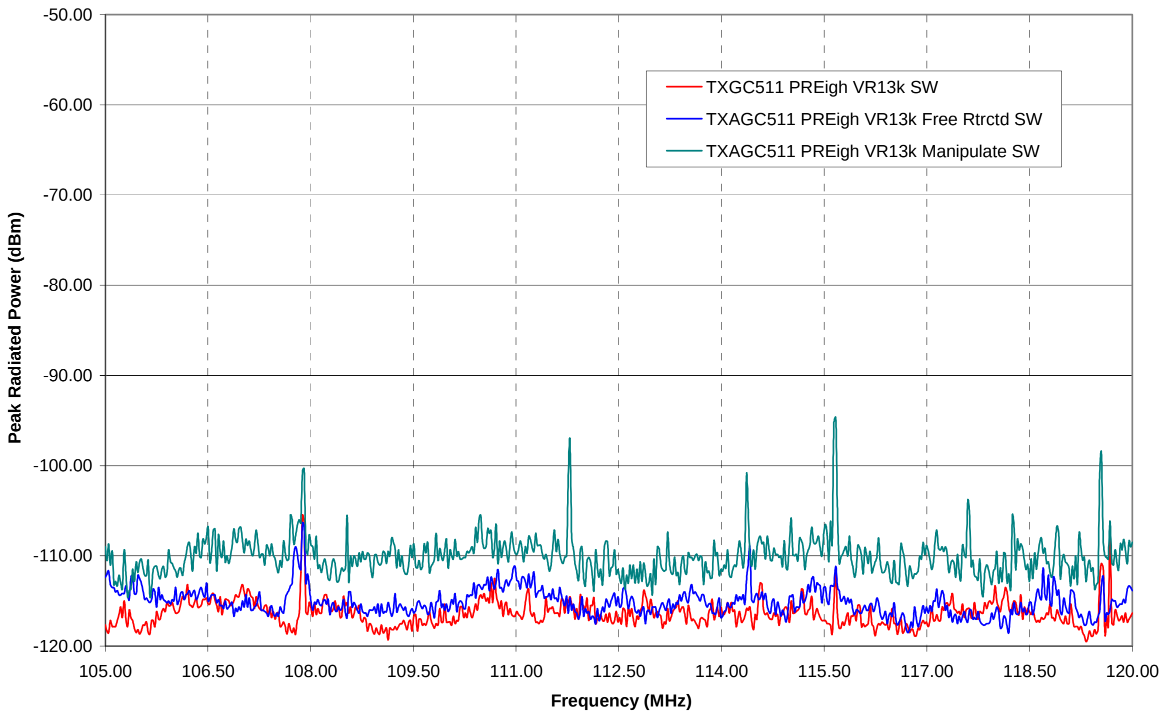

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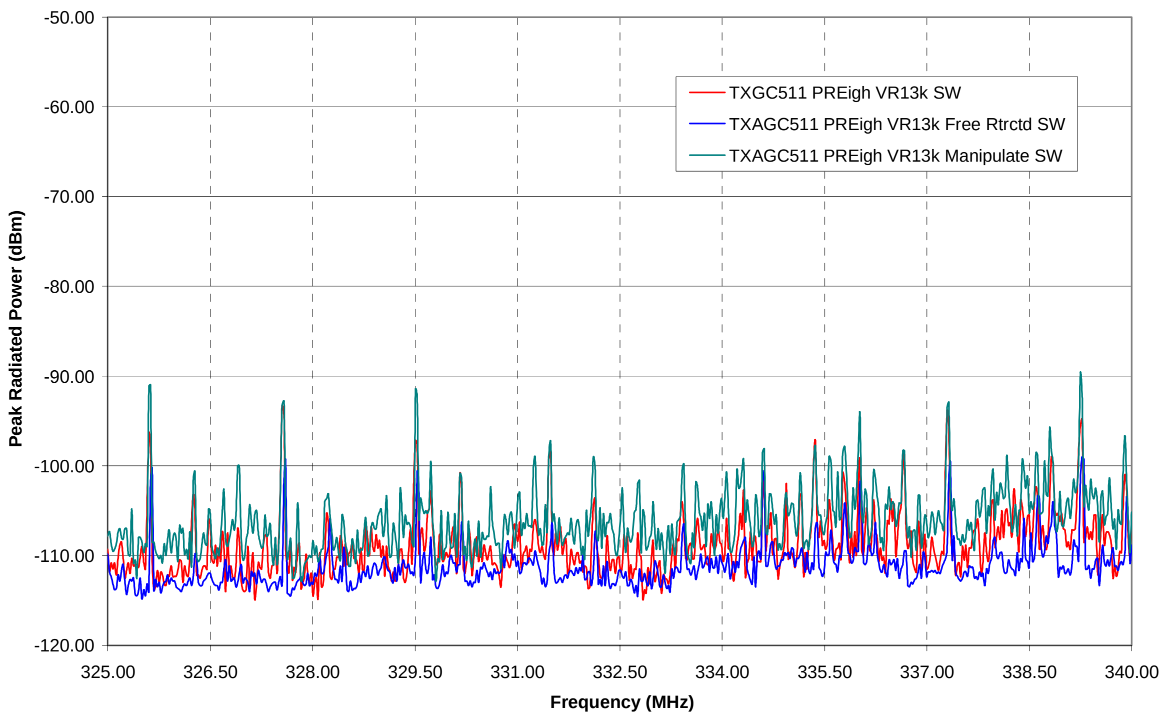

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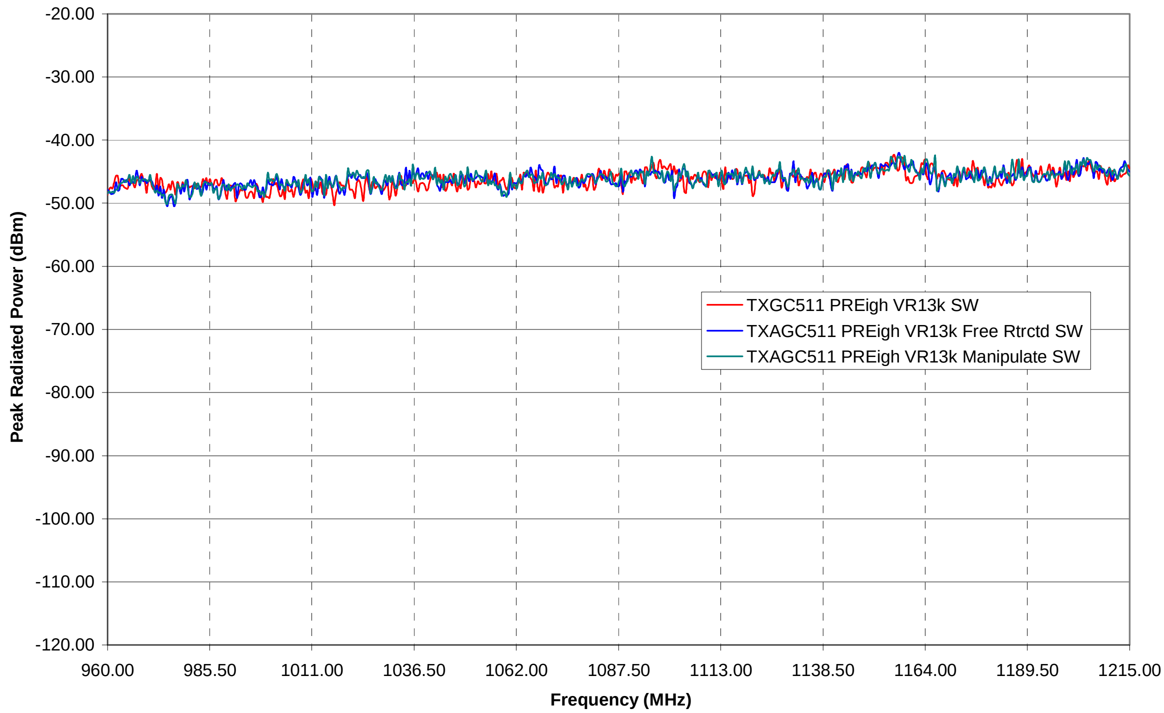

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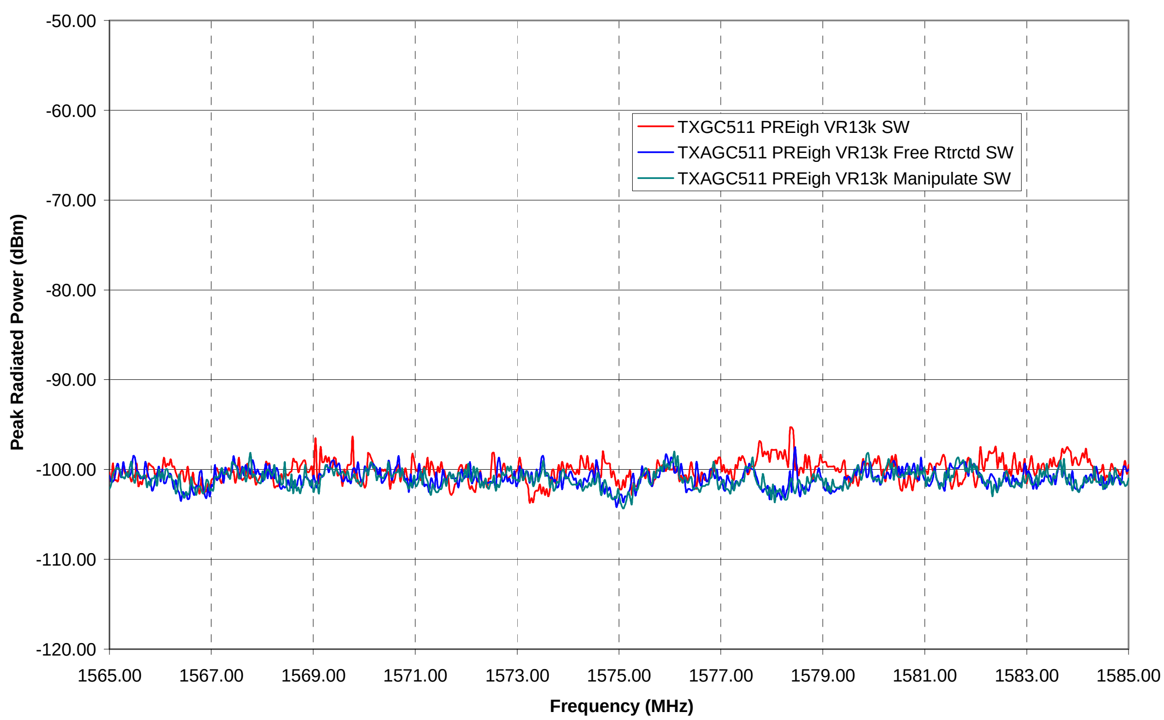

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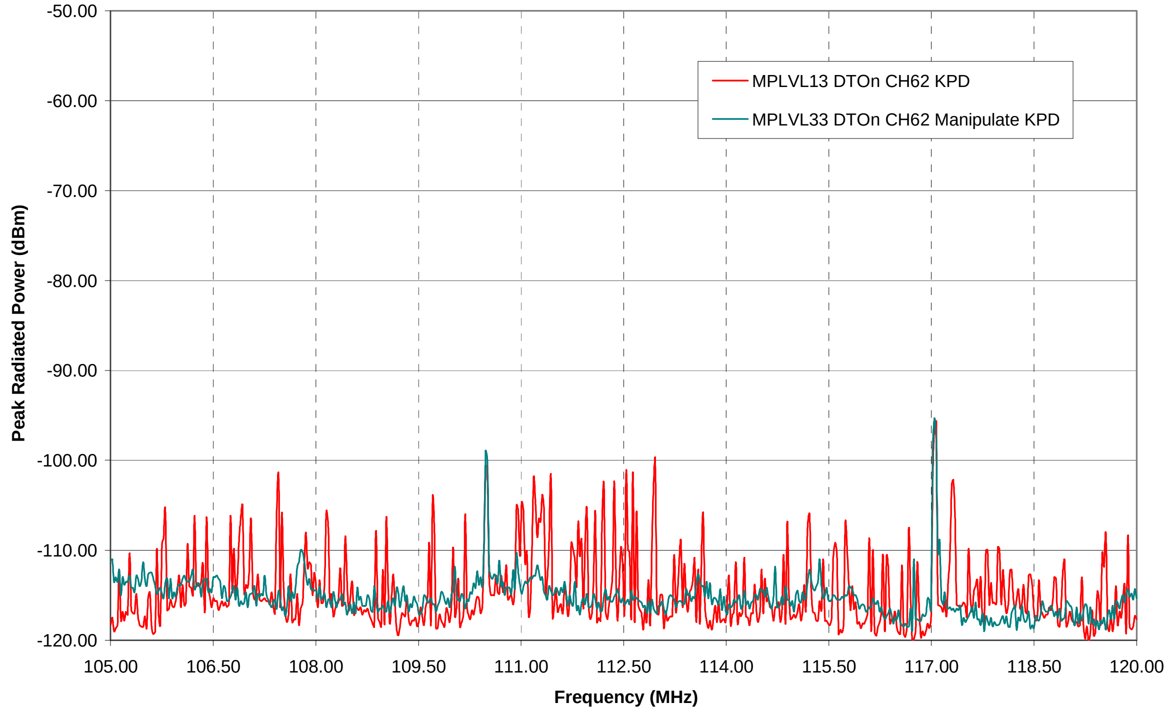

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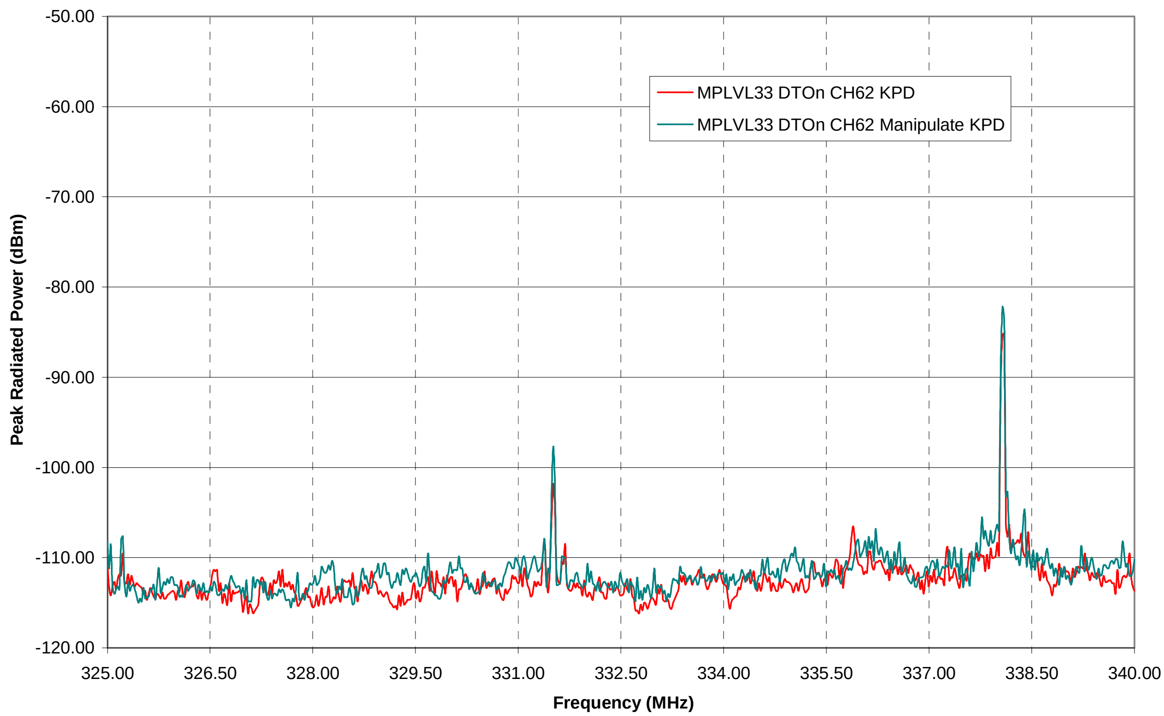

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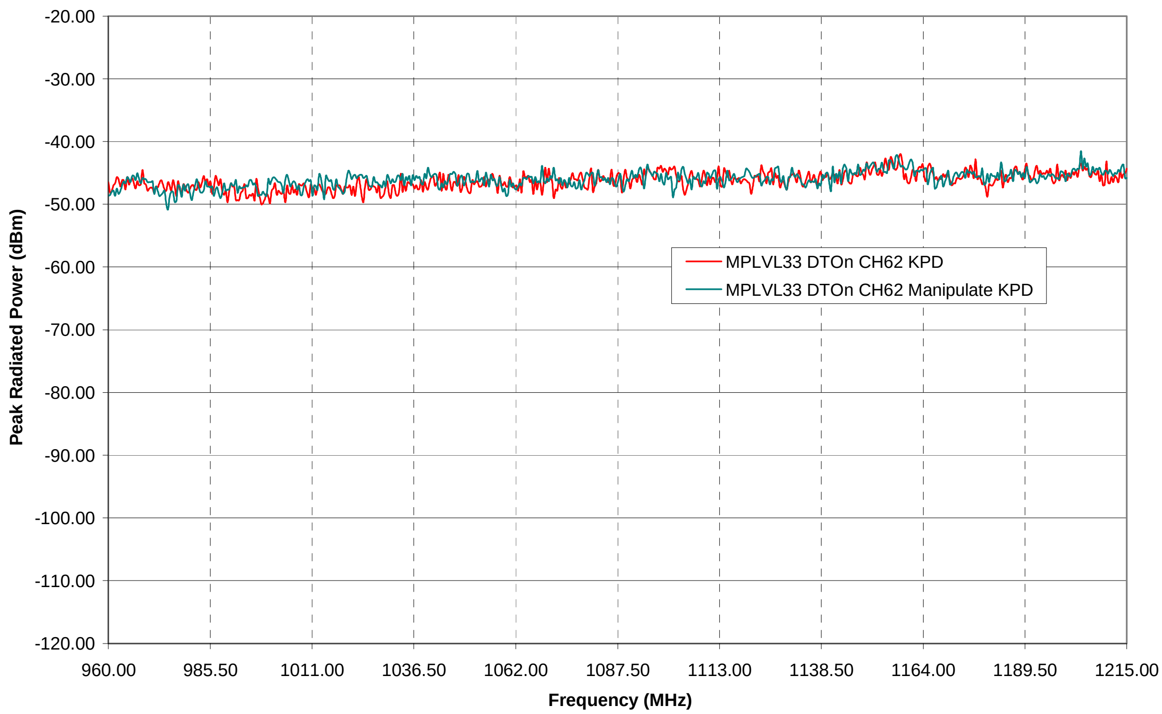

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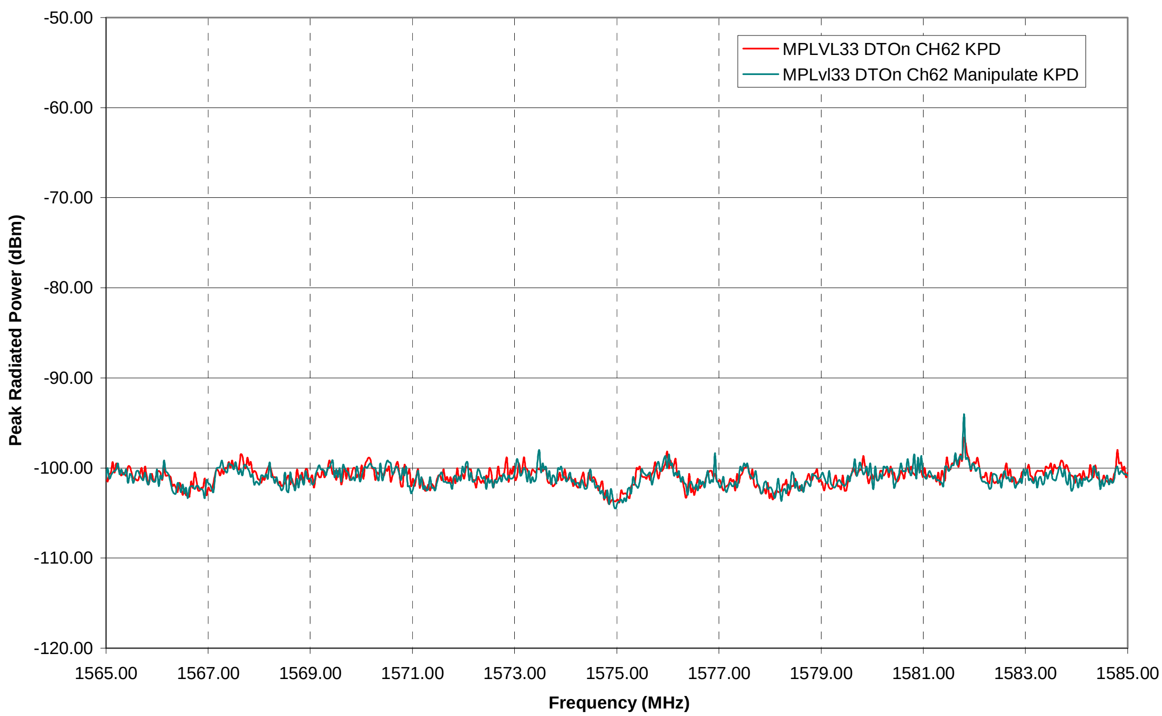

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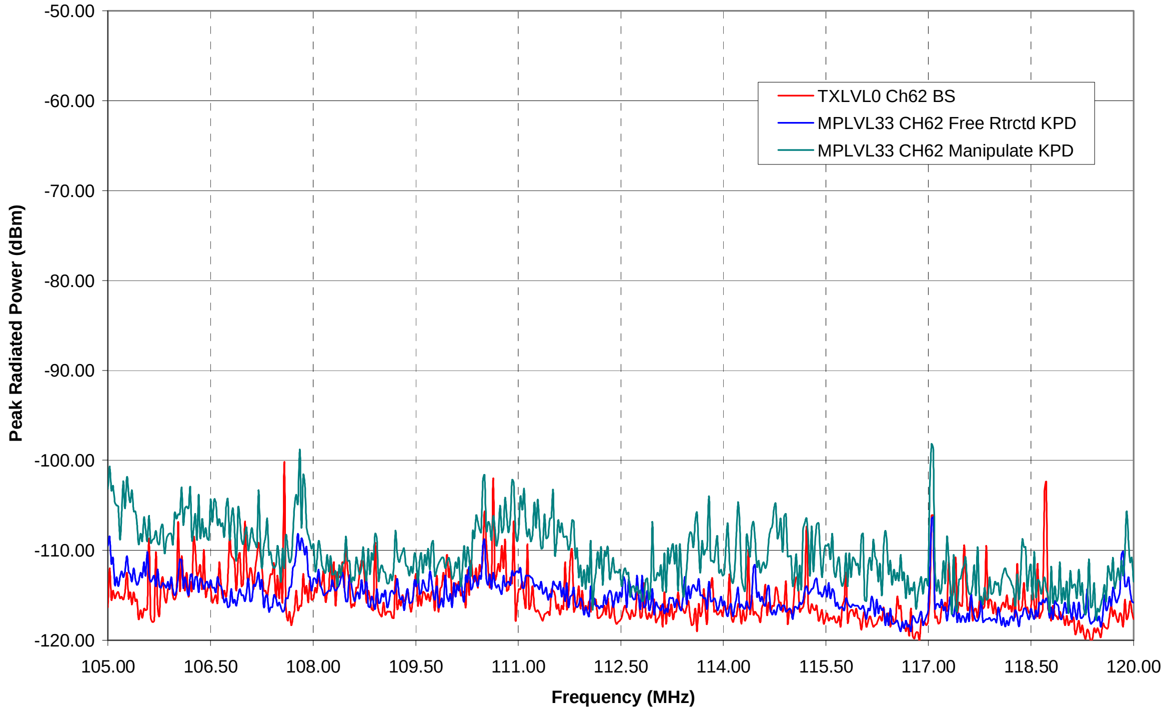

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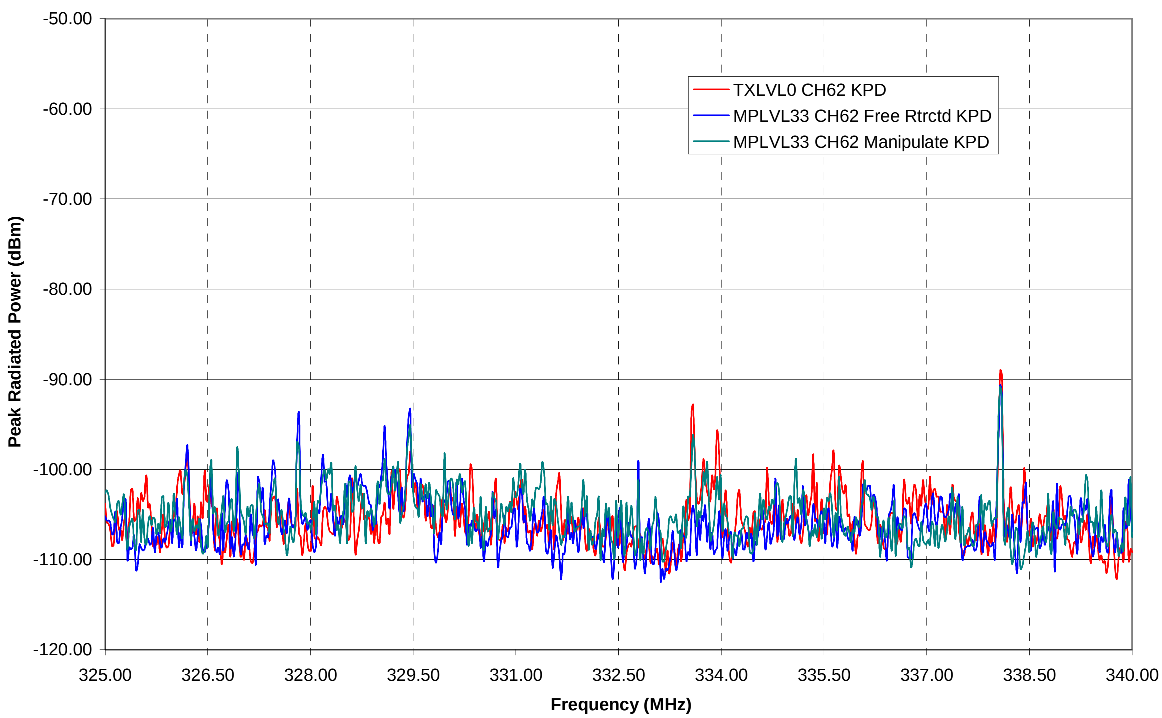

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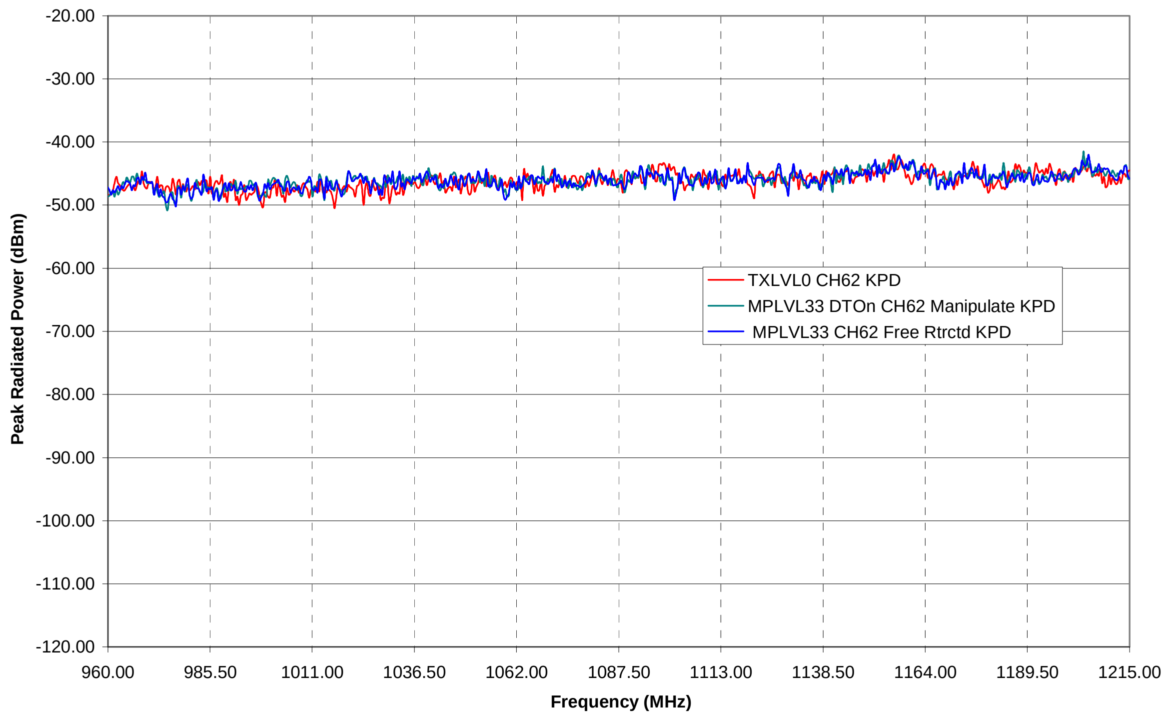

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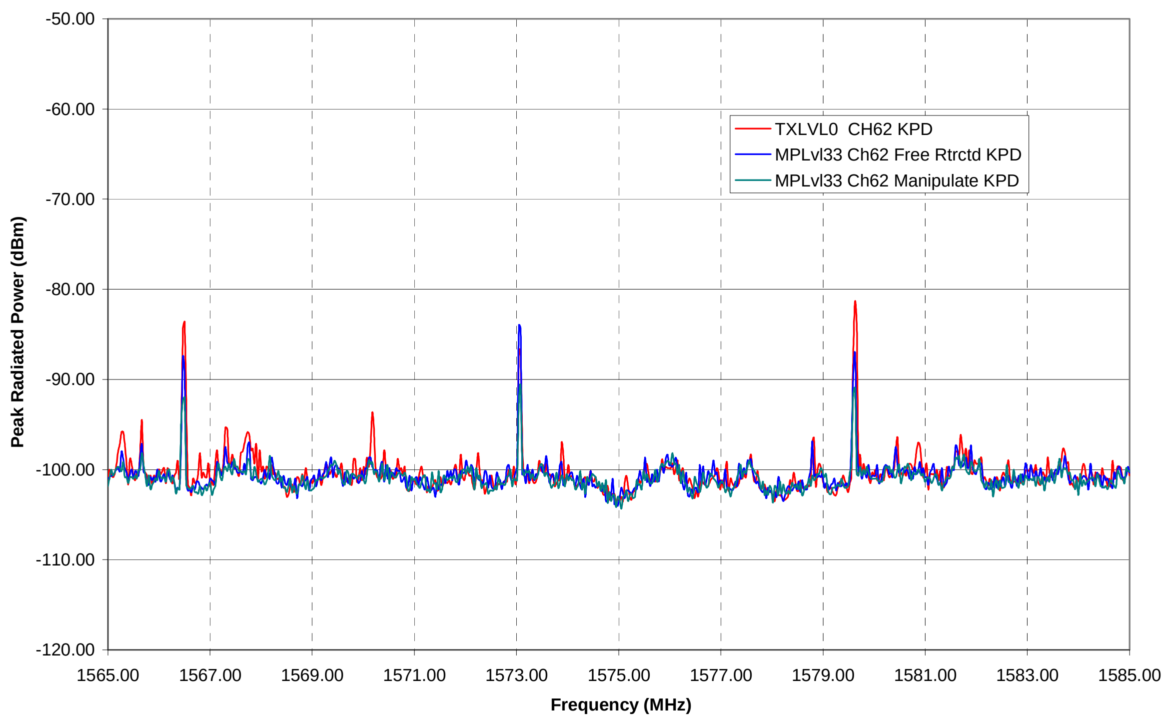

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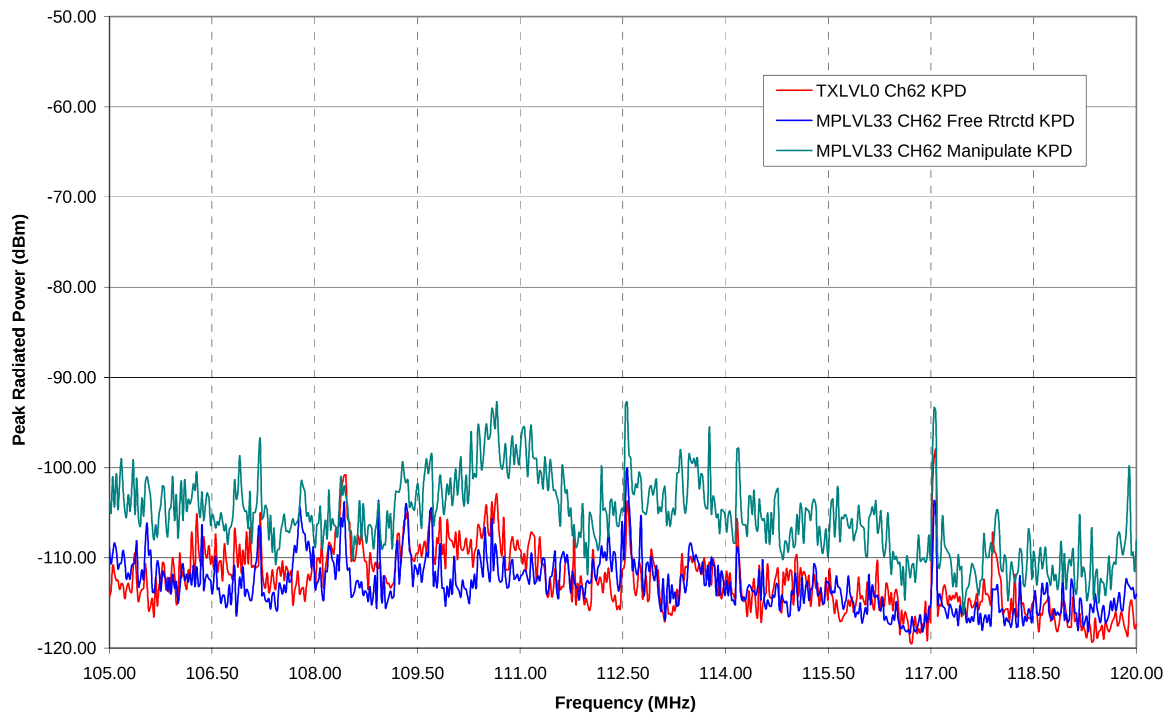

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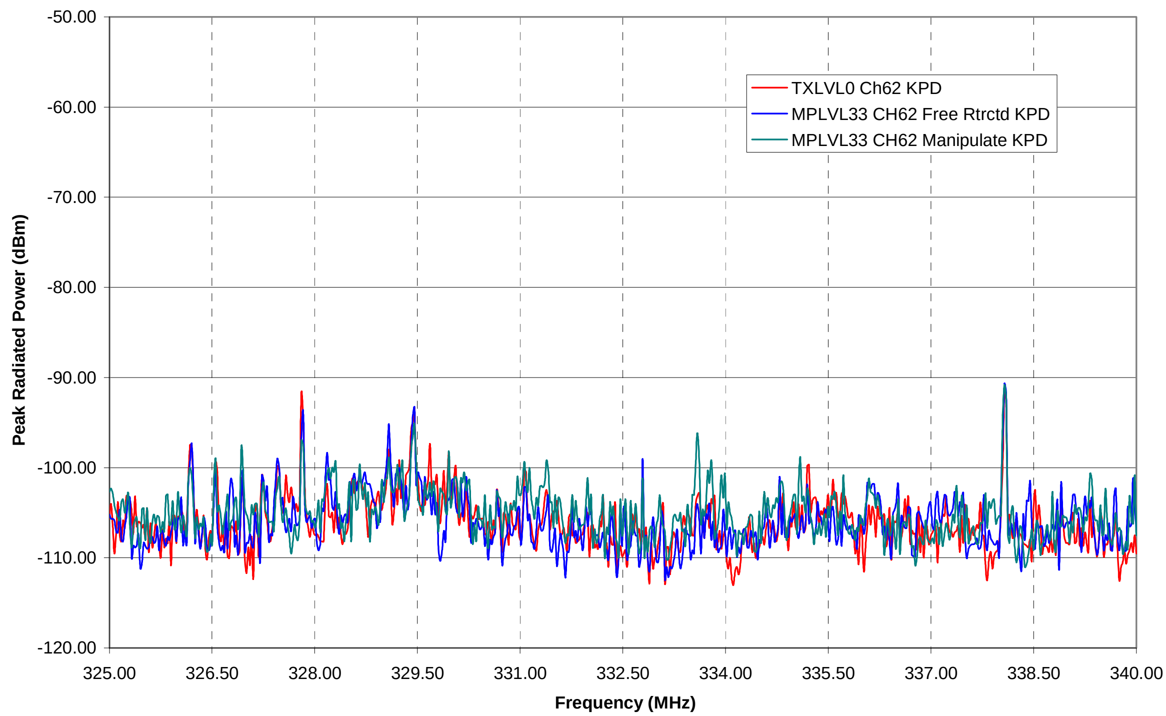

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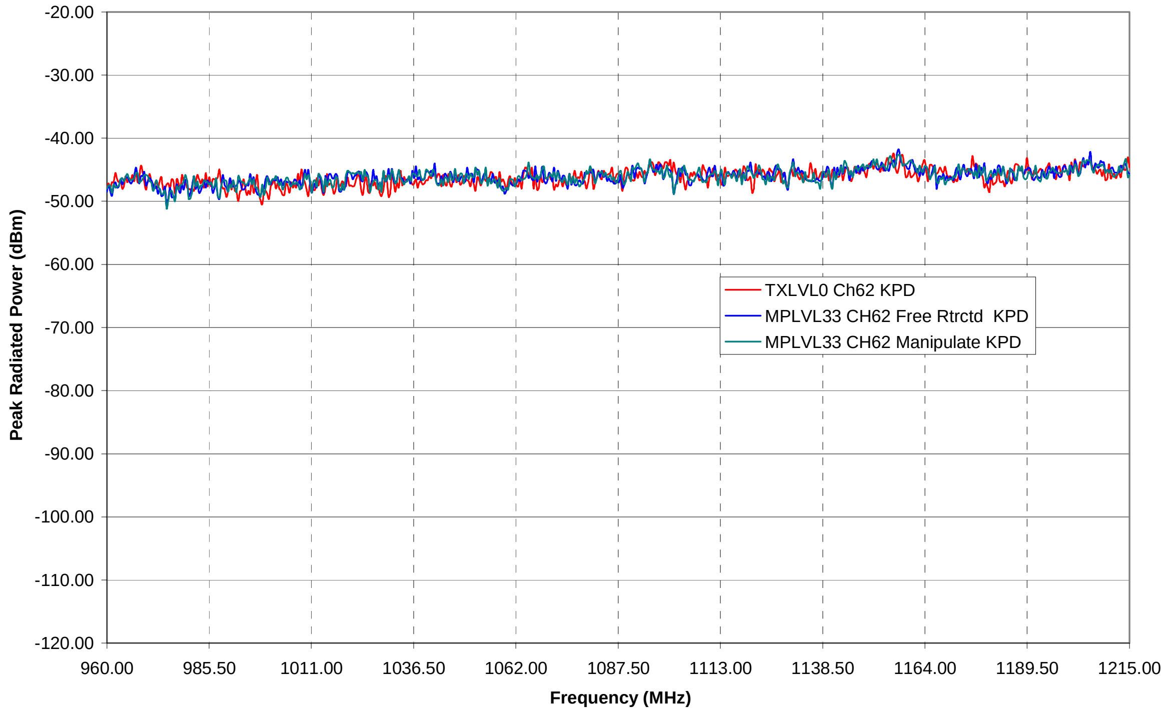

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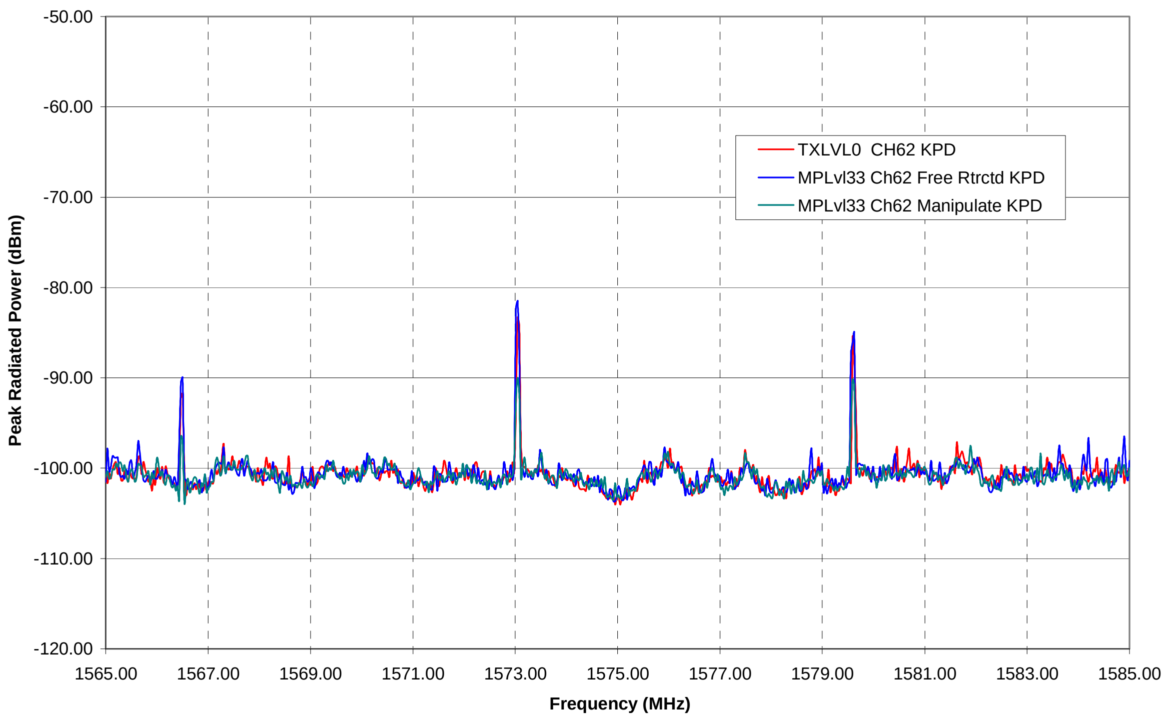

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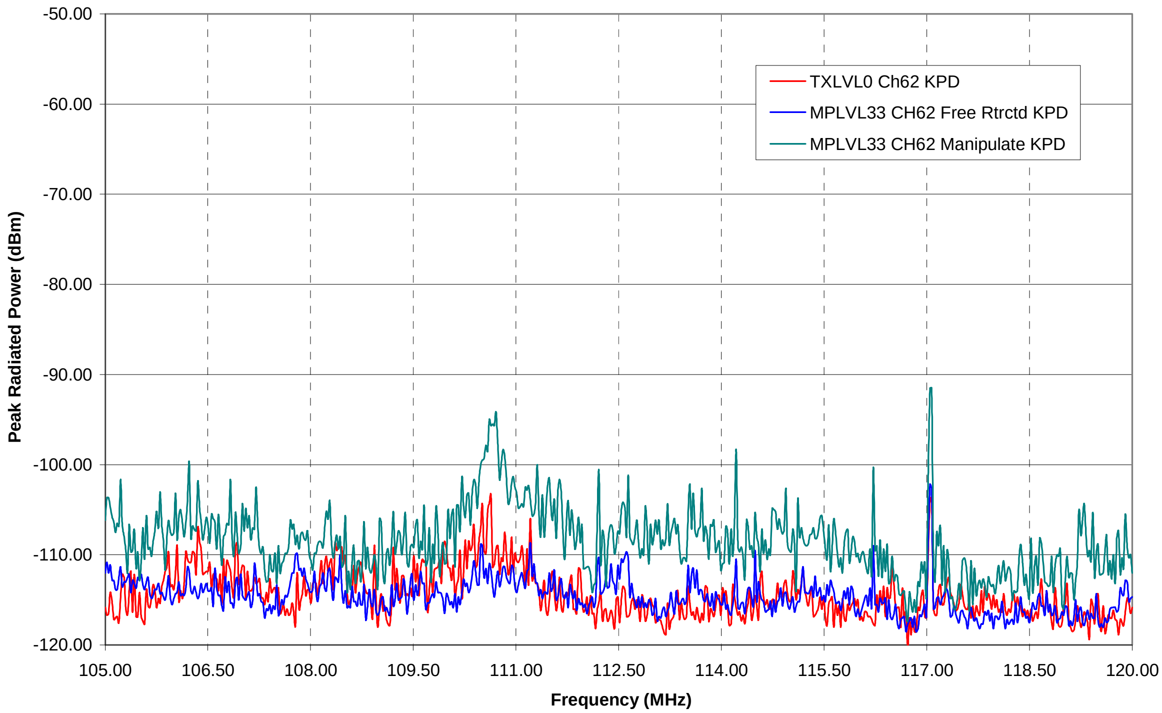

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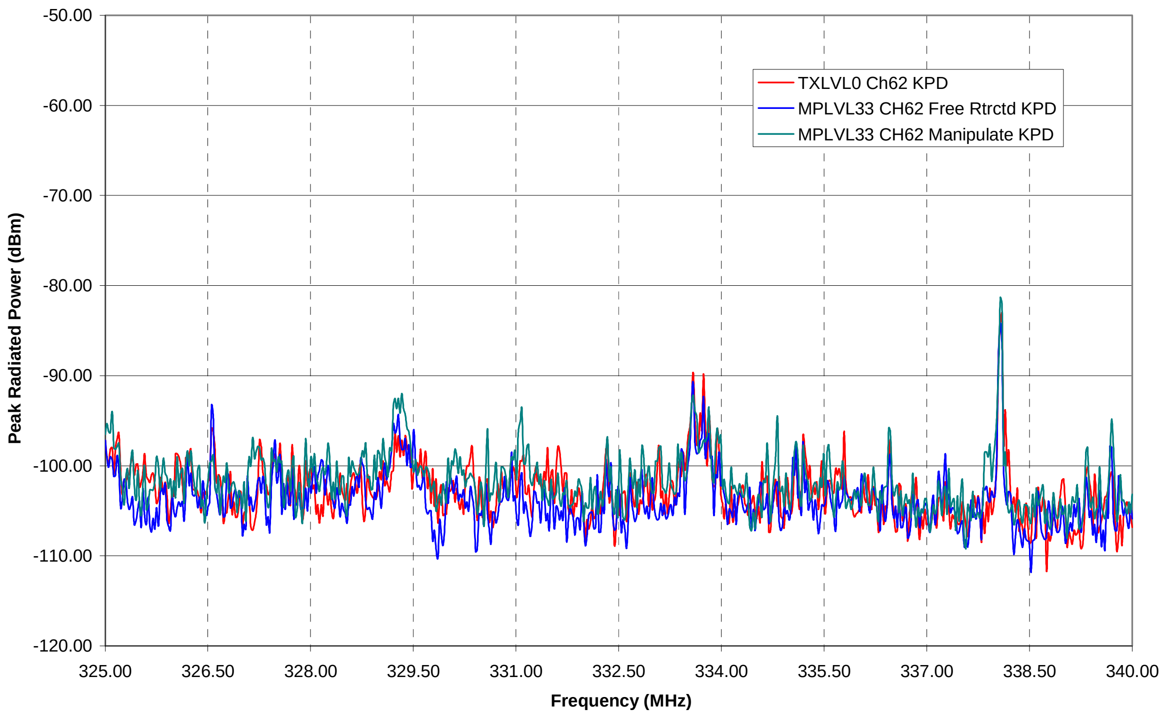

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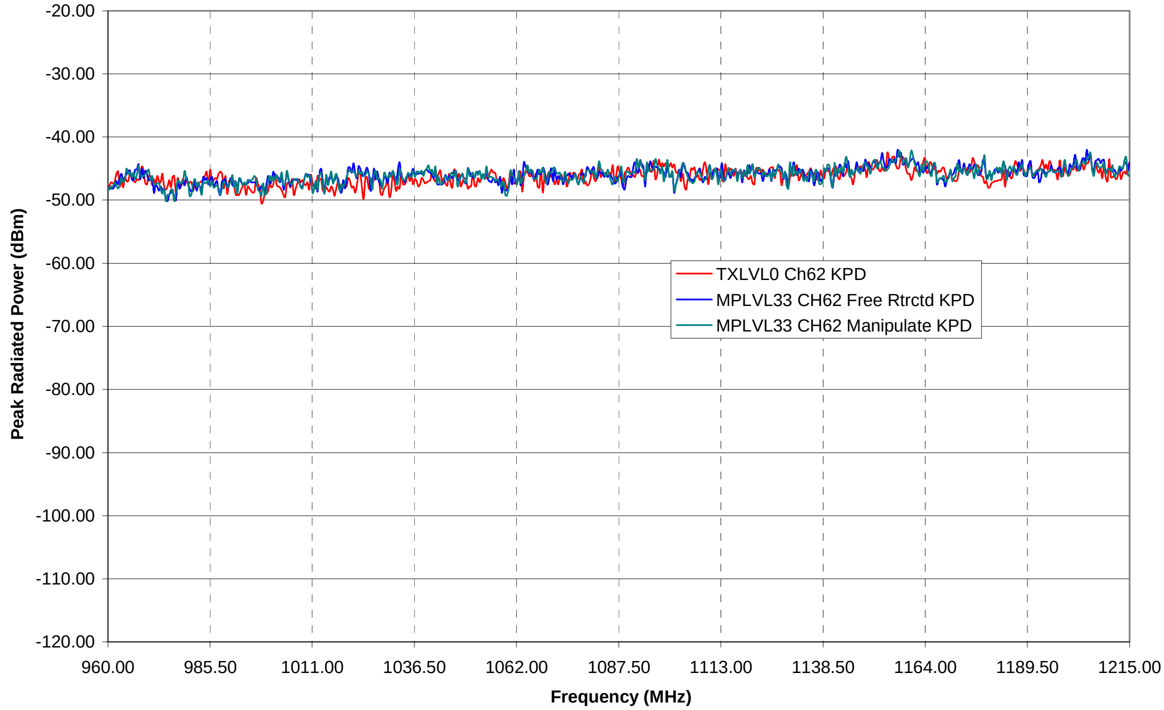

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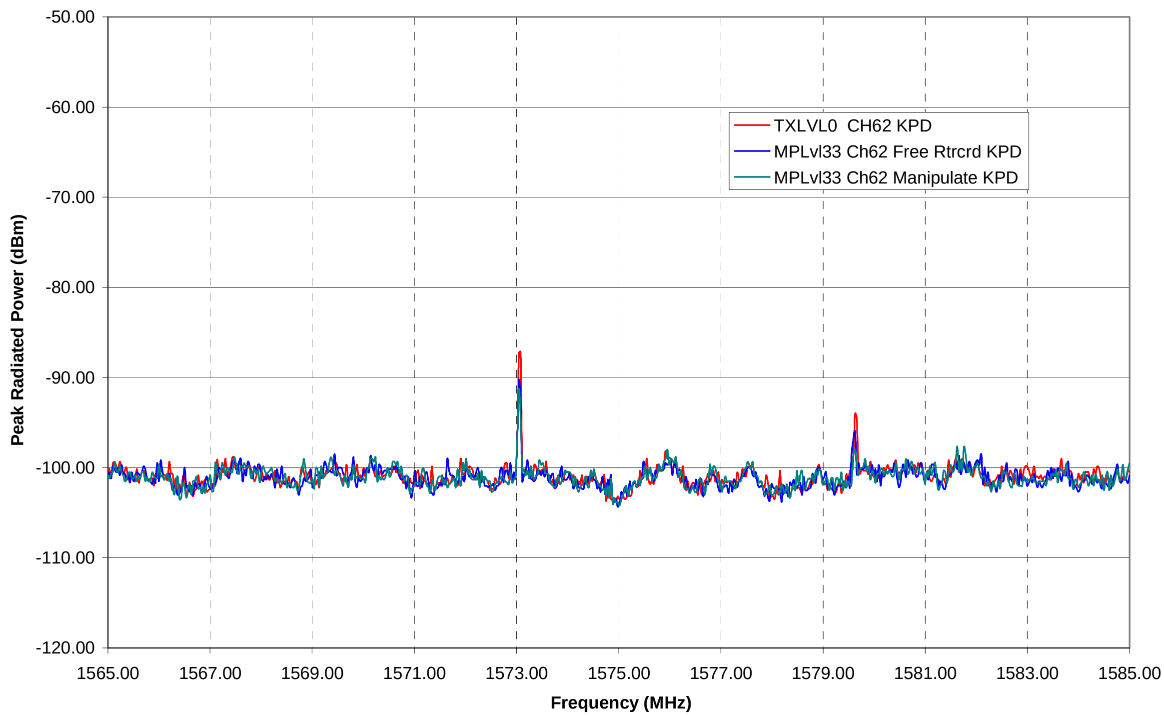

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14. ABSTRACT

To address the concern for cellular phone electromagnetic interference to aircraft radios, a radiated emission measurement process was developed for two dominant digital standards of wireless handsets. Spurious radiated emissions were efficiently characterized from devices tested in either a semi-anechoic or reverberation chamber, in terms of effective radiated power. Eight representative handsets (four from each digital standard) were commanded to operate while varying their radio transmitter parameters (power, modulation, etc.). This report provides a detailed description of the measurement process and resulting data, which may subsequently be used by others as a basis of consistent evaluation of other portable transmitters using a variety of wireless transmission protocols. Aircraft interference path loss and navigation radio interference threshold data from numerous reference documents, standards, and NASA partnerships were compiled. Using these data, a preliminary risk assessment is provided for wireless phone interference to aircraft Localizer, Glideslope, Very High Frequency Omni directional Range, and Global Positioning Satellite radio receivers on typical transport airplanes. The report identifies where existing data for device emissions, interference path loss, and navigation radio interference thresholds need to be extended for an accurate risk assessment for wireless transmitters in aircraft.

15. SUBJECT TERMS

Electromagnetic compatibility; Electromagnetic interference; Aviation; Portable electronic devices; Aircraft radios

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