3.4 Wireless Phone Measurement Results

This section reports the measurement results for the 17 GSM and 16 CDMA phones. The measurement process used and the test mode selections were reported in Sections 3.2 and 3.3. The devices tested are shown in Tables 3.3-3, 3.3-4 and Figures 3.3-4, 3.3-5.

Due to the large volume of collected data, the results in this section are the final emission envelope for each of the phones. Each phone emission envelope is determined by retaining the maximum value at each frequency for all phone test modes. The phone test modes include idle mode, voice mode, various data rates, frequency channels, and operating bands (cellular or PCS).

The results are grouped into CDMA and GSM subsections, due to different test modes used for the two technologies. Emissions in each measurement band are organized in groups of five or six phones for ease of viewing and comparisons. In addition, a noise floor is plotted which represents the instrument's (spectrum analyzer's) noise level which was processed and calibrated in the same way as the data. This noise floor establishes the sensitivity of the measurement system. Sixth harmonics of the GSM and CDMA cellular band transmissions are identified in the graphs for Band 5. Appendices A and B show additional test result details.

Section 3.4.1 reports the results for the GSM phones, and Section 3.4.2 for the CDMA phones. Section 3.4.3 further reduces the data reported in Sections 3.4.1, 3.4.2, Appendix A and Appendix B by presenting scattered plots of the peak emission values for each phone operating in voice mode, data mode, cellular band and PCS band. These summary charts help to quickly identify phones that have certain characteristics, such as large emission difference between cellular versus PCS band operations.

In most cases, phone emission levels were significantly lower in idle modes (with and without BSS signal) than in active modes. Idle-mode emissions were usually not observed above the measurement noise floor. The exceptions included three phones that had their maximum idle modes emissions as high as their active mode emissions. Band 3 and Band 5 were the measurement bands in these cases. However, this finding is still preliminary due to the limited number of idle modes considered. In any case, the idle mode emissions were included in determining the phone maximum emission results presented in 3.4.1 and 3.4.2.

3.4.1 GSM/GPRS phones

Band 1

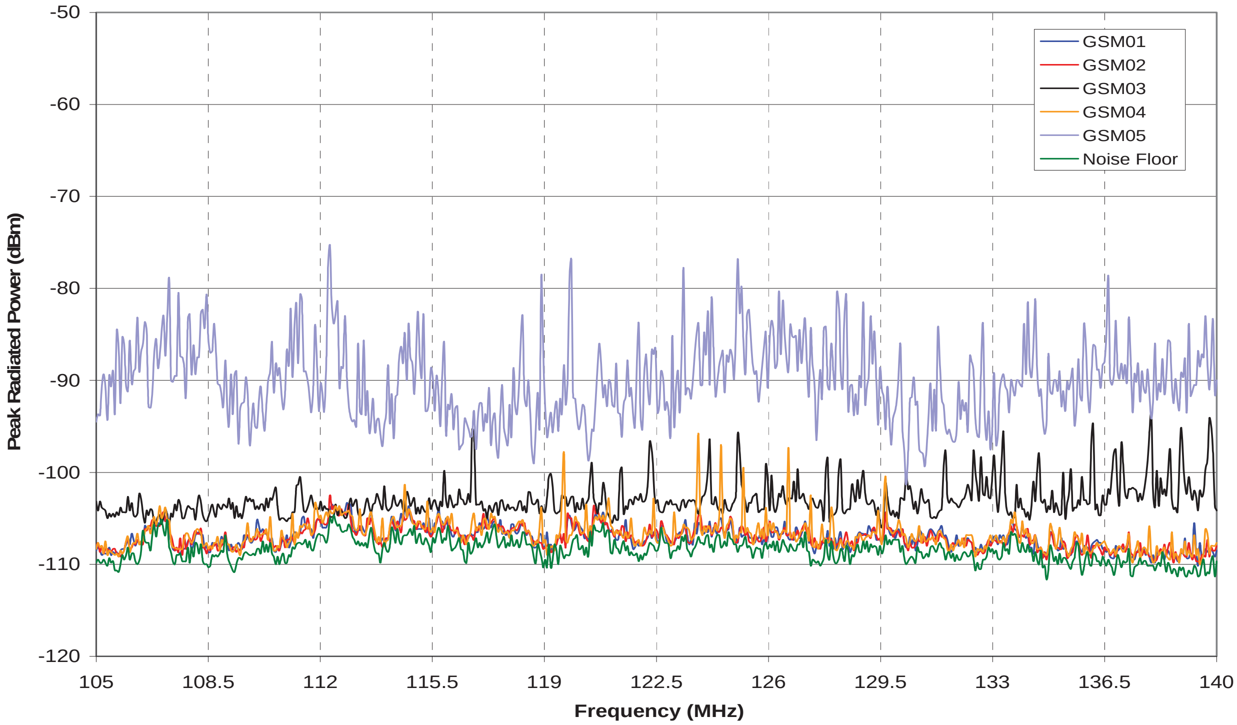

Figure 3.4-1: Individual phone emission envelopes. GSM phones 1 through 5. Band 1.

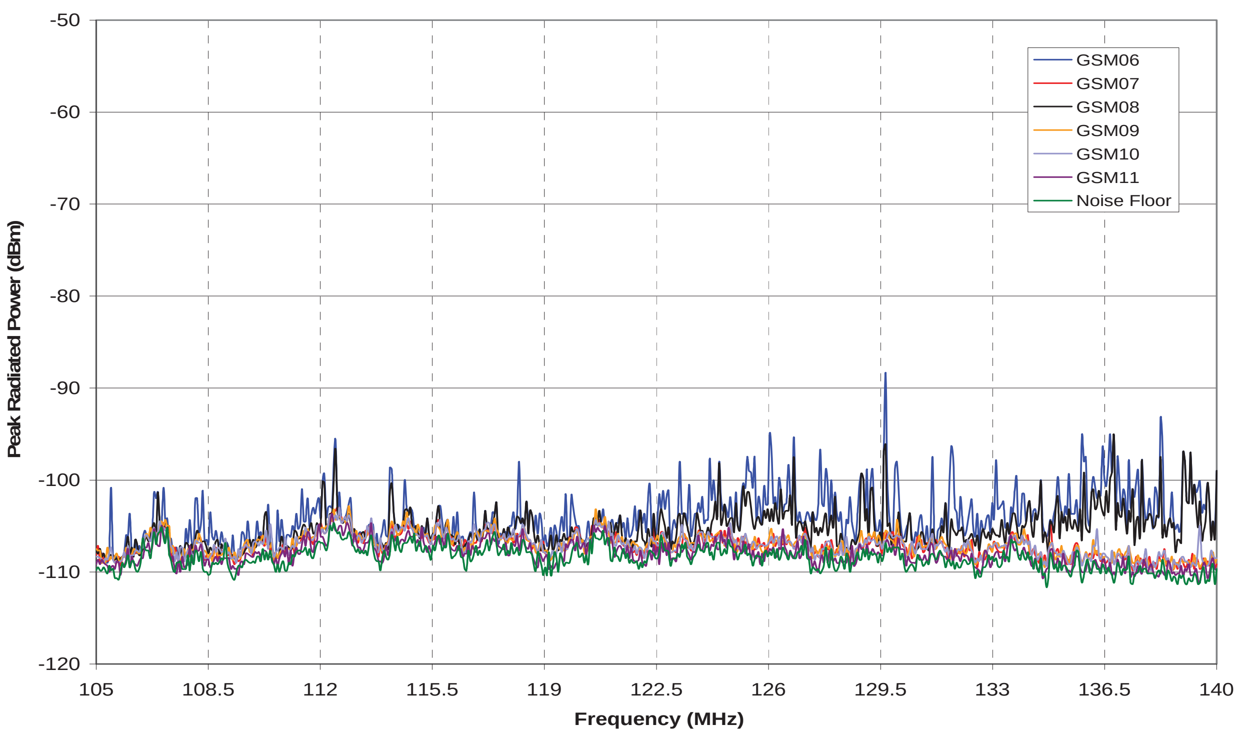

Figure 3.4-2: Individual phone emission envelopes. GSM phones 6 through 11. Band 1.

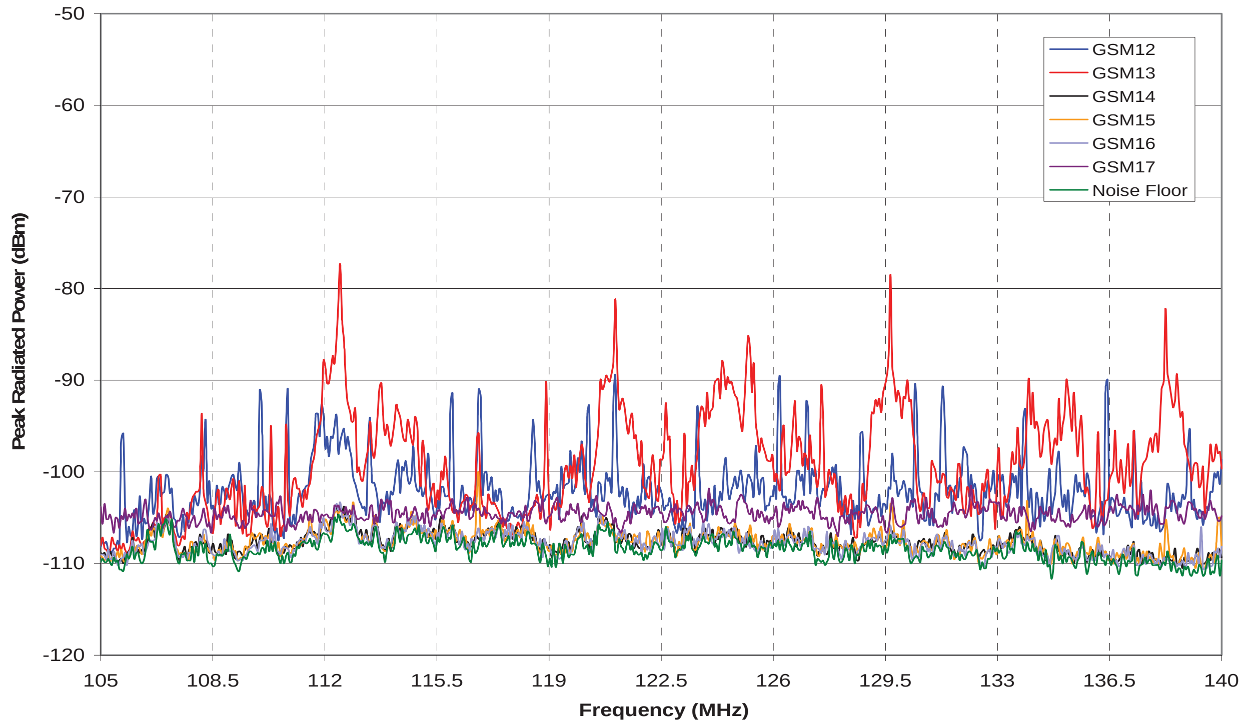

Figure 3.4-3: Individual phone emission envelopes. GSM phones 12 through 17. Band 1.

Band 2

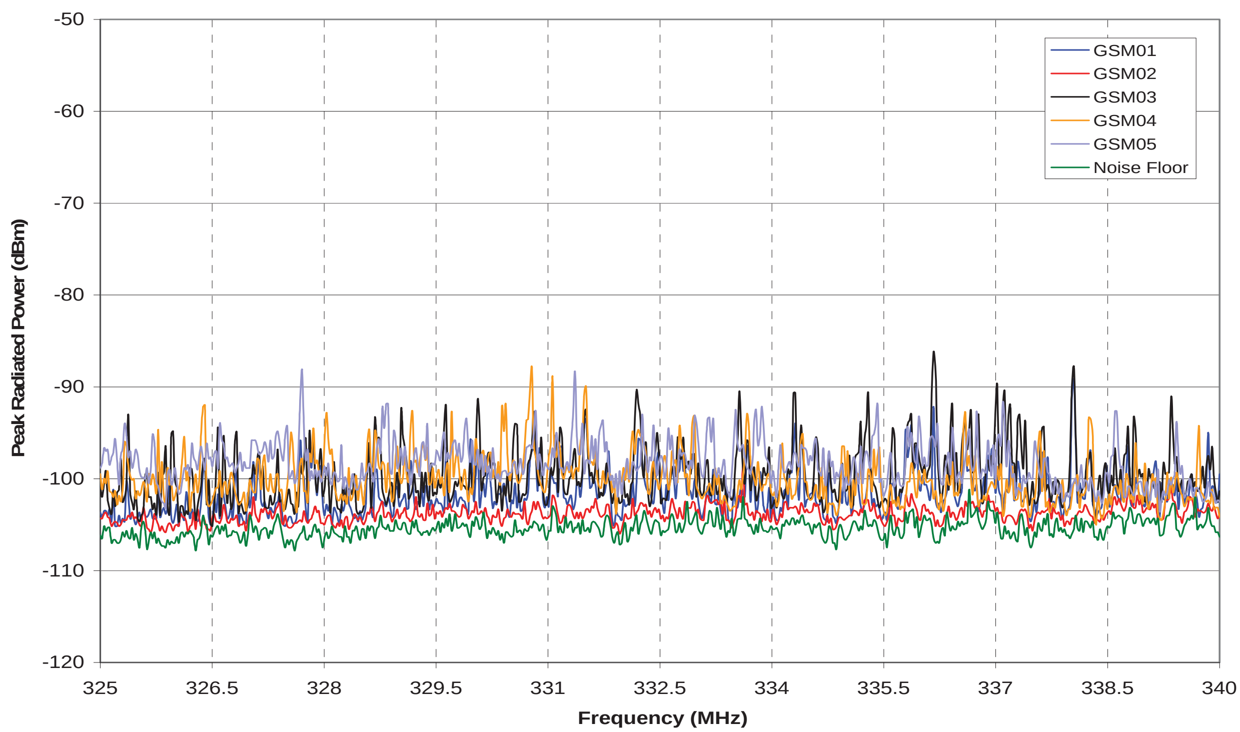

Figure 3.4-4: Individual phone emission envelopes. GSM phones 1 through 5. Band 2.

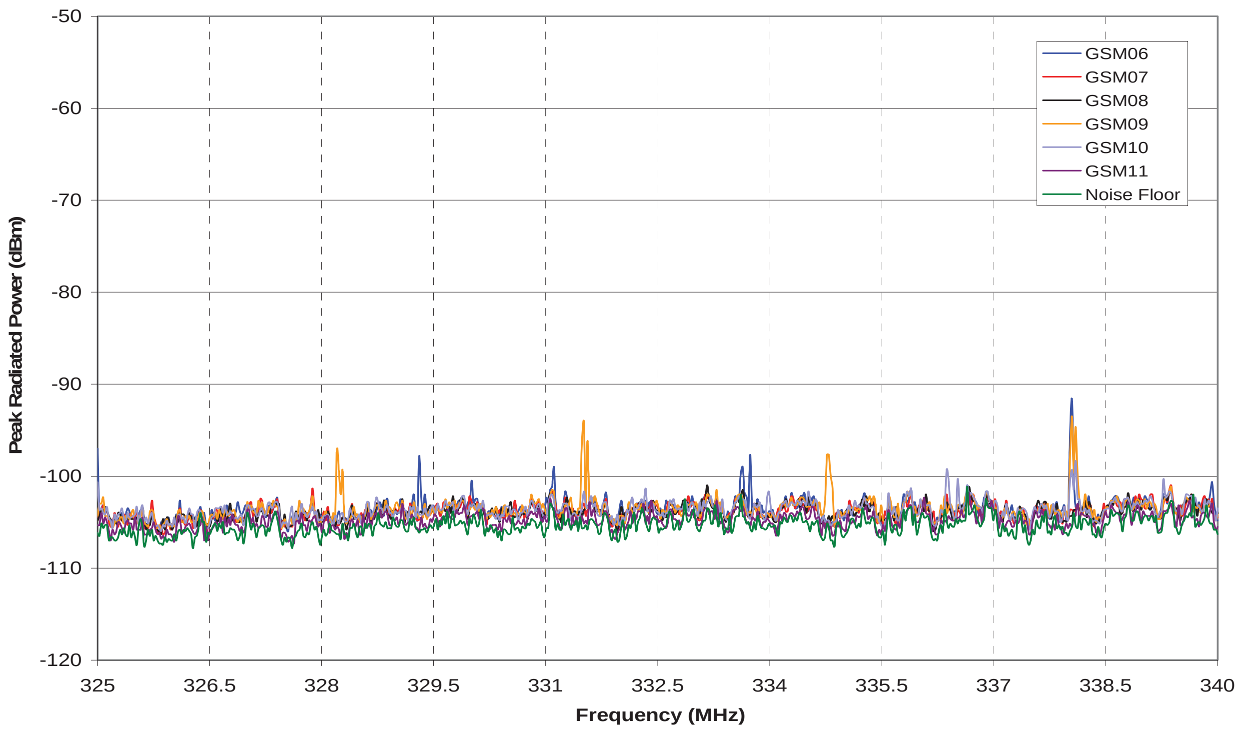

Figure 3.4-5: Individual phone emission envelopes. GSM phones 6 through 11. Band 2.

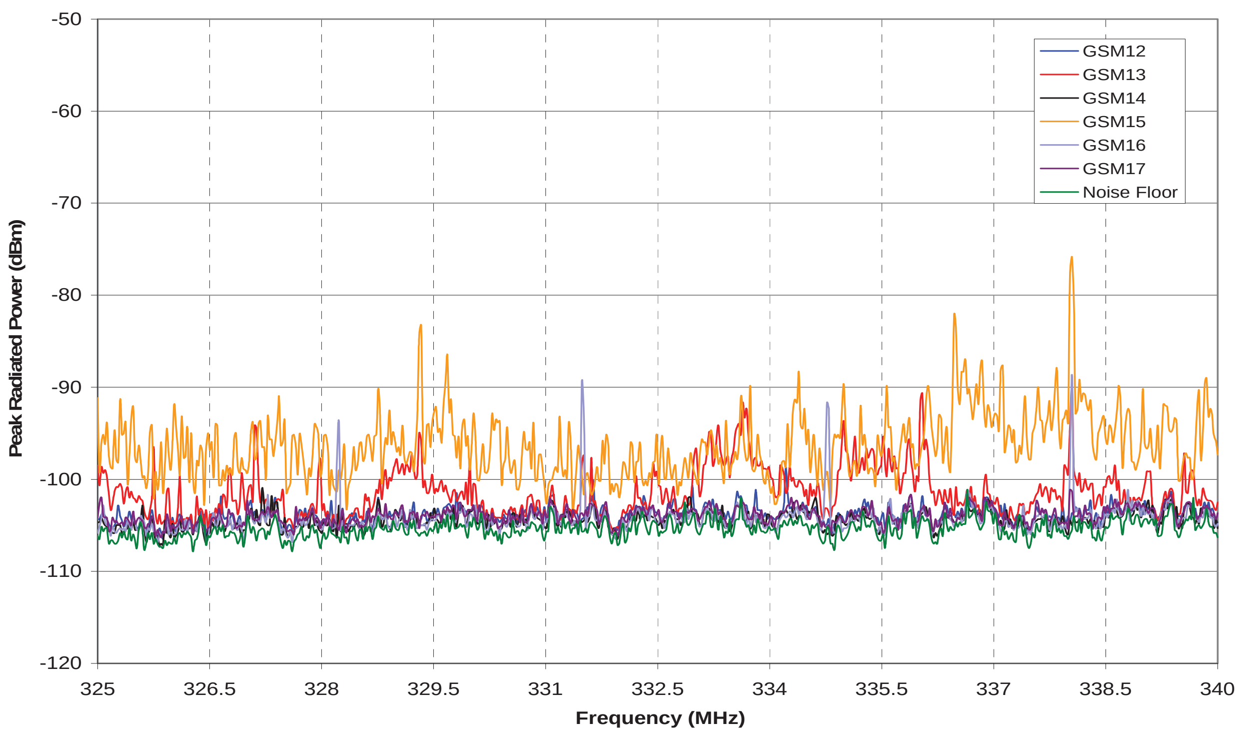

Figure 3.4-6: Individual phone emission envelopes. GSM phones 12 through 17. Band 2.

Band 3

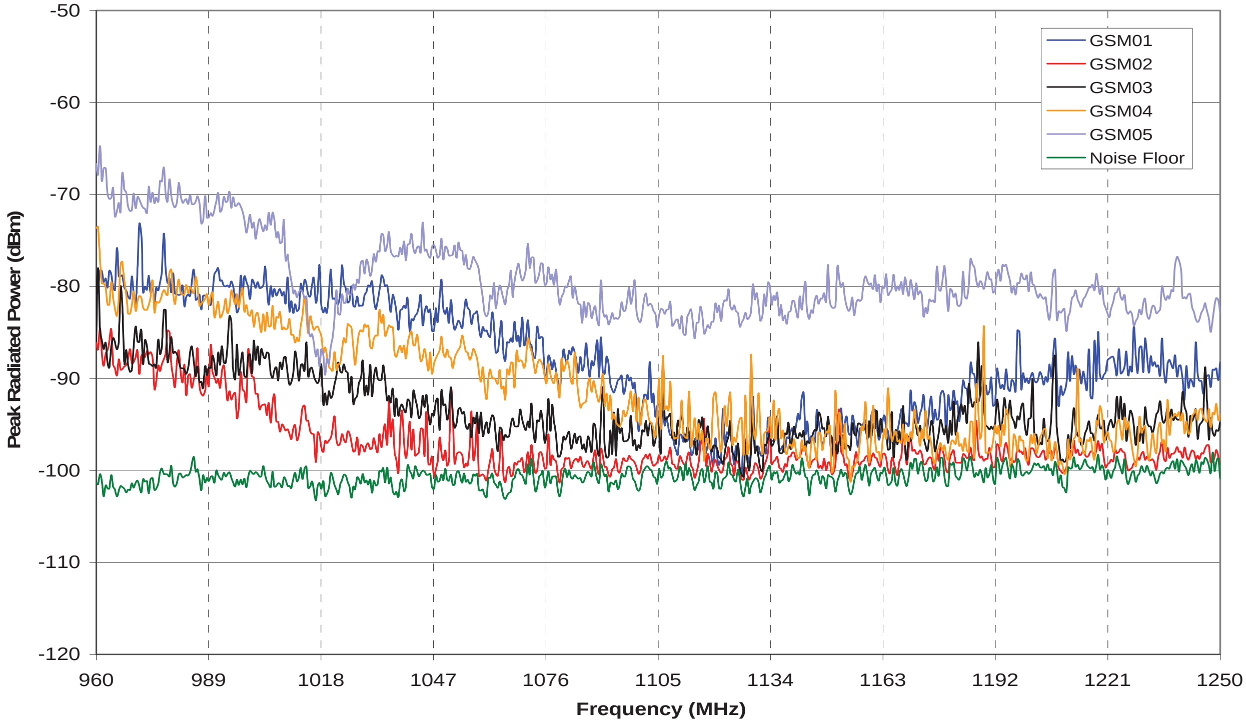

Figure 3.4-7: Individual phone emission envelopes. GSM phones 1 through 5. Band 3.

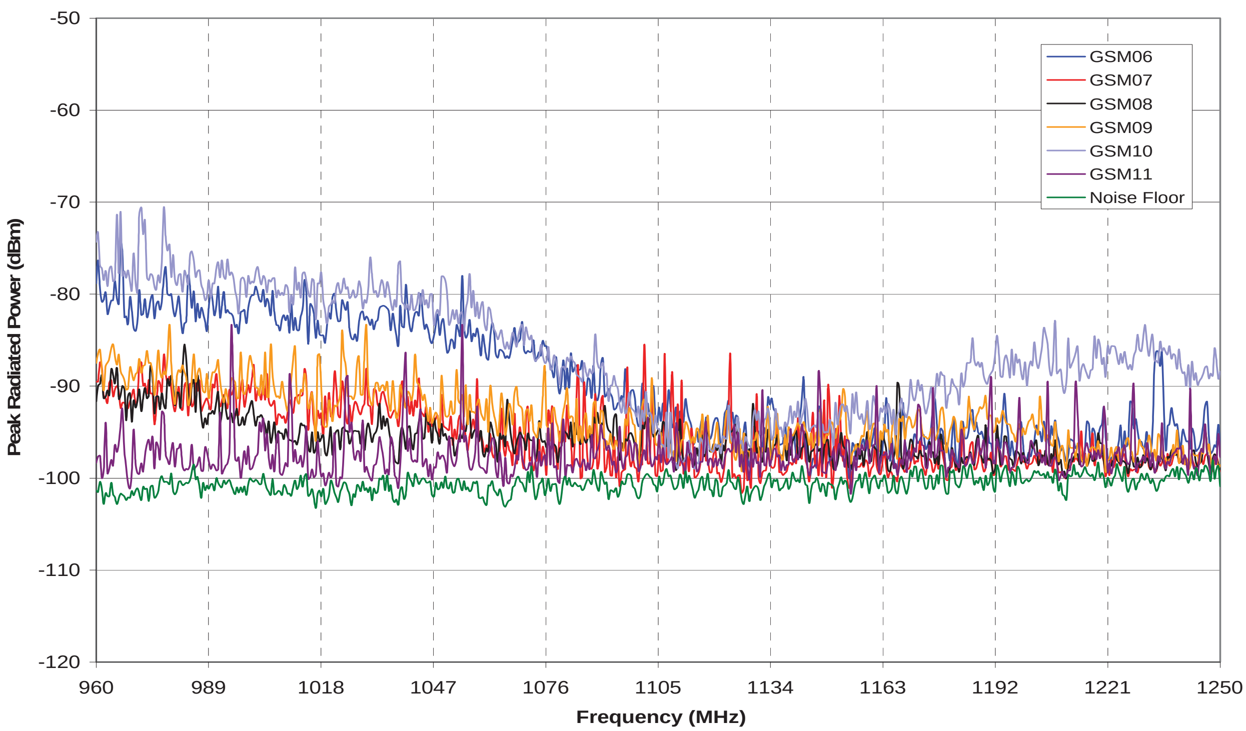

Figure 3.4-8: Individual phone emission envelopes. GSM phones 6 through 11. Band 3.

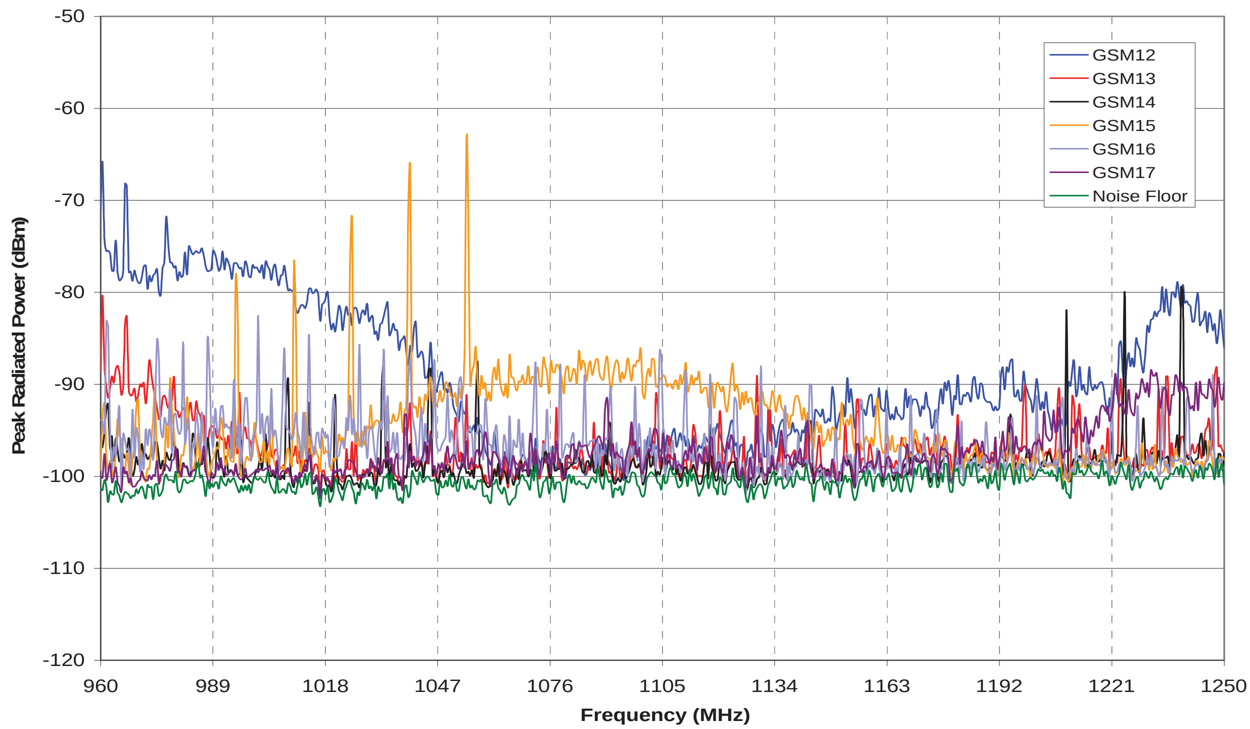

Figure 3.4-9: Individual phone emission envelopes. GSM phones 12 through 17. Band 3.

Band 4

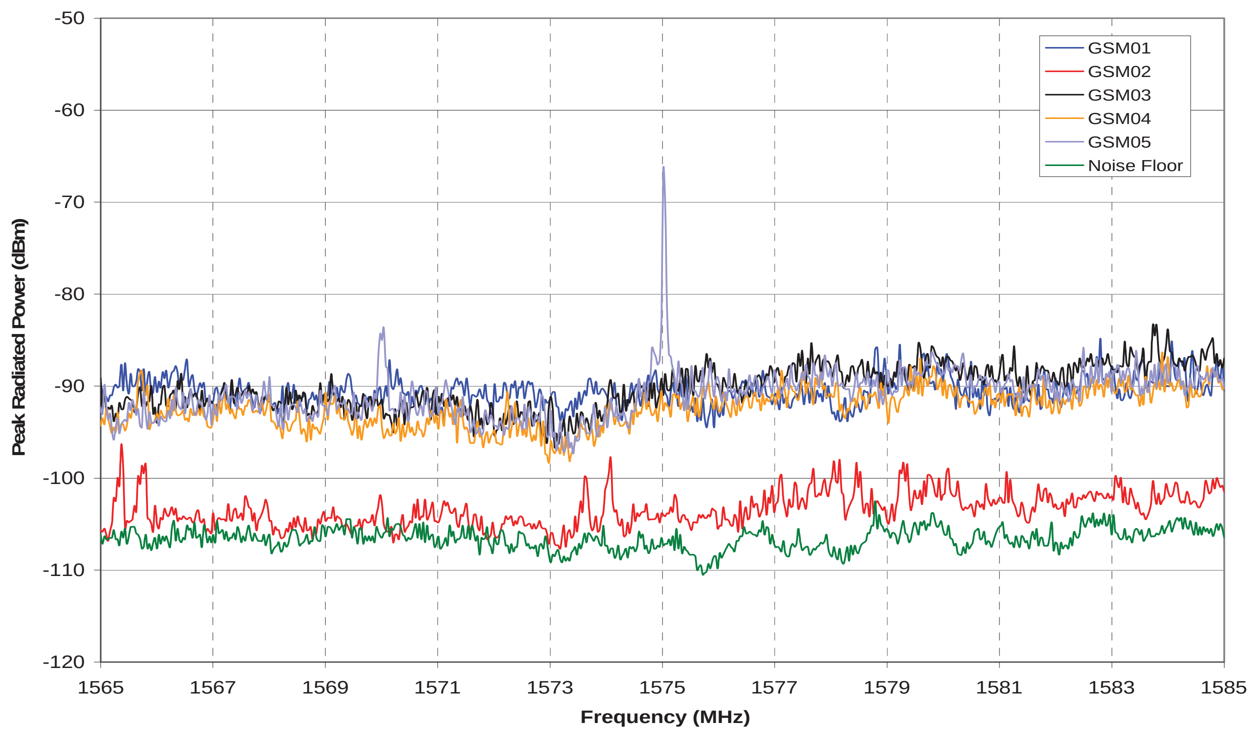

Figure 3.4-10: Individual phone emission envelopes. GSM phones 1 through 5. Band 4.

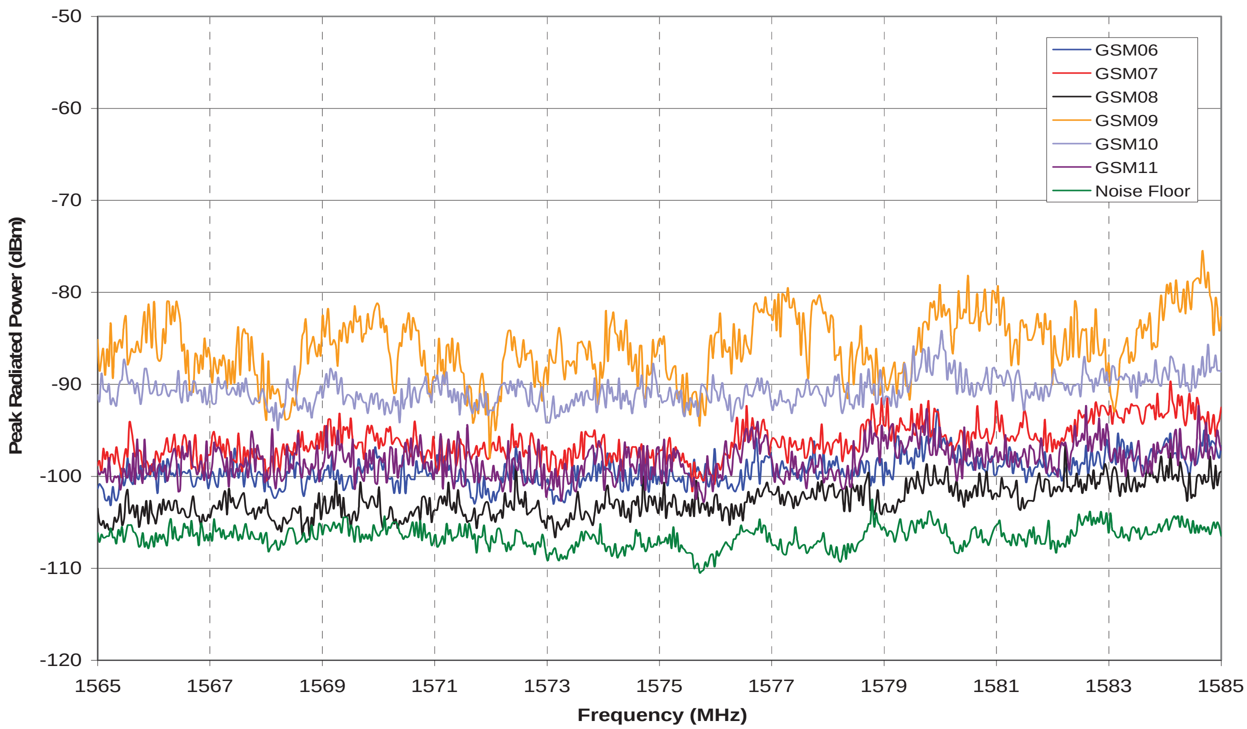

Figure 3.4-11: Individual phone emission envelopes. GSM phones 6 through 11. Band 4.

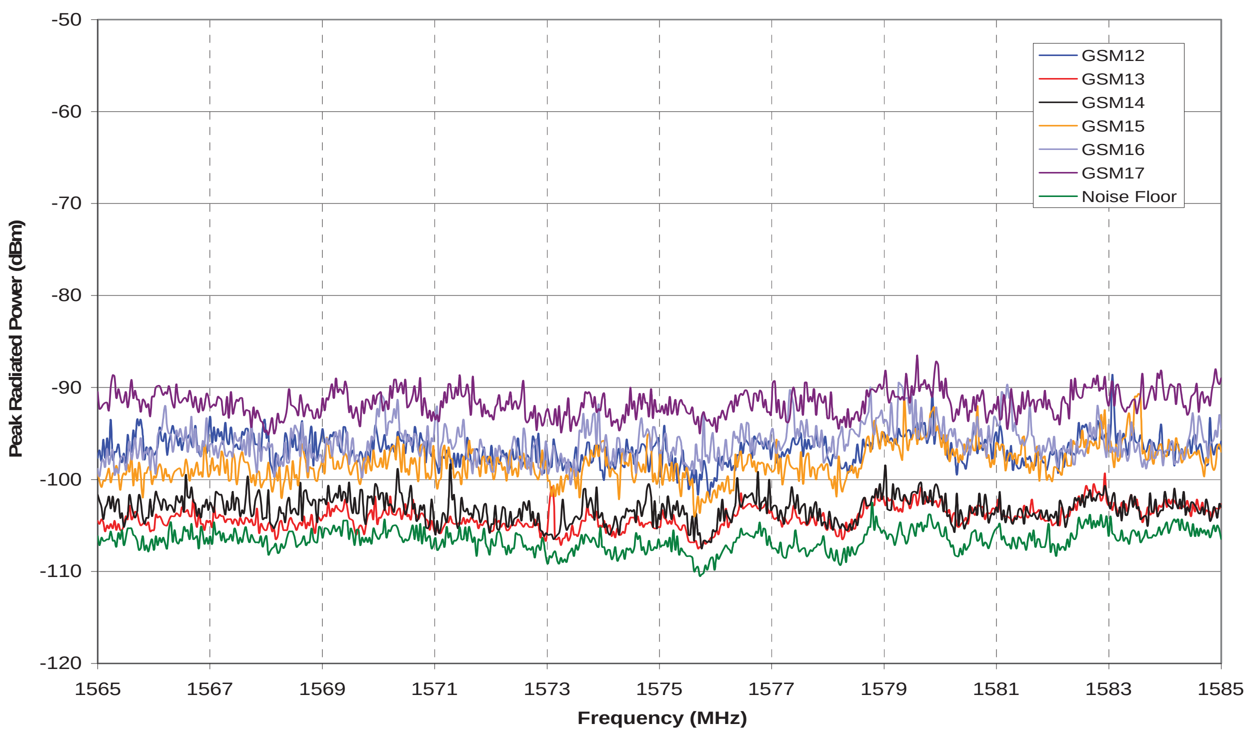

Figure 3.4-12: Individual phone emission envelopes. GSM phones 12 through 17. Band 4.

Band 5

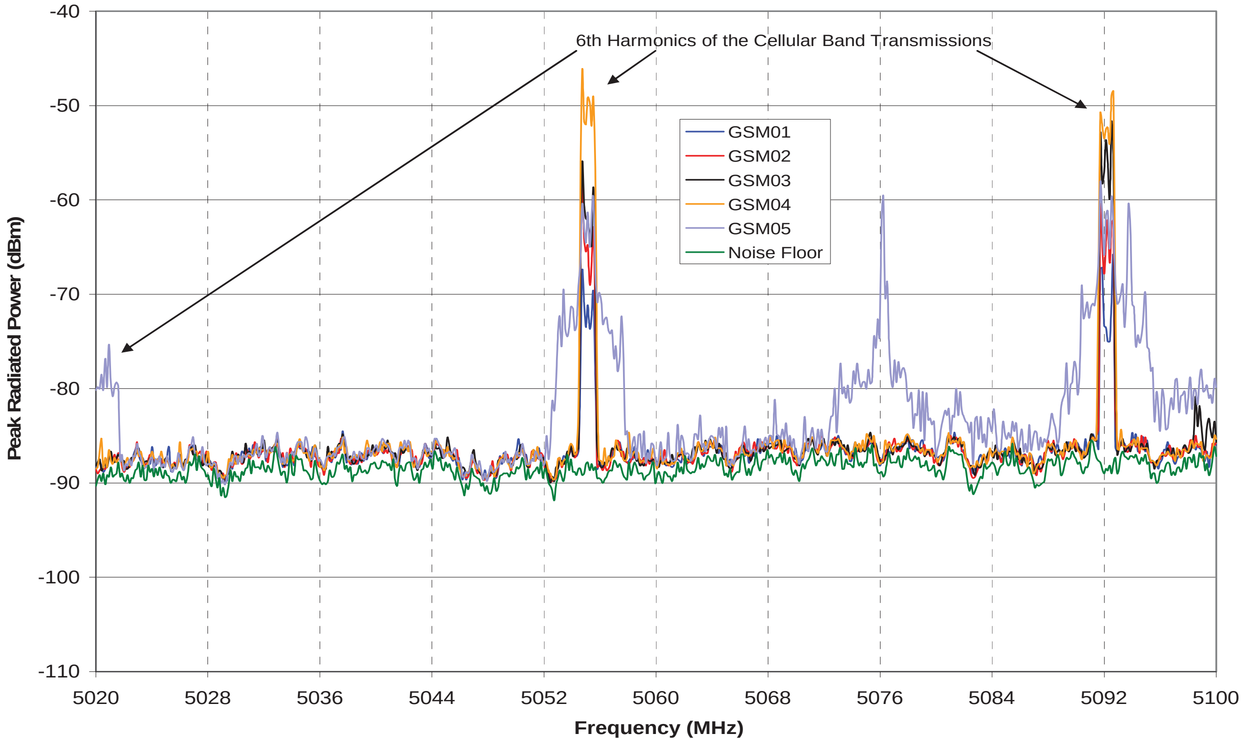

Figure 3.4-13: Individual phone emission envelopes. GSM phones 1 through 5. Band 5.

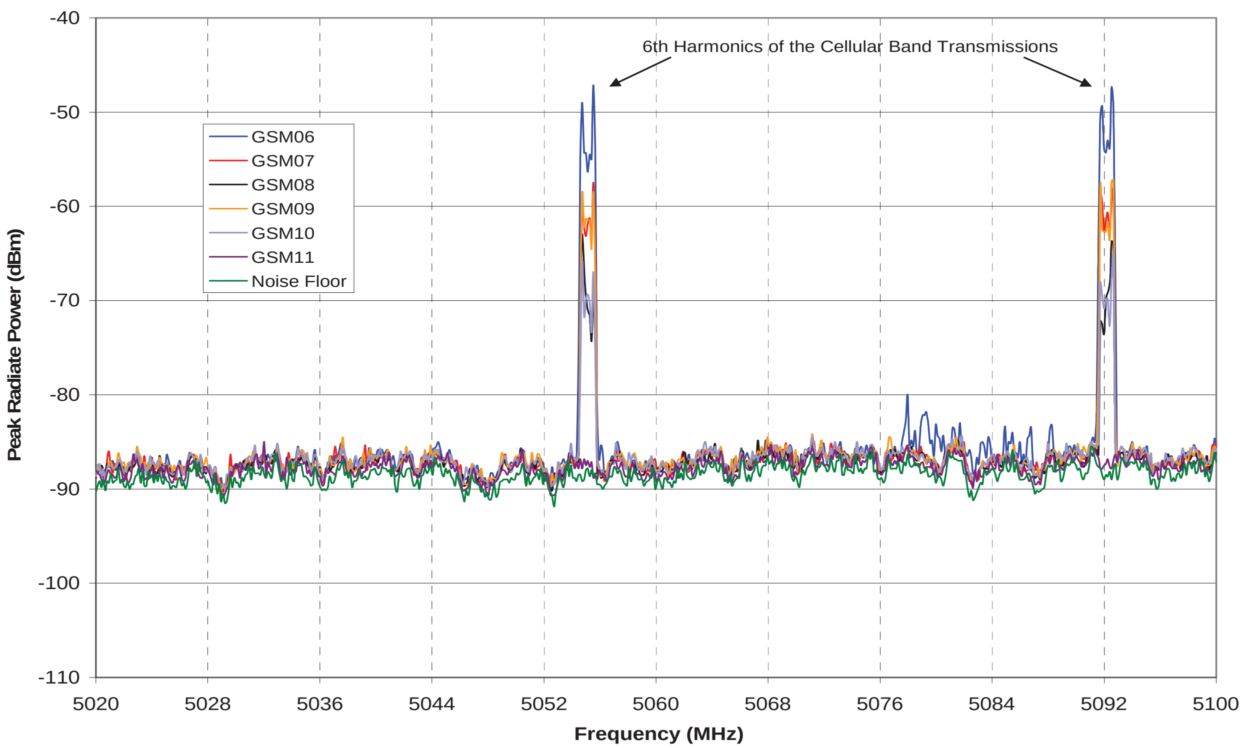

Figure 3.4-14: Individual phone emission envelopes. GSM phones 6 through 11. Band 5.

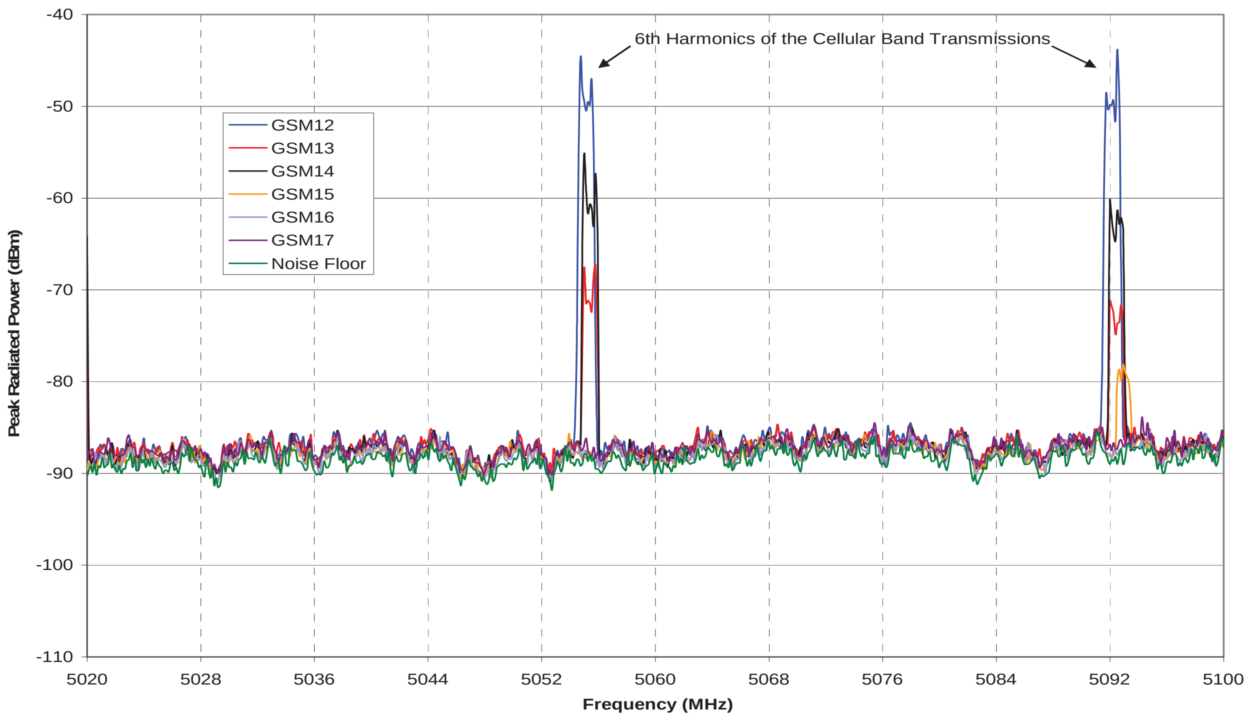

Figure 3.4-15: Individual phone emission envelopes. GSM phones 12 through 17. Band 5.

3.4.2 CDMA phones

Band 1

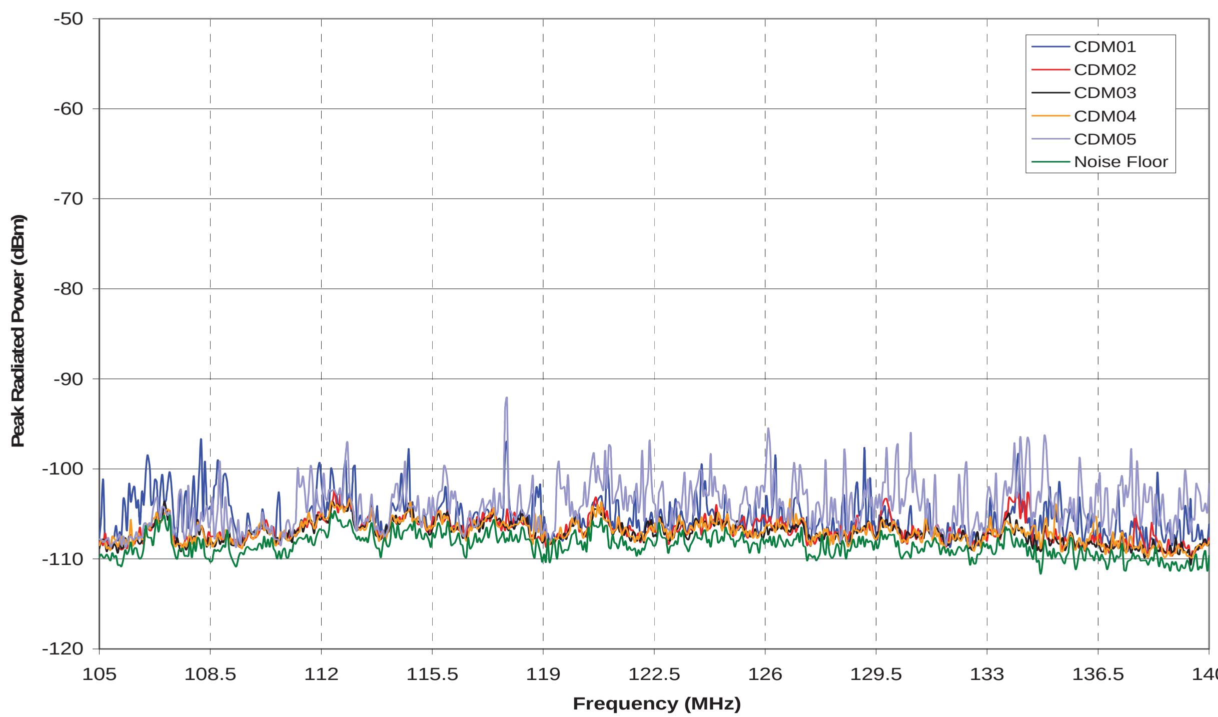

Figure 3.4-16: Individual phone emission envelopes. CDMA phones 1 through 5. Band 1.

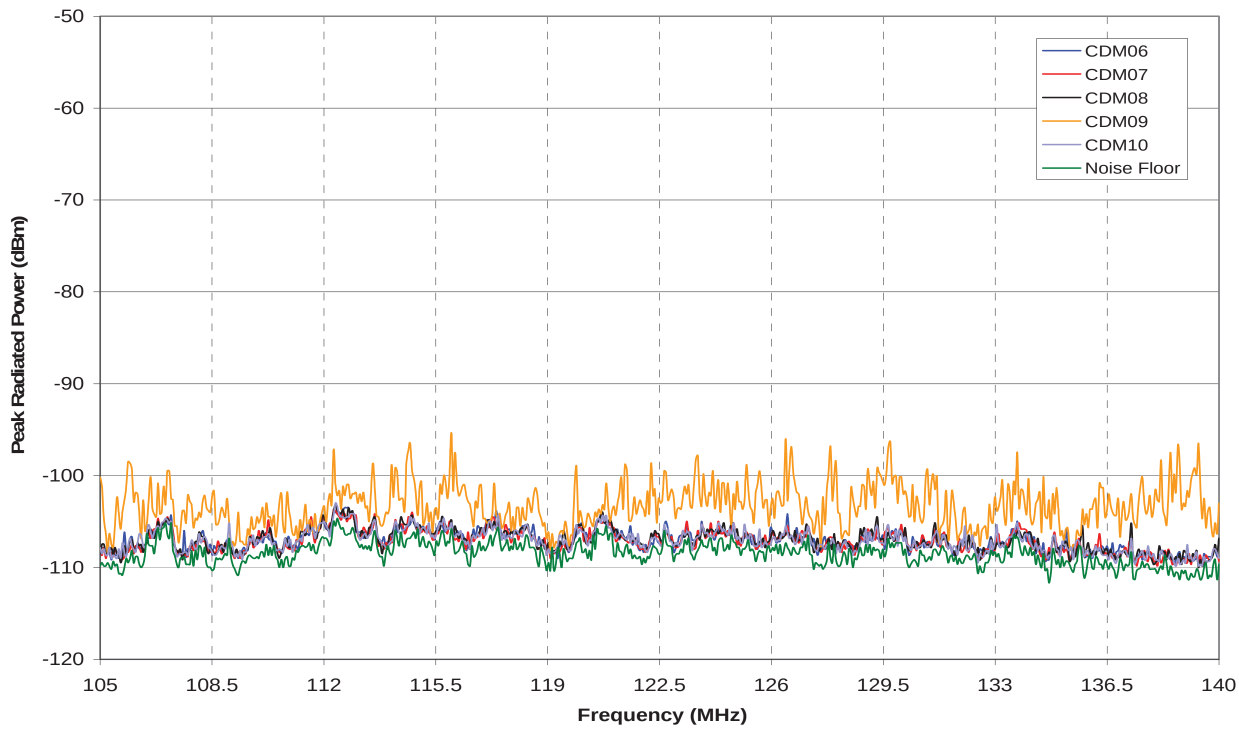

Figure 3.4-17: Individual phone emission envelopes. CDMA phones 6 through 10. Band 1.

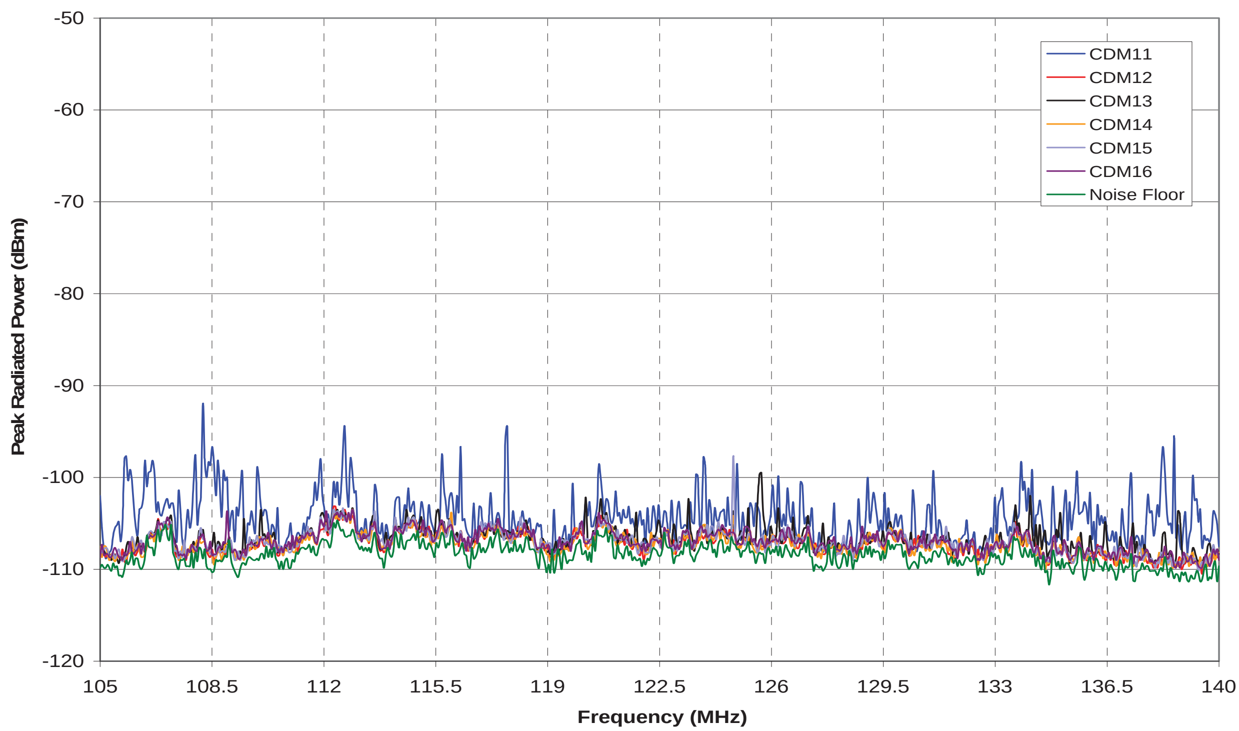

Figure 3.4-18: Individual phone emission envelopes. CDMA phones 11 through 16. Band 1.

Band 2

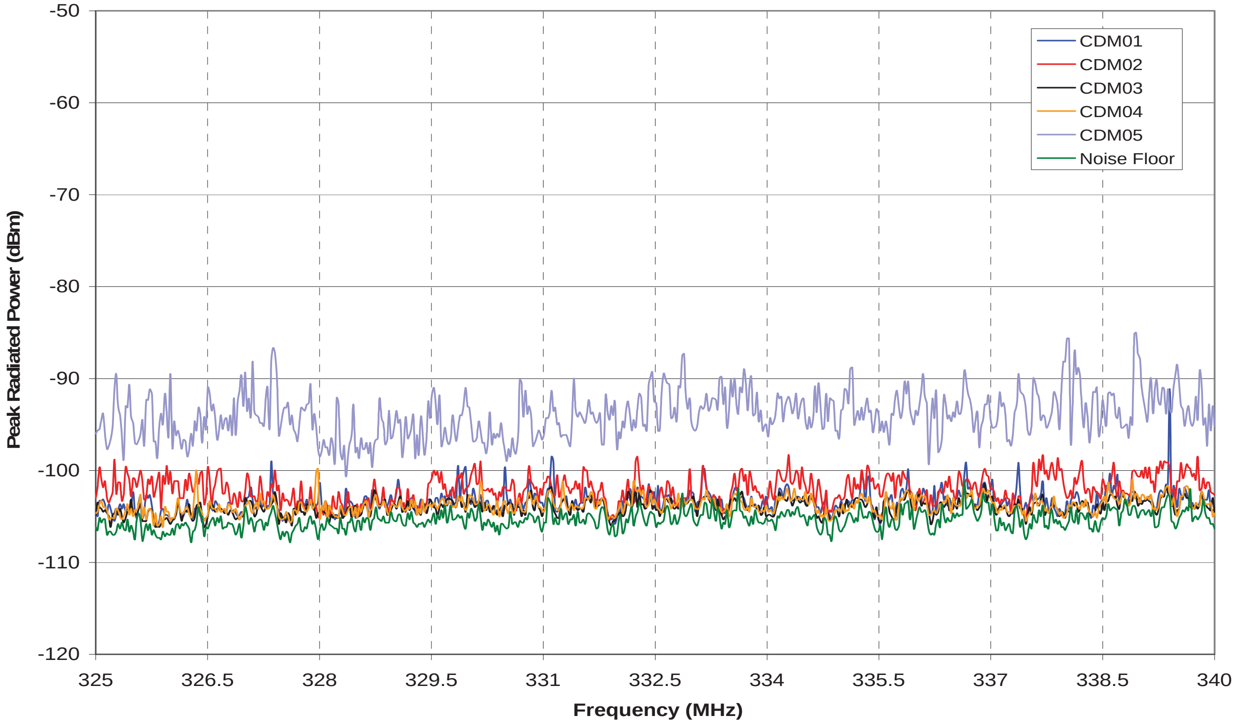

Figure 3.4-19: Individual phone emission envelopes. CDMA phones 1 through 5. Band 2.

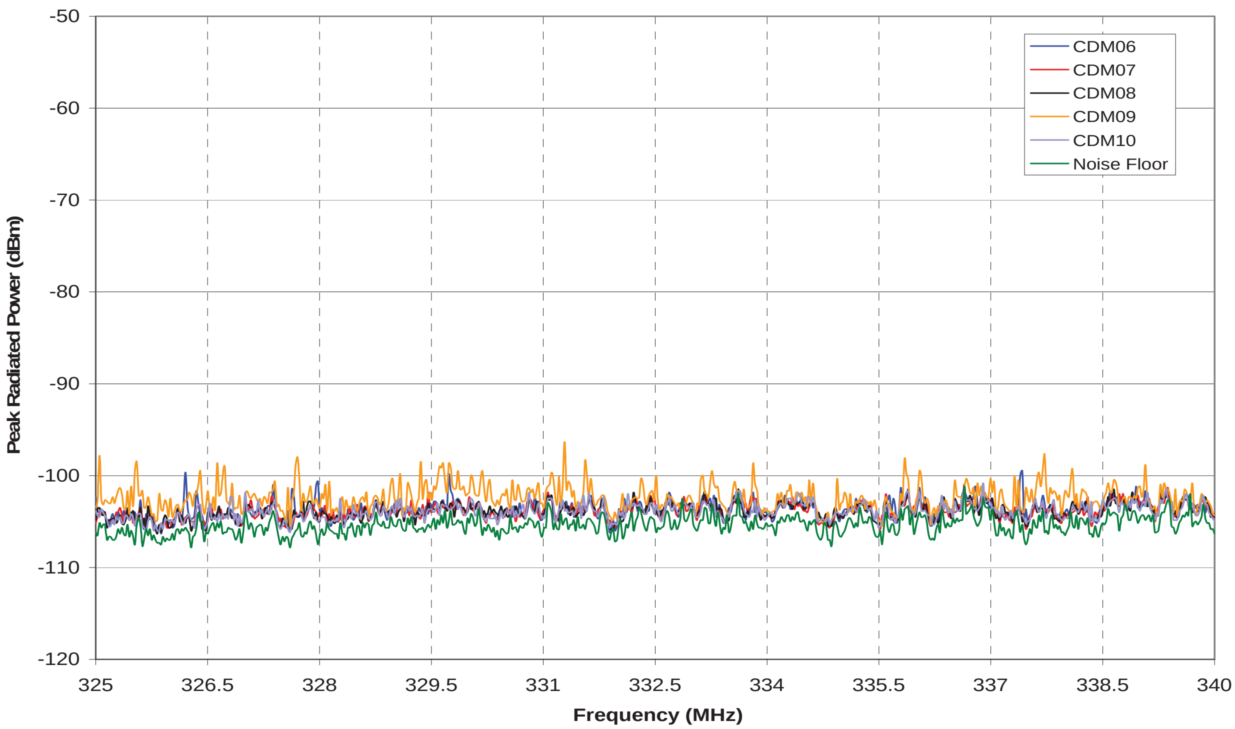

Figure 3.4-20: Individual phone emission envelopes. CDMA phones 6 through 10. Band 2.

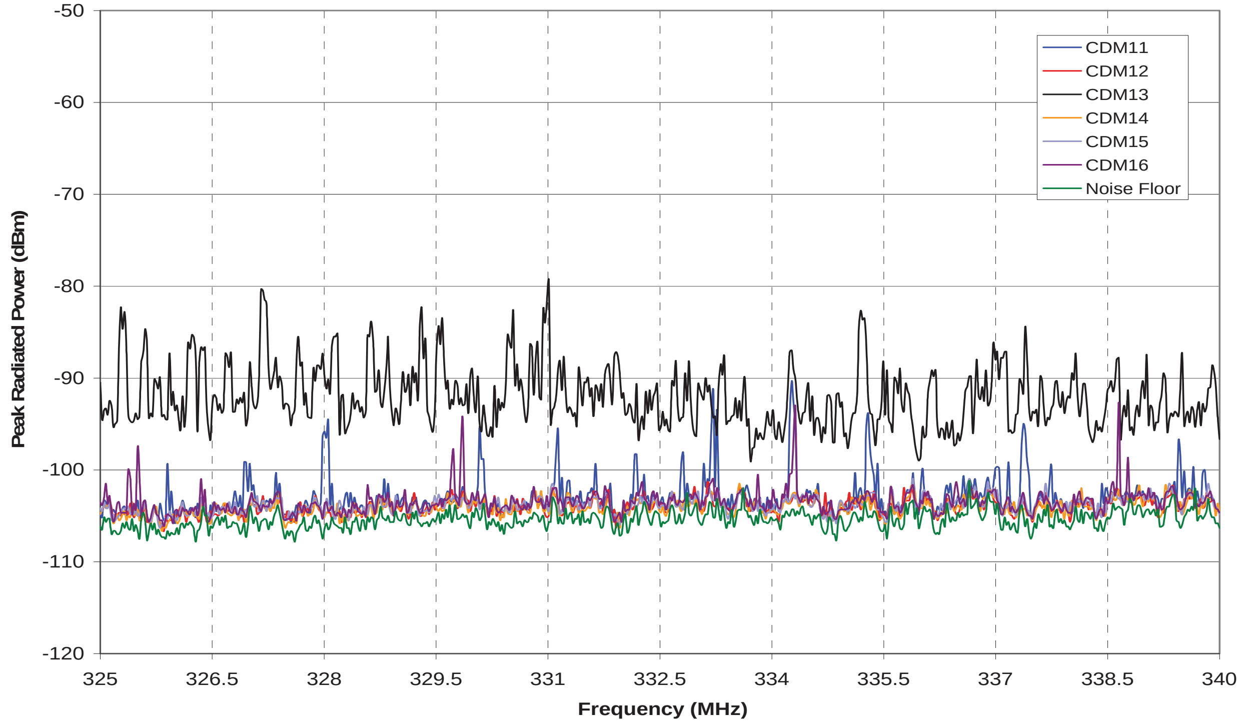

Figure 3.4-21: Individual phone emission envelopes. CDMA phones 11 through 16. Band 2.

Band 3

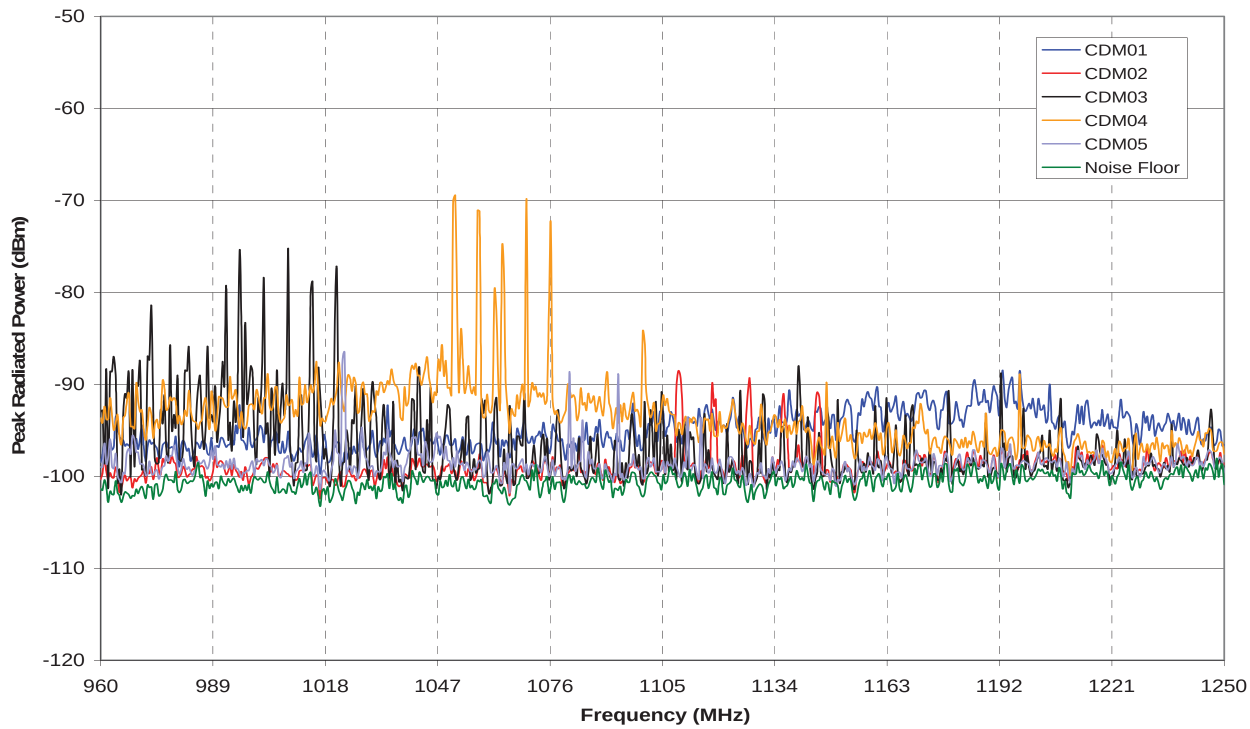

Figure 3.4-22: Individual phone emission envelopes. CDMA phones 1 through 5. Band 3.

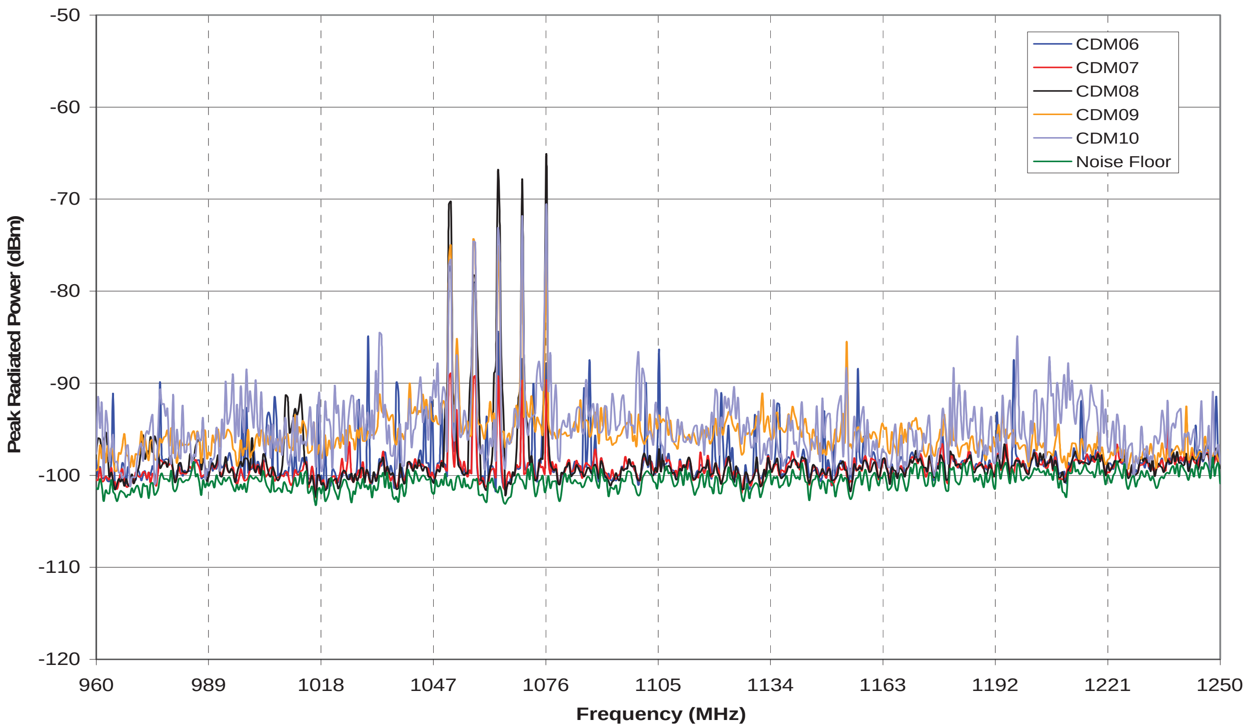

Figure 3.4-23: Individual phone emission envelopes. CDMA phones 6 through 10. Band 3.

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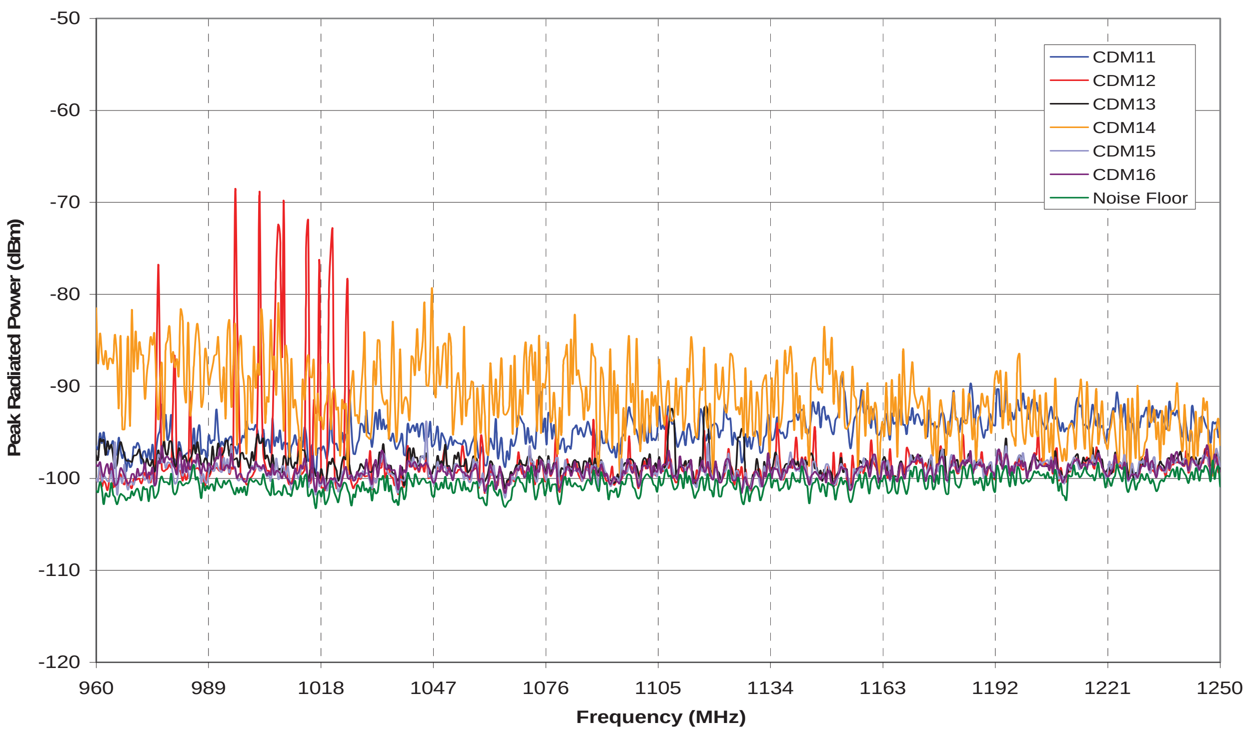

Figure 3.4-24: Individual phone emission envelopes. CDMA phones 11 through 16. Band 3.

Band 4

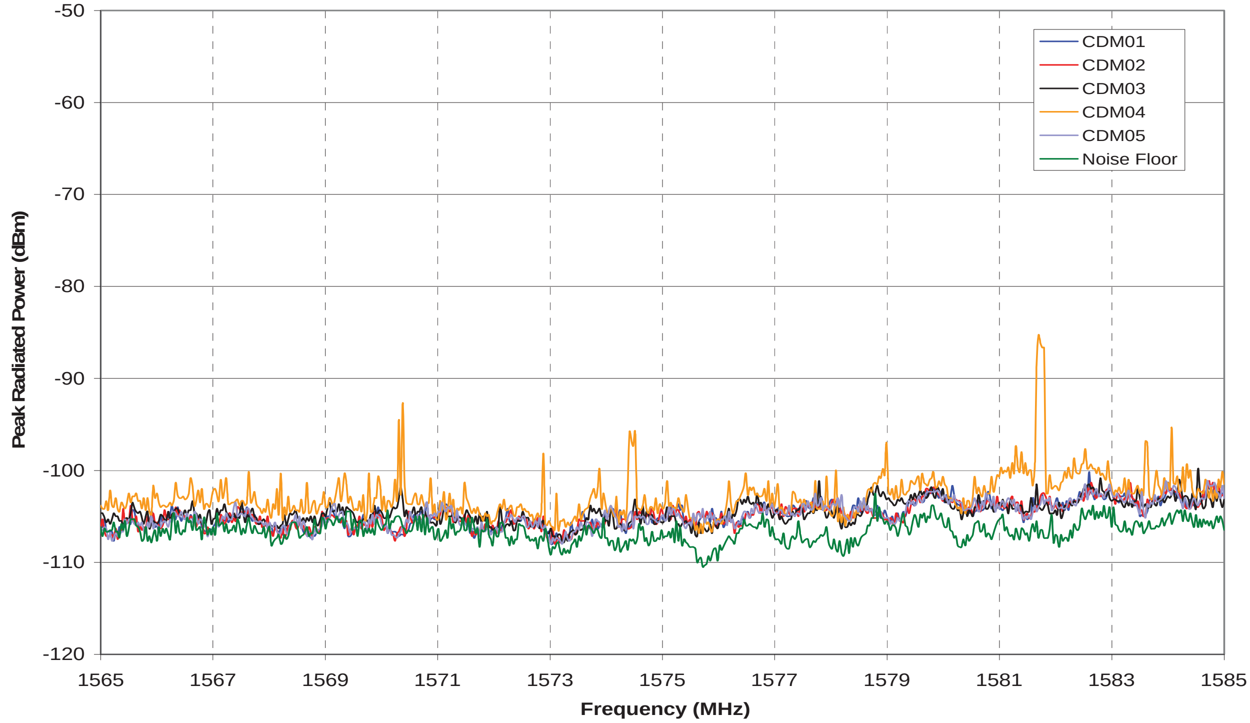

Figure 3.4-25: Individual phone emission envelopes. CDMA phones 1 through 5. Band 4.

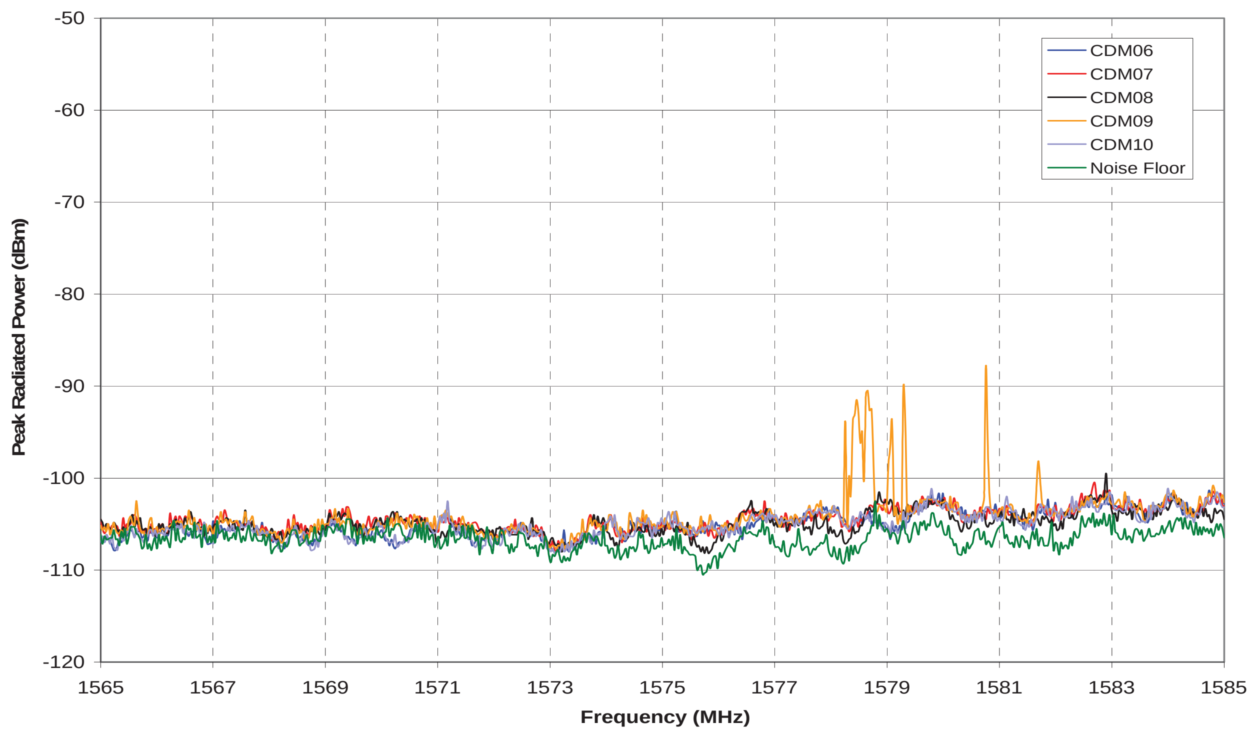

Figure 3.4-26: Individual phone emission envelopes. CDMA phones 6 through 10. Band 4.

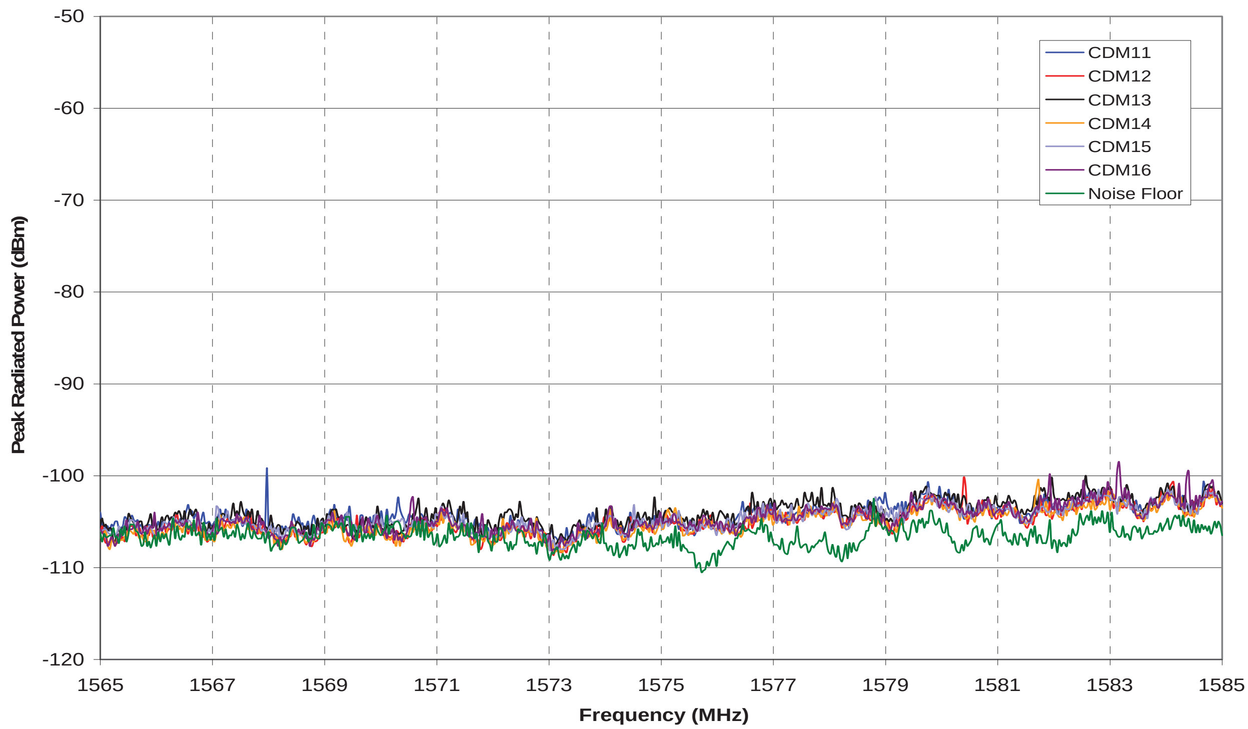

Figure 3.4-27: Individual phone emission envelopes. CDMA phones 11 through 16. Band 4.

Band 5

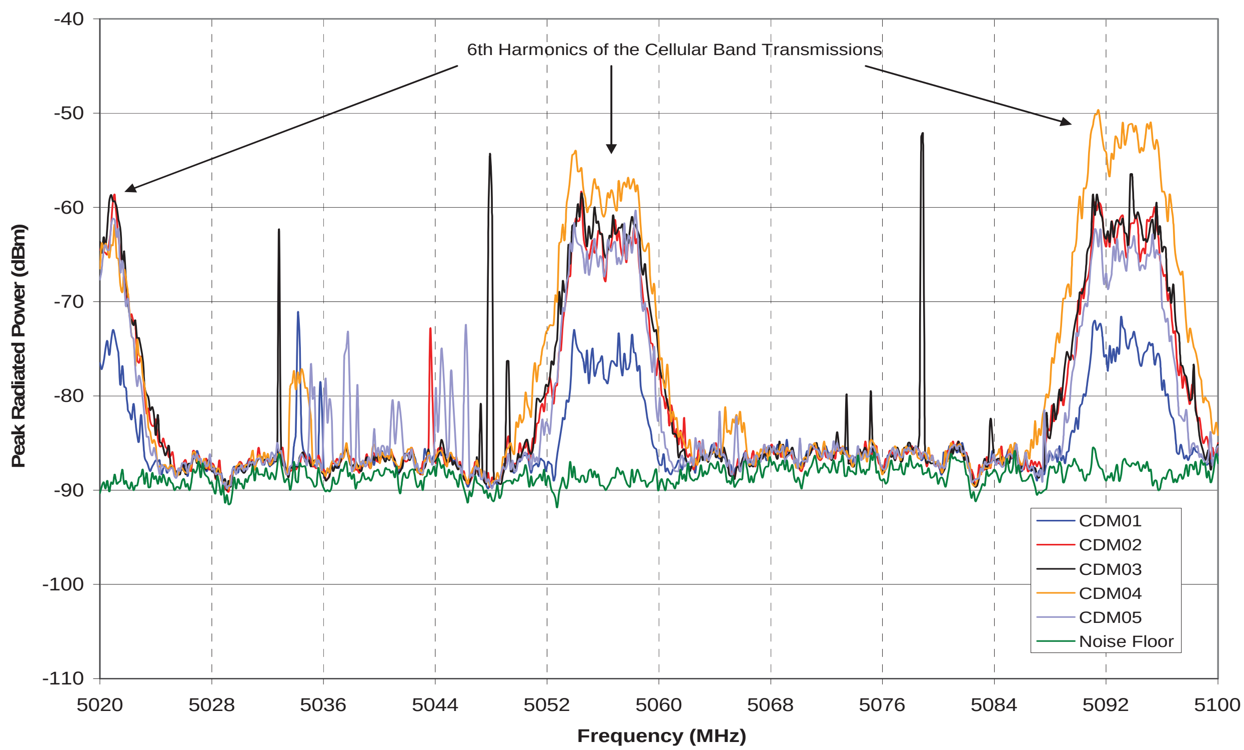

Figure 3.4-28: Individual phone emission envelopes. CDMA phones 1 through 5. Band 5.

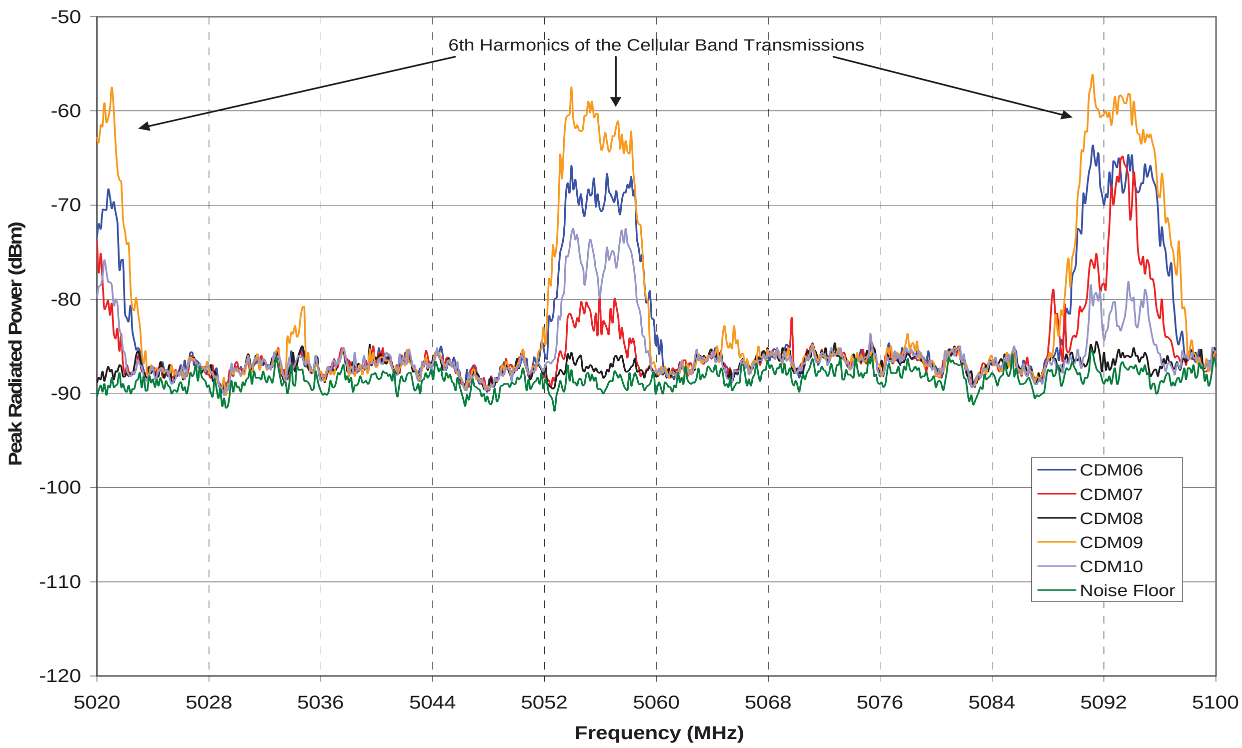

Figure 3.4-29: Individual phone emission envelopes. CDMA phones 6 through 7. Band 5.

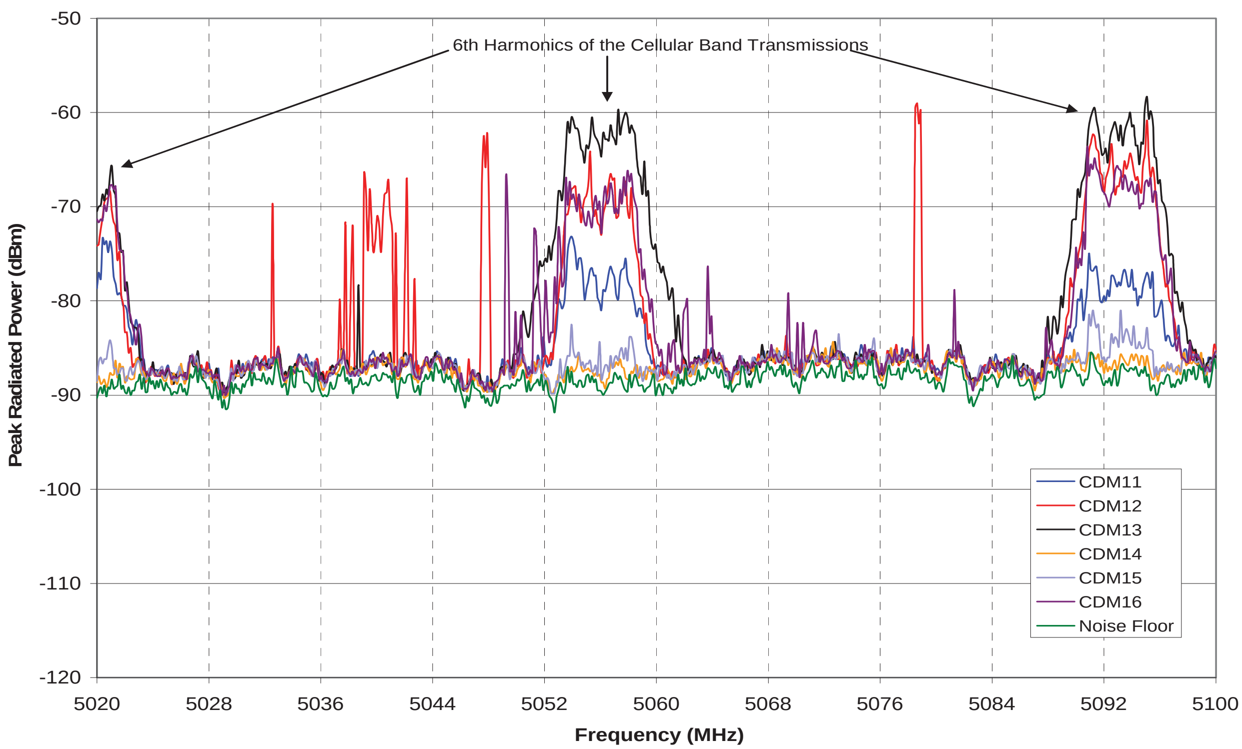

Figure 3.4-30: Individual phone emission envelopes. CDMA phones 11 through 16. Band 5.

3.4.3 Summary of Emission Data

This section summarizes all emission data from all phones and test modes into two charts for each measurement band. The maximum emissions in data and voice modes from each wireless phone are compared side-by-side within each of the GSM or CDMA groups. These charts show the different maximum emissions from each device operating in different spectrum and in voice versus data modes.

It is generally observed that in Band 1 and Band 2, each device's emissions are similar regardless whether it is operating in the cellular band or PCS band. This is not the case for Band 3, 4 or 5. In addition, in most cases the emissions in the voice and data modes are similar for any single device (within 2-5 dB). The exceptions include GSM01 in Band 2, CDM06 in Band 3, GSM09 in Band 4, and a few others.

The maximum emission values in the five bands are used in the safety margin calculations in a later section.

Band 1

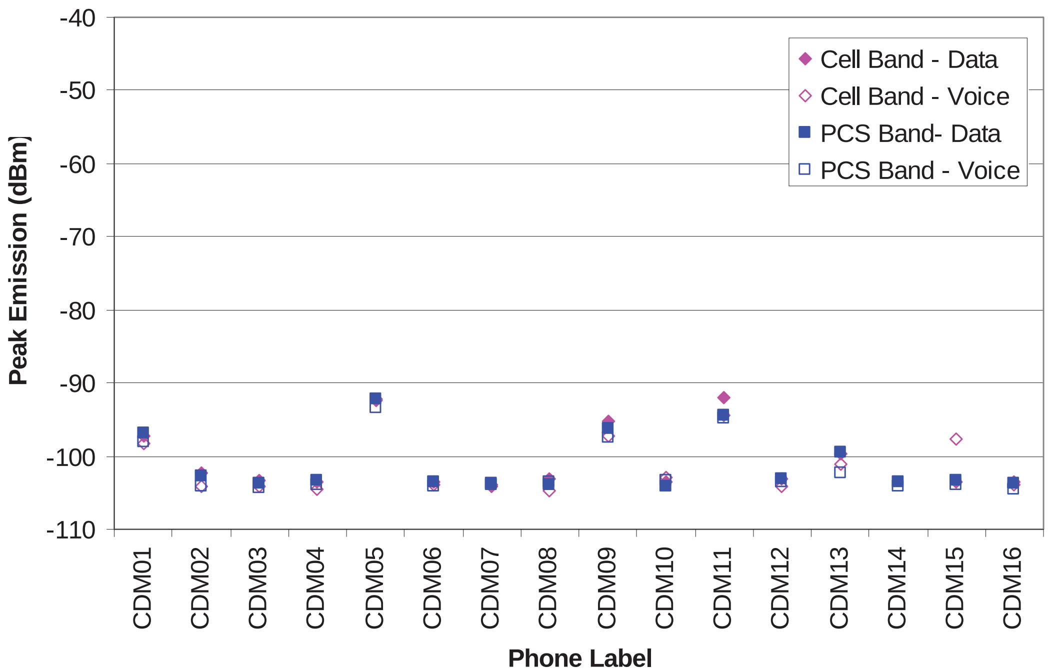

Figure 3.4-31: Band 1 CDMA wireless phone emission. Phone operating in cellular or PCS bands.

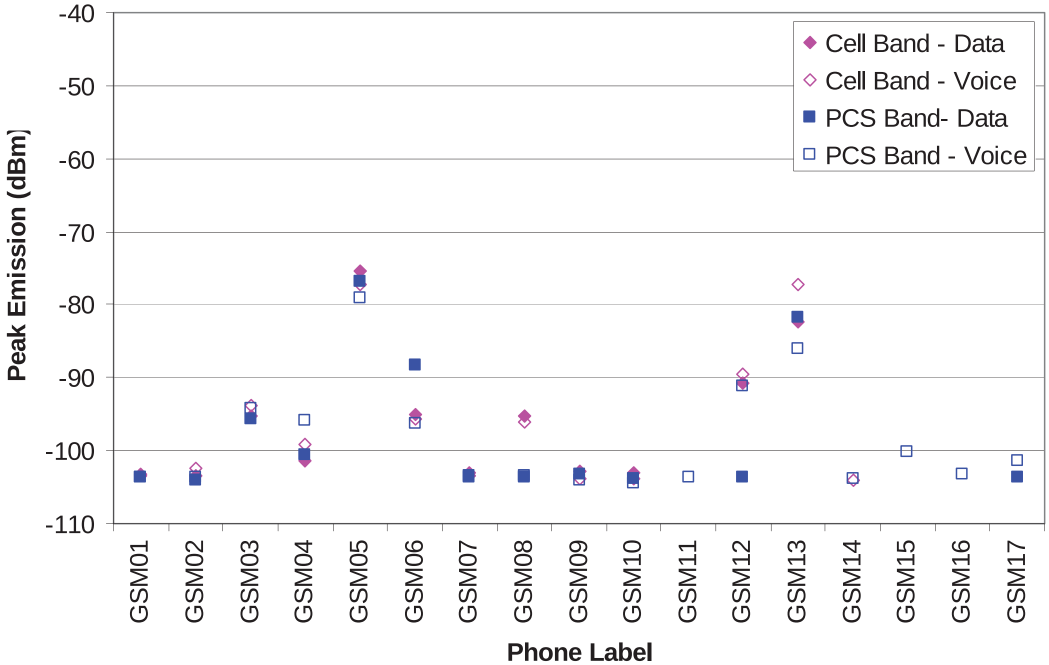

Figure 3.4-32: Band 1 GSM/GPRS wireless phone emissions. Phone operating in cellular or PCS bands.

Band 2:

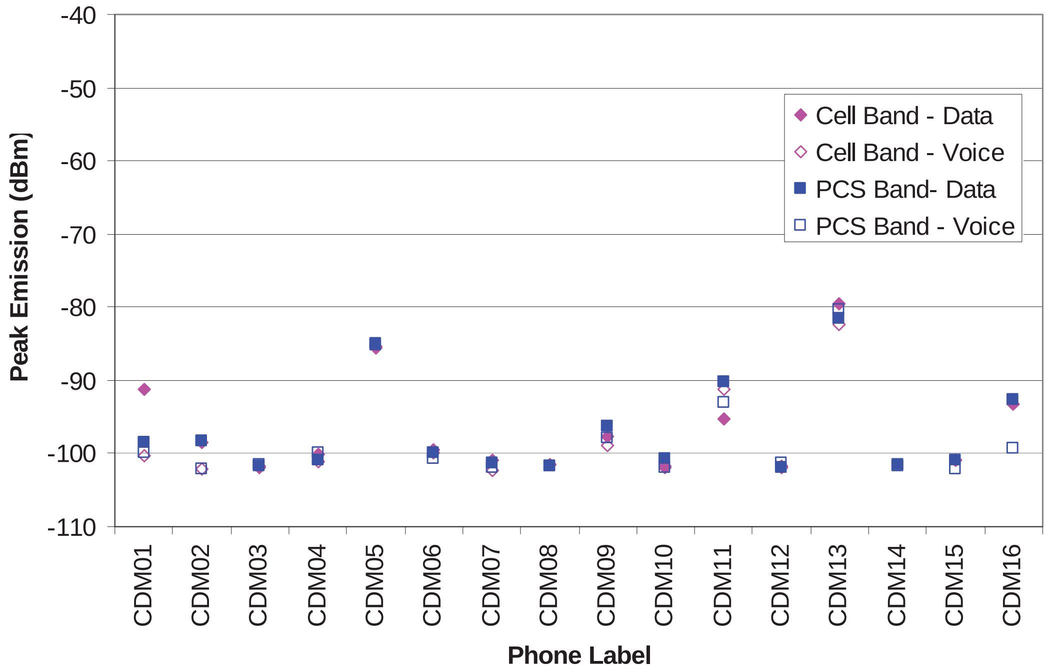

Figure 3.4-33: Band 2 CDMA wireless phone emissions. Phone operating in cellular or PCS bands.

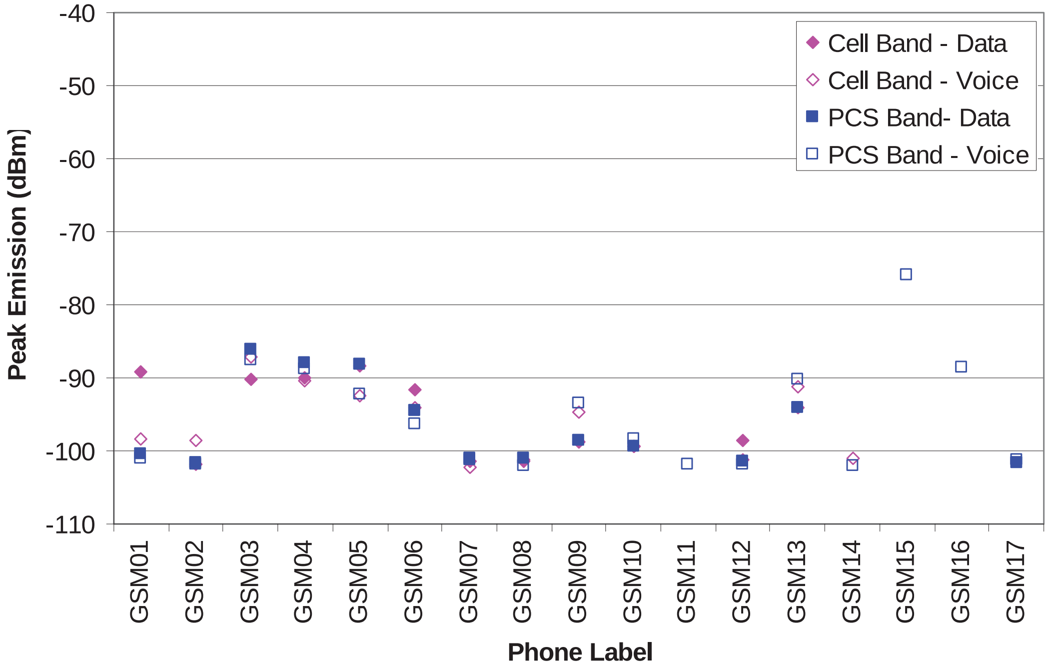

Figure 3.4-34: Band 2 GSM/GPRS wireless phone emissions. Phone operating in cellular or PCS bands.

Band 3

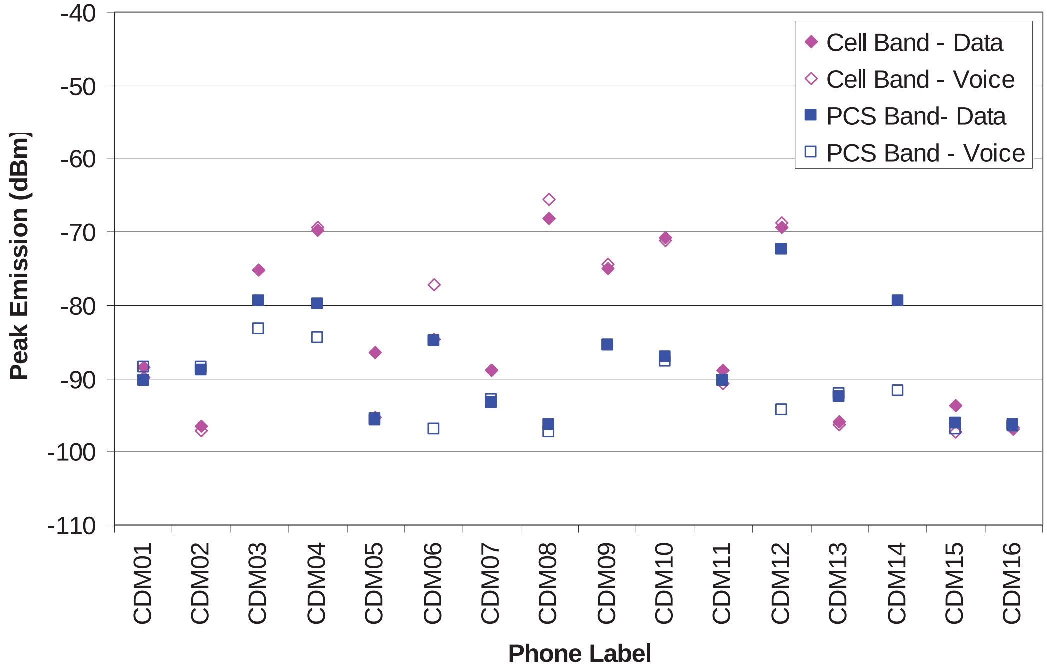

Figure 3.4-35: Band 3 CDMA wireless phone emissions. Phone operating in cellular or PCS bands.

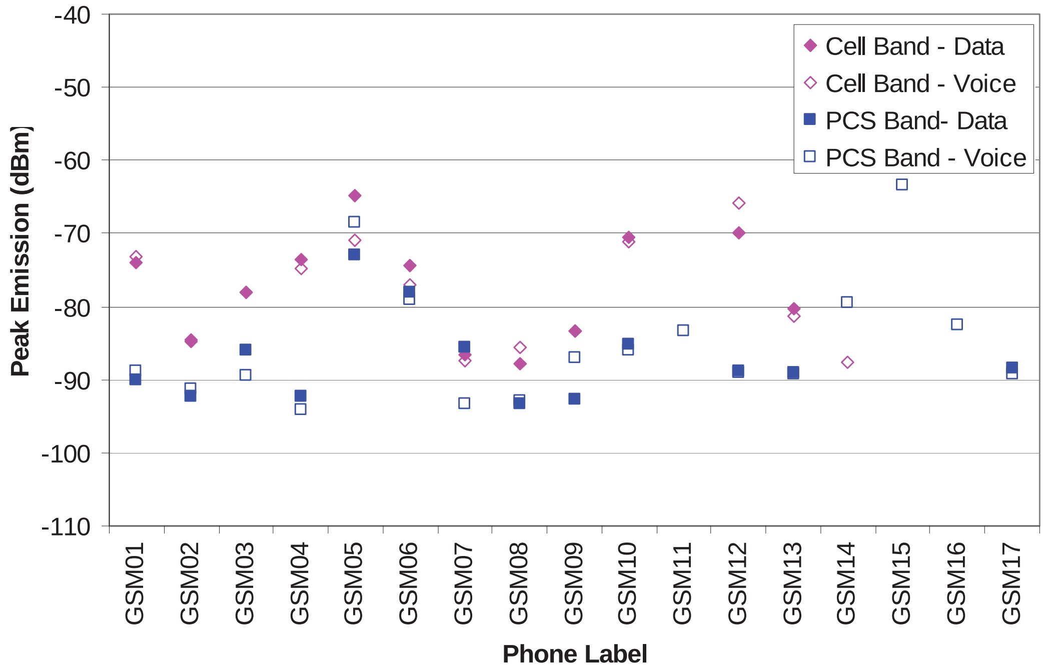

Figure 3.4-36: Band 3 GSM/GPRS wireless phone emissions. Phone operating in cellular or PCS bands.

Band 4

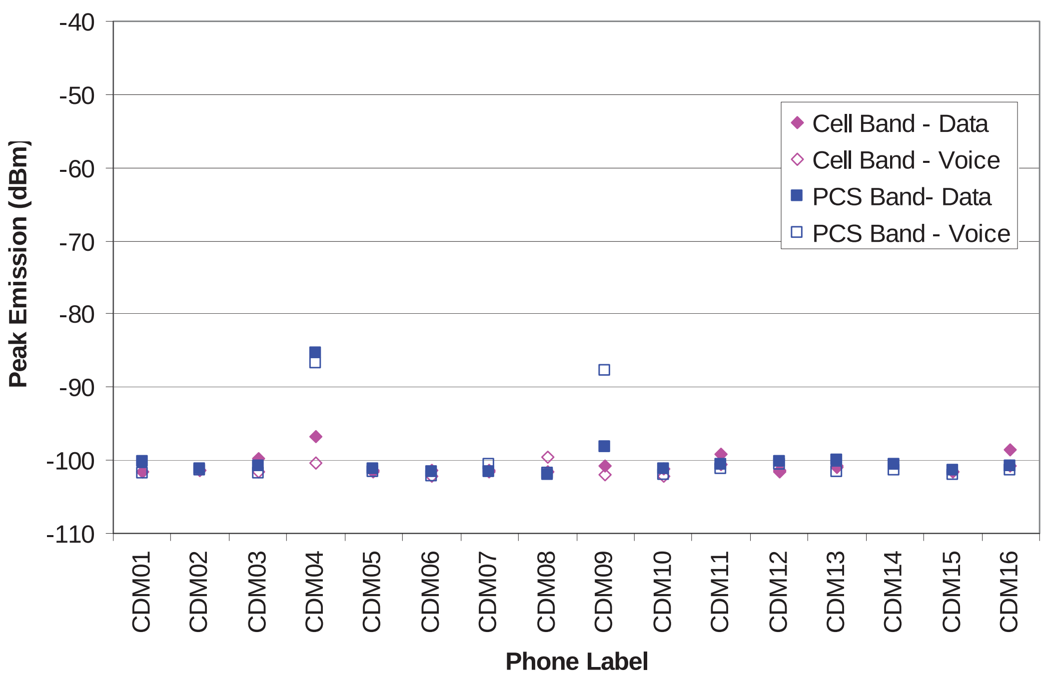

Figure 3.4-37: Band 4 CDMA wireless phone emissions. Phone operating in cellular or PCS bands.

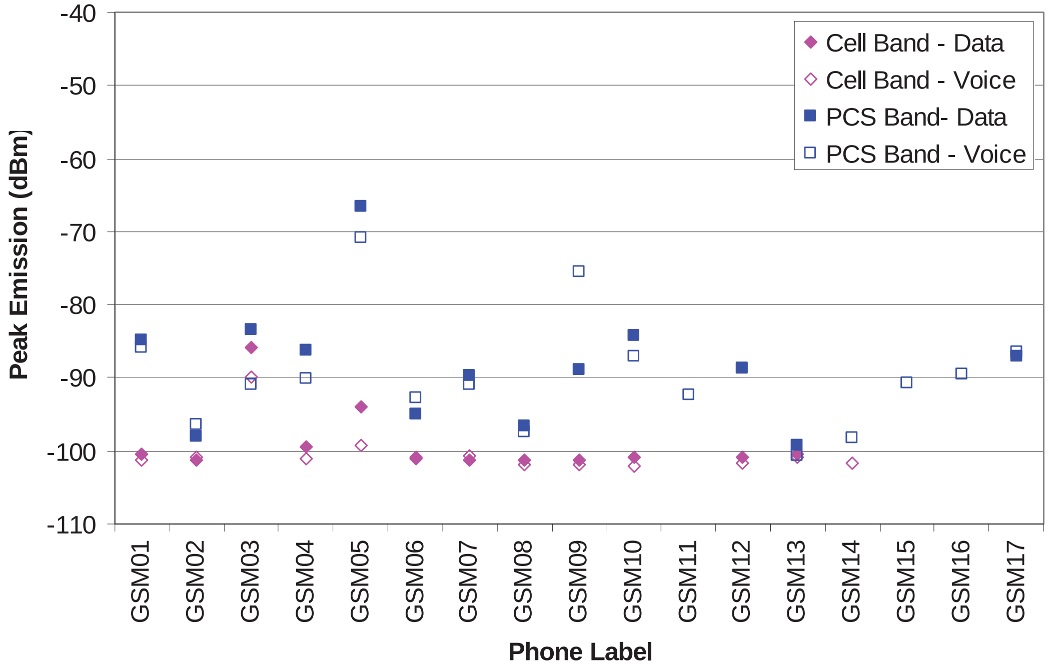

Figure 3.4-38: Band 4 GSM/GPRS wireless phone emissions. Phone operating in cellular or PCS bands.

Band 5:

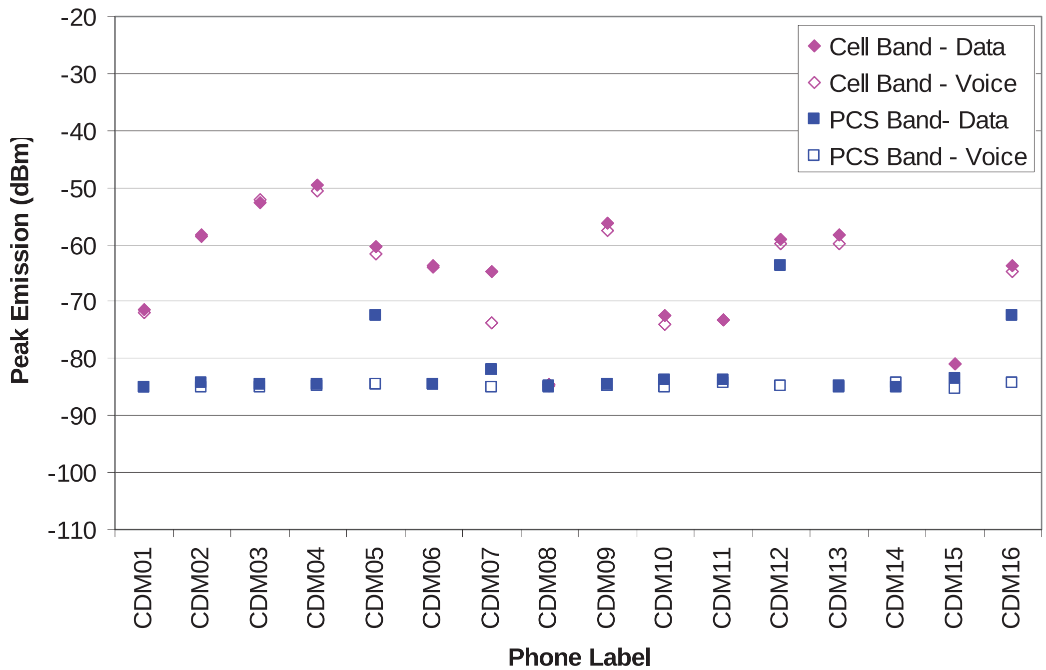

Figure 3.4-39: Band 5 CDMA wireless phone emissions. Phone operating in cellular or PCS bands.

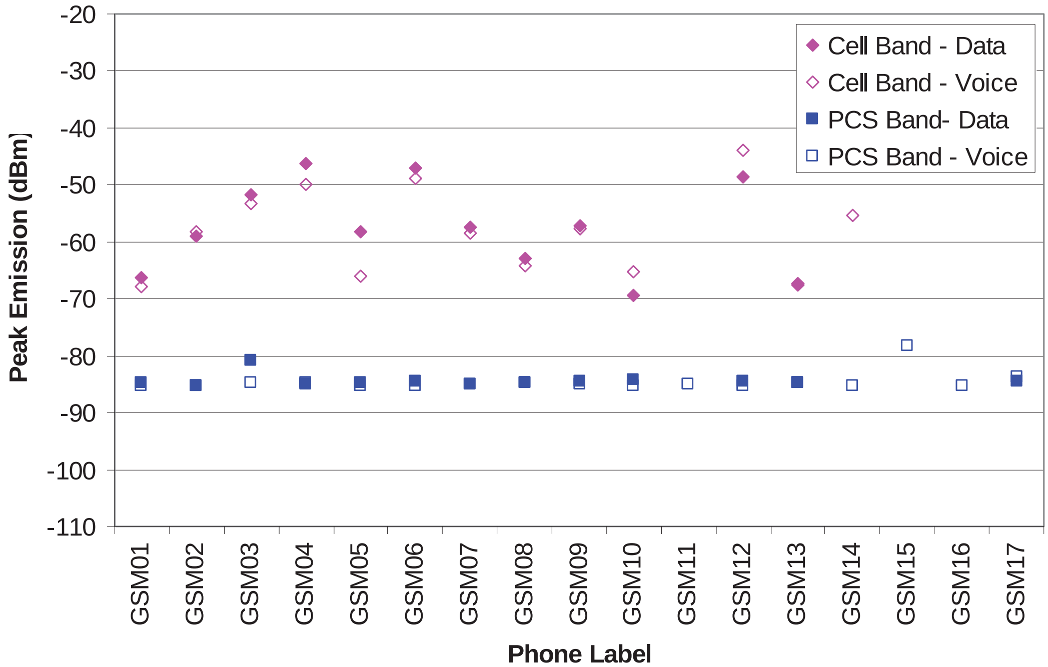

Figure 3.4-40: Band 5 GSM/GPRS wireless phone emissions. Phone operating in cellular or PCS bands.

3.5 Baseline Emissions from Standard Laptop Computers and PDA

Emission measurement results from several laptop computers, PDAs and a portable printer (PRN) are used as a baseline for devices currently allowed on an aircraft. The measurements were performed and reported in an earlier efforts [2]-[3], and the summary of the results are repeated here for comparison purposes. The comparison can be used to evaluate the risks to aircraft radio bands from wireless phones versus non-transmitting PEDs such as laptop computers and PDAs. These PEDs are currently allowed during certain phases of a flight.

Measurements of the PEDs emissions were performed in all five test bands similar to this effort. However, the 105-140 MHz band was divided into two separate bands, called Band 1 and Band 1a. Band 1 covers from 105 to 120 MHz, and the results were reported in [2]. Band 1a covers 116 to 140 MHz, with the results first reported in [2]-[3]. Since this current report combines the old Band 1 and Band 1a into a new band, named Band 1, the PEDs emission data in the new Band 1 are shown in two separate charts.

The PEDs tested are listed in Table 3.5-1

Table 3.5-1: Laptop Computers, PDA, and Mobile Printer Models

Host Designation	Manufacturer	Model
LAP1	Dell	Latitude C640
LAP2	Hewlett Packard	Pavilion n6395
LAP3	Sony Vaio & Dock	PCG-641R PCGA-DSM51
LAP4	Dell	Latitude C800
LAP5	Fujitsu	Lifebook
LAP6	Panasonic	Toughbook CF-47
LAP7	Fujitsu	Lifebook CP109733
LAP8	Gateway	450SX4
PDA1	Palm	m515
PDA2	Toshiba	e740
PRN	Hewlett Packard	DeskJet 350

Laptop Computers

Spurious radiated emissions were recorded for eight laptop computers, with each operating in five modes. Operating modes, or processing tasks that may be performed by a laptop, include: idle, screensaver, file transferring, CD playing, and DVD playing. Radiated emissions from the modes were measured separately. The overall maximum emission envelope across the band of all operating modes is termed as the radiated peak envelope of the laptop.

The PEDs devices were measured using the same facility and instruments. However, the PED emissions were measured with 1) a different pre-amplifier in the receive path, 2) an equipment operator in the chamber, and 3) without measurement path filters. These differences may affect the measurement noise floor, but should not affect the emission results since they are accounted for in the calibration. Different laptop computer operating modes are explained below:

- Idle: Idle mode testing is conducted as a normal desktop screen is displayed.
- Screensaver: The flowerbox screensaver was selected to be a large, smooth, checkerboard cube pattern that spins and blooms at maximum complexity. This selection is a simple way to simulate computationally intensive operations.
- File Transfer: This mode includes transferring files from the hard drive to the Personal Computer (PC) Card hard drive, which is well shielded with all metal casing.
- CD Playing: The computer plays music CD, exercising the audio circuitry.
- DVD Playing: The computer plays movie DVD, exercising the video system.

PDA and Printer

A PDA baseline consisted of the idle and file-transfer modes. File transfer in this case was performing a backup operation to a secure digital or compact flash card. The printer testing consisted of the idle mode with the unit powered on.

Results – PEDs Emission

The following charts in this section report the PED data envelopes, with each chart containing plots of all individual PED envelopes. Each individual PED envelope was generated from the measured emissions data, including idle mode and all other PED test modes discussed earlier. The charts also show composite maximum envelopes that represent the highest emission level of all devices at any given frequency.

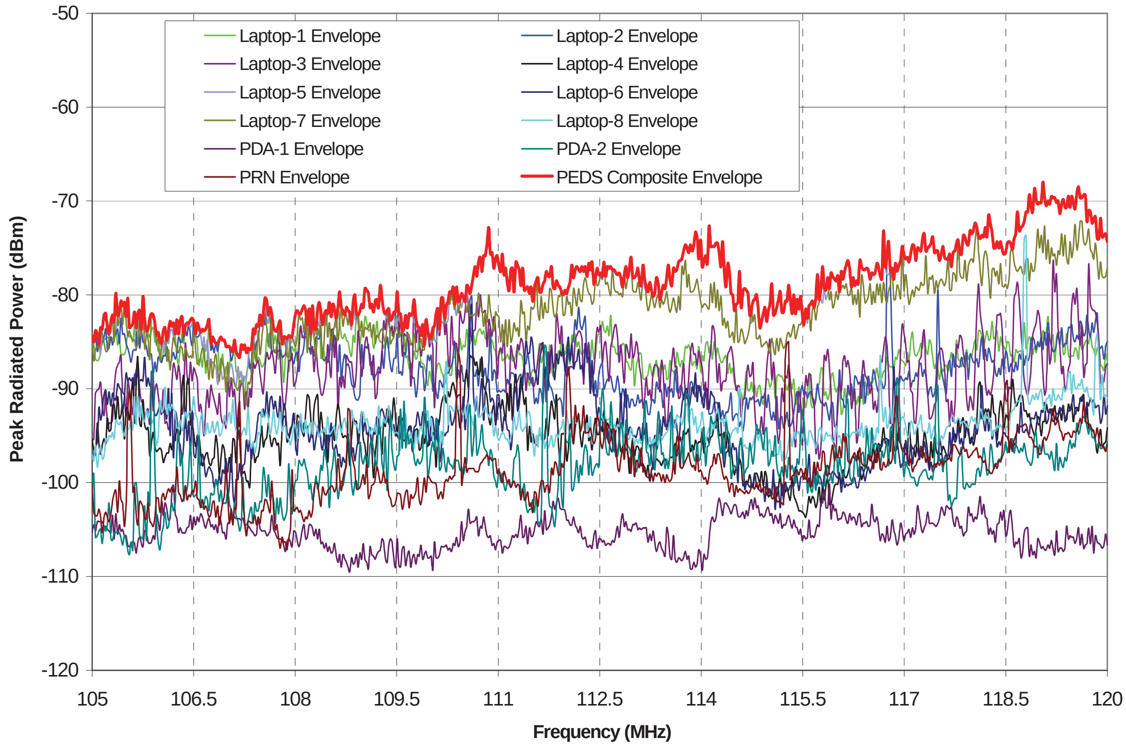

Figure 3.5-1: Individual PED Envelopes and PEDS Composite Envelope for Band 1a (105 MHz to 120 MHz).

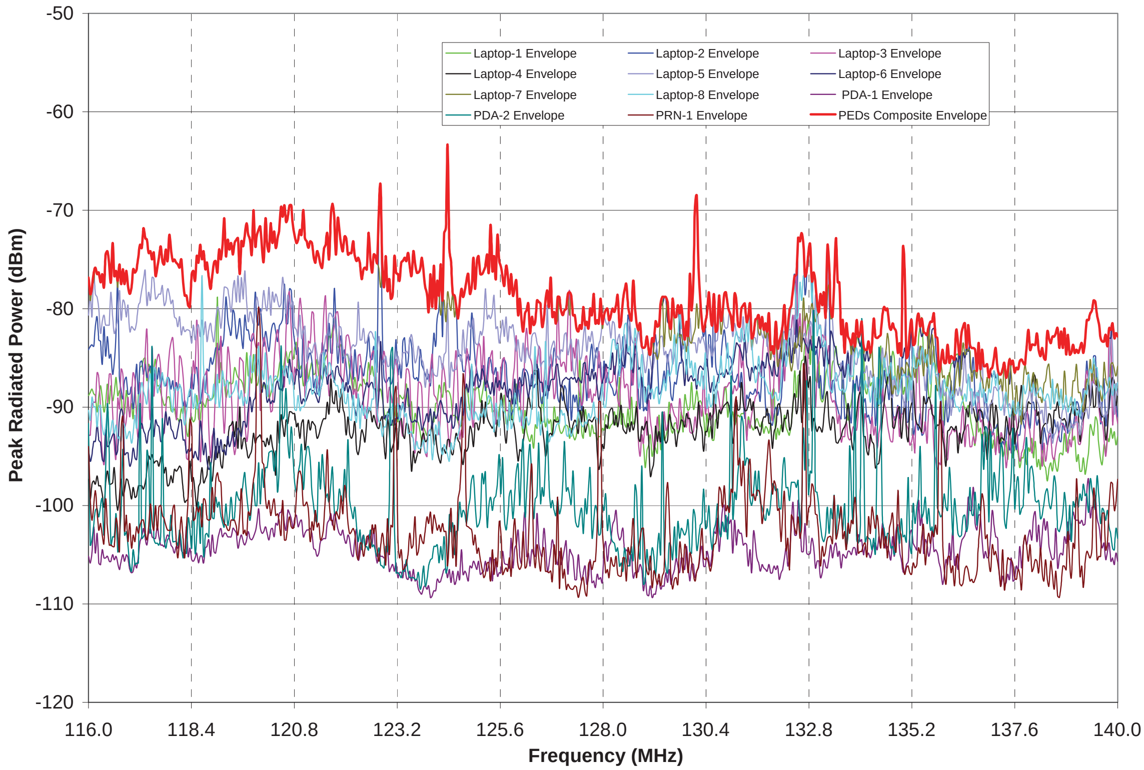

Figure 3.5-2: Individual PED Envelopes and PEDs Composite Envelope for Band 1b.

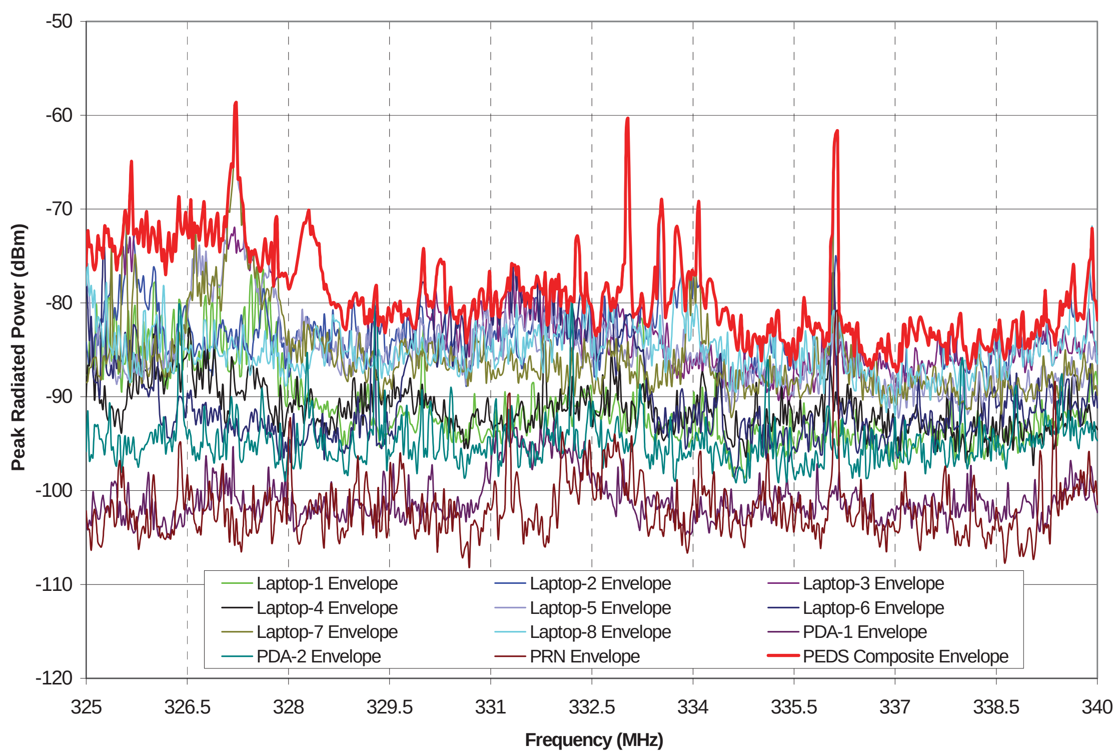

Figure 3.5-3: Individual PED Envelopes and PEDS Composite Envelope for Band 2.

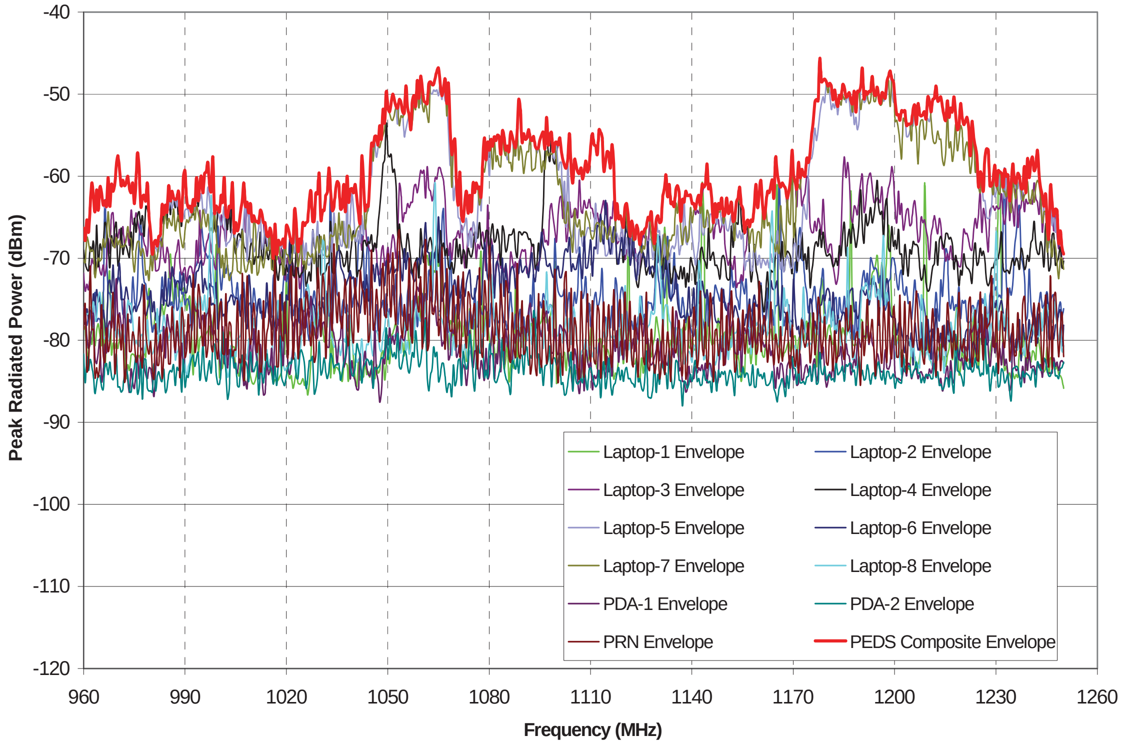

Figure 3.5-4: Individual PED Envelopes and PEDS Composite Envelope for Band 3.

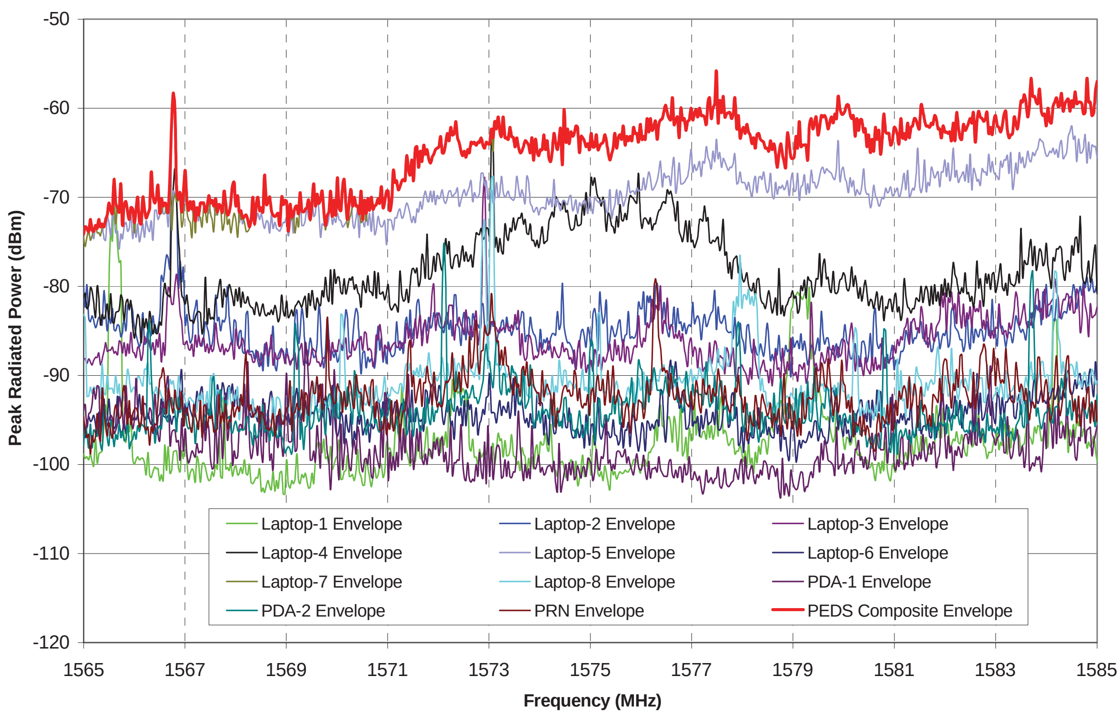

Figure 3.5-5: Individual PED Envelopes and PEDS Composite Envelope for Band 4.

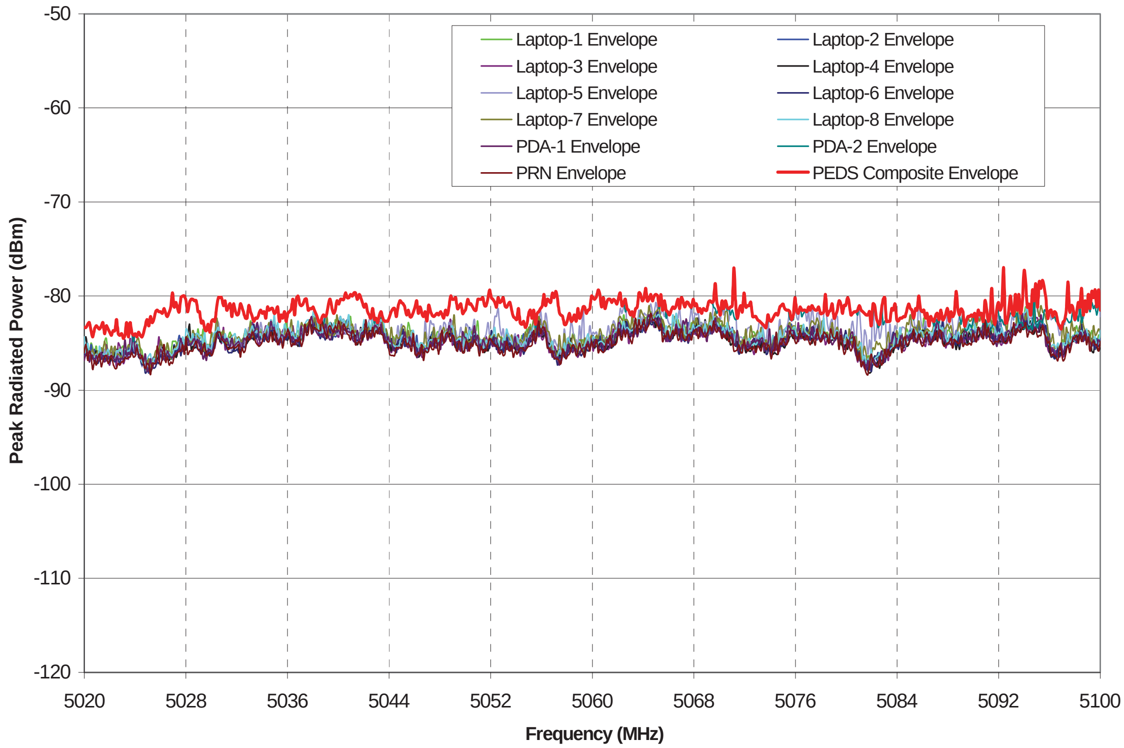

Figure 3.5-6: PEDs Individual and Composite Envelope for Band 5.

3.6 Summary of Maximum Emissions from Wireless Phones

This section summarizes maximum emission results reported in the earlier sections. In addition, comparisons with the corresponding FCC and RTCA/DO-160 emission limits are reported.

3.6.1 Summary of Maximum Emission Results

Table 3.6-1 summarizes emission data by reporting the maximum emission value of different device groups. The devices are grouped according to whether they operate in the cellular or PCS bands, or if they belong to the baseline laptop computers/PDA group.

The corresponding aircraft radio-navigation systems with frequency spectrum aligned within the measurement bands are grouped together as shown. These systems are potentially affected by any high emissions within their measurement bands. The data are also used in the safety margin calculations in a later section.

Figure 3.6-1 graphically illustrates the data in Table 3.6-1. The figure shows that the peak emissions from all 17 GSM and 16 CDMA phones are lower than the peak emissions from the eight laptop computers and PDAs. The exception is Band 5, where harmonics from the cellular band phones fall inside the band and their maximum levels exceed the laptop/PDA emissions. Fortunately, MLS is the only aircraft system operating in Band 5, and the system is not widely used in the US.

It is important to note that the lines in Figure 3.6-1 are only for linking the data points at the markers for visual effects. Their magnitudes between the markers have no data values.

Table 3.6-1: Maximum Emission from Wireless Phones in Aircraft Bands (in dBm)

Measurement Band	Frequency (MHz)	Cell-Band Phones (GSM & CDMA)	PCS-Band Phones (GSM & CDMA)	Baseline Laptops PDAs	Aircraft Bands
Band 1	105 - 140	-75.3	-76.8	-63.3	LOC, VOR, VHF-Com
Band 2	325 - 340	-79.5	-75.8	-58.7	GS
Band 3	960 - 1250	-64.7	-63.3	-45.7	TCAS, DME, GPS L2
Band 4	1565 -1585	-85.8	-66.5	-55.8	GPS L1
Band 5	5020 - 5100	-43.8	-63.8	-77.0	MLS

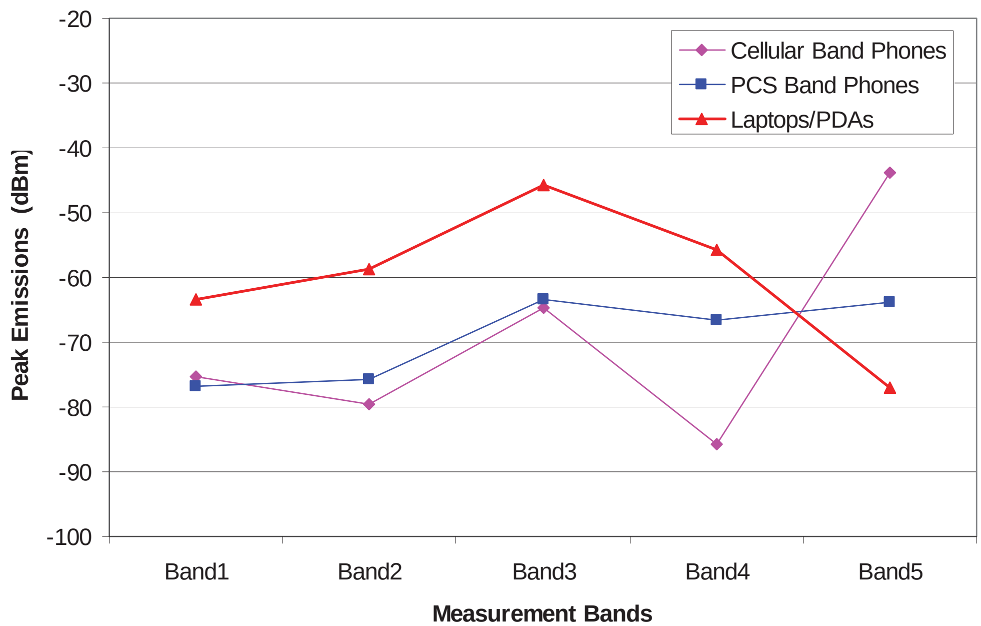

Figure 3.6-1: Maximum phone emissions and comparison with emissions from laptop computers and PDA.

3.6.2 Emission Limits

This section specifies the relevant limits used for comparison with the measurement results. The limits used include FCC limits for unintentional radiators (PEDs), FCC spurious emission limits for wireless phones, and the aircraft installed equipment limits. Table 3.6-2 summarizes the spurious emission limits used in the comparison in section 3.6.3.

FCC Emission Limits

Table 3.6-2 shows the FCC Part 15.109 [19] limits for unintentional radiators (PEDs), the RTCA/DO-160 Category M limits, and the FCC spurious emission limits for wireless phones in the cellular [20] and PCS bands [21].

For both cellular and PCS band operating phones, the out-of-band spurious and harmonic emissions must be attenuated below the intended output power, *P*, by at least 43 + 10 *log*(*P*) dB. Calculation shows that the limit is simply -13 dBm ERP for cellular band devices and -13 dBm EIRP for PCS band devices.

RTCA/DO-160 Category M Limits

The RTCA/DO-160 Section 21 [22] Category M emission limit is selected for comparison with spurious emissions from passenger carry-on electronic devices since these devices can be located in the passenger cabin or in the cockpit of a transport aircraft, where apertures (such as windows) are electromagnetically significant. The quote below is the definition for the Category M radiated emissions limit specified in RTCA/DO-160 Section 21:

> "*Category **M:***
> *This category is defined for equipment and interconnected wiring located in areas where apertures are em significant and not directly in view of radio receiver's antenna. This category may be suitable for equipment and associated interconnecting wiring located in the passenger cabin or in the cockpit of a transport aircraft*."

For the RTCA/DO-160 Category M limit listed in Table 3.6-2, the limit value for each *measurement band* is chosen to be the lowest limit of the *aircraft bands* within it. As an illustration, the emission measurement Band 3 covers TCAS, ATCRBS, DME, GPS L2 and GPS L5. The emission limit for the whole measurement band is chosen to be the lowest limit of all the systems listed. In this case, the lowest value is 50 dBμV/m for TCAS, DME and ATCRBS since the limits for GPS L2 and GPS L5 are higher. In addition, the emission limit for each aircraft radio band is chosen to be the lowest value between its lowest and highest frequency limits.

Power Conversion

To compare with measured emission data in dBm, the field limits in FCC Part 15 and the RTCA/DO-160 Category M are converted to the equivalent *EIRP* using Equation 3.6-1. In addition, *ERP* can be computed from *EIRP* using Equation 3.6-2.

$$EIRP = \frac{E^2 \cdot 4\pi R^2}{120\pi} \text{ (watts)} \qquad \text{(Eq. 3.6-1)}$$

$$ERP\,(dBm) = EIRP(dBm) - 2.15\,(dB) \qquad \text{(Eq. 3.6-2)}$$

where *E* = Electric Field Intensity at distance R (*V/m*)

R = Distance (*m*)

Ideally, *E* field measurement is taken in the direction of maximum radiation from the test device. To convert power, *EIRP*, from watts to dBm, use the expression *10 * log(1000*EIRP)*. For the RTCA/DO-160 limit given in *dBμV/m*, the unit is converted to *V/m* before applying Equation 3.6-1.

Table 3.6-2: Estimated FCC and RTCA spurious radiated emission limits

	FCC Part 15 Limit (μV/m @ 3m)	**RTCA/DO-160 Cat. M Limit** (dBμV/m @ 1m)	**FCC Part 15 Limit** (*EIRP*, dBm)	**RTCA/DO-160 Cat. M Limit** (*EIRP*, dBm)	**FCC Phone Limits (EIRP, dBm)**	
					Cell-Band Device (= -13 dBm ERP)	PCS-Band Device
Band 1	150	34	**-51.7**	**-70.8**	**-10.85**	**-13**
Band 2	200	52.9	**-49.2**	**-51.9**	**-10.85**	**-13**
Band 3	500	50	**-41.2**	**-54.8**	**-10.85**	**-13**
Band 4	500	53	**-41.2**	**-51.8**	**-10.85**	**-13**
Band 5	500	71.8	**-41.2**	**-33.0**	**-10.85**	**-13**

3.6.3 Measurement Results and Spurious Emission Limit Comparison

Radiated emissions measured using a reverberation chamber provide results in "total radiated power" (*TRP*) within the measurement resolution bandwidth. *TRP* is different from *EIRP* and *ERP* except for antennas or devices with an isotropic radiation pattern. Rather,

$$EIRP \text{ (dBm)} = TRP \text{ (dBm)} + D_G \text{ (dB), and} \quad \text{(Eq. 3.6-3)}$$

where D_G is *directivity*, or maximum *directive gain* of the test device. Directive gain of any device is a measure of radiated power as a function of aspect angle referenced to the isotropic value. For spurious emissions, D_G is the directivity at the spurious emission frequency of interest. D_G is usually difficult to measure or calculate since maximum radiation angles and radiation mechanisms for *spurious* emissions are often not known. Maximum theoretical estimation of D_G based on device size tends to significantly over-estimate the real directivity, especially at high frequency, because the device geometry is typically not designed to radiate efficiently as an antenna as assumed in the theoretical estimation. However, there are recent theoretical statistical developments to estimate the "expected" directivity for non-intentional radiators [23]. Additional details on expected directivity are discussed in Section 3.6.4.

For simplicity, the tested devices (phones and computer laptops/PDAs) are assumed to have unity D_G for spurious emissions. Thus, *TRP* is assumed to be the same as *EIRP* at all spurious frequencies of interest. This assumption introduces an uncertainty level equal to D_G, according to Equation 3.6-3. For a dipole antenna with small electrical length, D_G is close to 1.76 dBi (or dB relative to isotropic). For a half-wave dipole, D_G is close to 2.15 dBi. Thus, it is reasonable to assume for devices up to one-half a wavelength in size, the uncertainties should not be much more than 5 dB. This level of uncertainty is considered acceptable for a first order comparison.

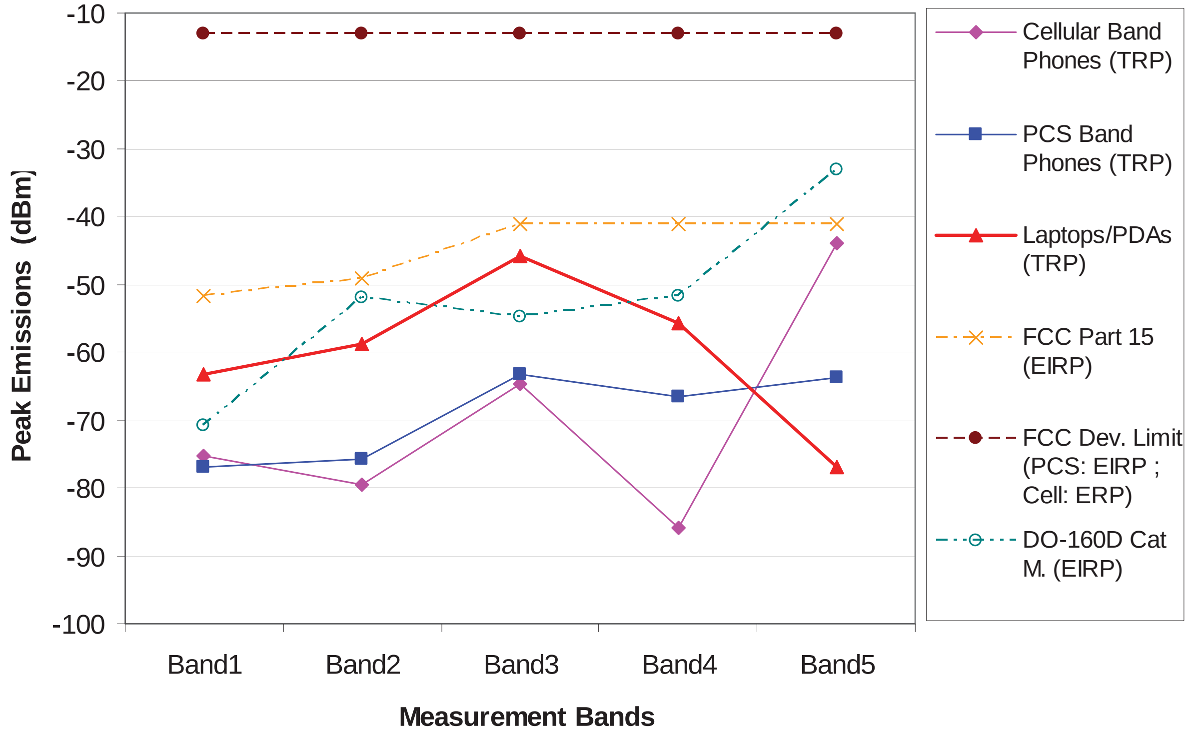

Figure 3.6-2: Emissions from wireless phones and comparison with emission limits.

Figure 3.6-2 shows that the spurious emissions from the wireless phones tested are below the aircraft installed equipment emission limits (RTCA/DO-160 Category M). They are also below the FCC Part 15 limits for unintentional transmitters such as laptop computers. The finding is still valid even after considering the uncertainty associated with devices' expected directivities. The expected directivity is between 5 and 8 dB for the wireless phones as shown in Section 3.6.4. The measured spurious emissions are also far below the -13 dBm FCC's wireless phone spurious limits (EIRP for PCS-band devices and ERP cellular-band devices).

3.6.4 Device Expected Directivity

The comparisons in the previous section were between the device's TRP and the FCC and RTCA/DO-160 equivalent EIRP limits, assuming unity directivity. For most devices, directivity is different than unity, and the limits must be adjusted downward by the amounts equal to the directivity of each individual device. This value can vary with frequency, device size and geometry. It is also difficult to estimate for spurious emissions since the specific radiation mechanisms are often not known.

Reference [23] provides a method to estimate the expected directivity from a statistical approach. This approach was intended for estimating the directivity of non-transmitting (intentionally) devices, or directivity at spurious frequencies. It is not intended for intentional transmitters such as antennas. In the approach, the expected directivity of a device can be estimated if its maximum dimension is known.

Wireless phones come in various sizes and configurations. Device sizes of the tested phones can vary from 8 cm (about 3 inches) to the maximum of 20 cm (about 8 inches) with the antennas extended and the phone in open configuration. Figure 3.6-3 shows the expected directivity for a device 20 cm in size, using the equations given in [23]. This figure shows the results of three calculations: 1) the theoretical maximum directivity for a high gain antenna of the same size, 2) the expected directivity for a 1-planar cut measurement, and 3) expected directivity for a 3-planar cut measurement. The chart shows directivity is between 5 dB near 100 MHz to 8 dB near 5 GHz.

These expected directivity values are provided for information purposes only. The method is yet to be widely accepted.

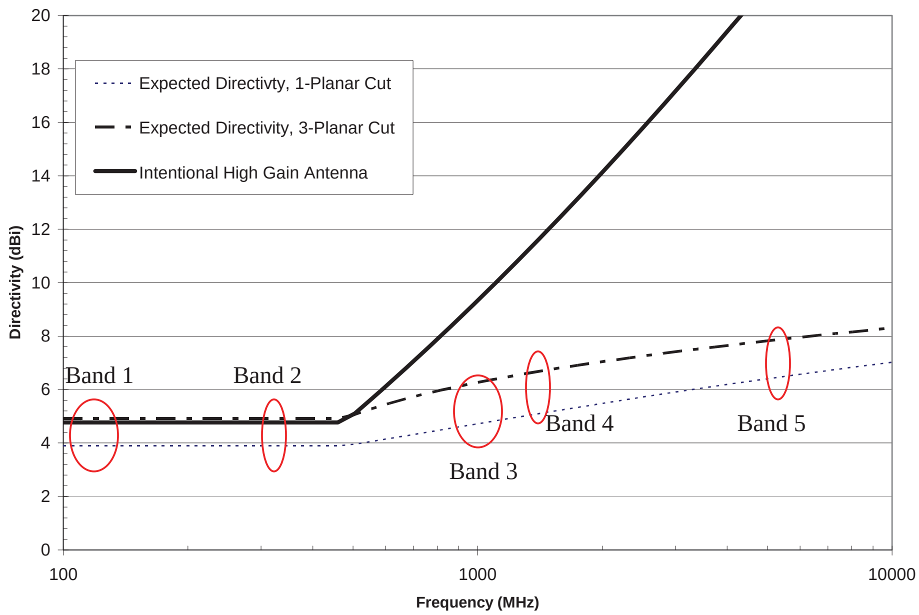

Figure 3.6-3: Expected directivity for a 20 cm (approximately 8 inches) unintentional transmitter

4 Aircraft Interference Path Loss

Aircraft IPL is the second of the three components needed for assessing the potential of interference from RF sources to aircraft receivers. Using World Jet Inventory [24] 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 as of 2002. Each aircraft type and series has a unique configuration of antenna placements and radio receiver installations. These variations may result in widely different IPL values. Reference [2] describes a recent effort to measure IPL for various radio receiver systems on six B737s and four B747s. The results were summarized and reported along with other previously available data for comparison. The summarized results are repeated here for risk assessment analysis.

This report defines IPL with respect to interference through aircraft radio receiver's antenna port. This interference mechanism is often called "front-door" interference. "Back-door" mechanisms typically involve interference signals coupling onto wires connected to the equipment, and is not addressed in this report.

A possible approach and set-up to measure the IPL data is described in Section 4.1. This approach was used in measuring IPL on B737s and B747s reported in [2] and shown in Figure 4.1-1. The minimum IPL from these measurements are reported in Section 4.2 along with other existing IPL data. Section 4.3 summarizes the minimum IPL data that are then used in the interference risk assessment in a later section.

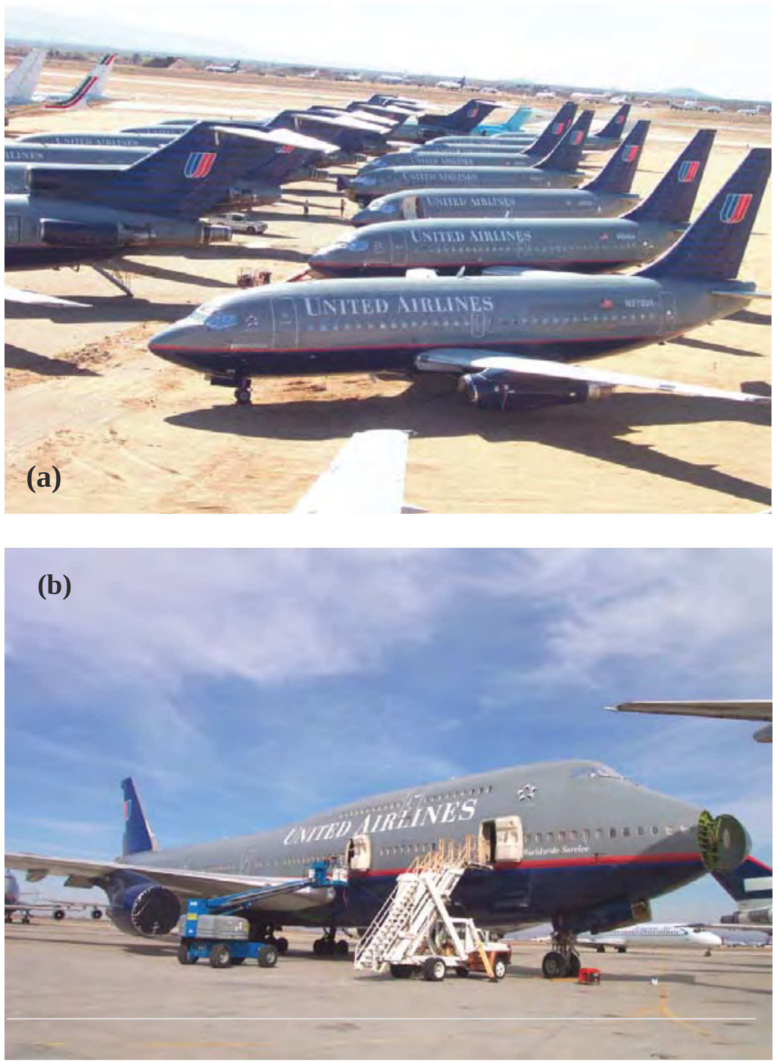

Figure 4.1-1: (a) B737-200 and (b) B747-400 aircraft at the measurement site. IPL data collected using the process described in this section.

4.1 IPL Measurement Method

It is assumed that for PEDs interference problems, the interference source is located within the passenger cabin, and the victims are aircraft radio receiver systems. A common path of PED interference is through the windows or door seams, along the aircraft body, and into the aircraft antennas. The interference signal picked up by the antennas is channeled back into the receivers to potentially cause interference if the signal is of sufficient strength.

Figures 4.1-2 and 4.1-3 illustrate typical radio receiver interference coupling paths and a possible setup for conducting IPL measurements. This setup was used in [2]. The setup shows a tracking source provides RF power to the transmit antenna, and a spectrum analyzer is utilized to measure the signal received by the aircraft antenna. The frequency-coupled spectrum analyzer and tracking source pair allows for frequency sweeps, resulting in more thorough measurements and reduced test time. Swept-CW setup is preferred over discrete frequency measurement, according to RTCA/DO-233. A pair of test cables connect the instruments to the aircraft antenna cable and to the transmit antenna. An amplifier may be needed to increase the signal strength delivered to the transmit antenna, and a pre-amplifier may be used in the receive path near the spectrum analyzer for increased dynamic range. This pre-amplifier (not shown in Figure 4.1-3) may be internal to the spectrum analyzer.

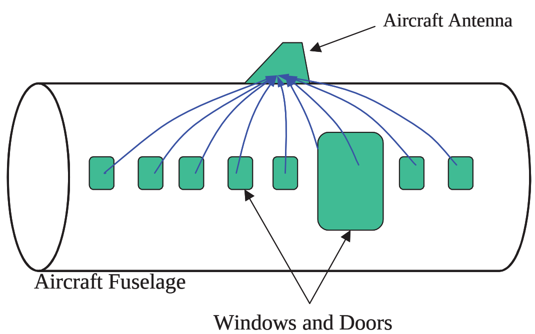

Figure 4.1-2: A typical radio receiver interference coupling path for a top mounted aircraft antenna.

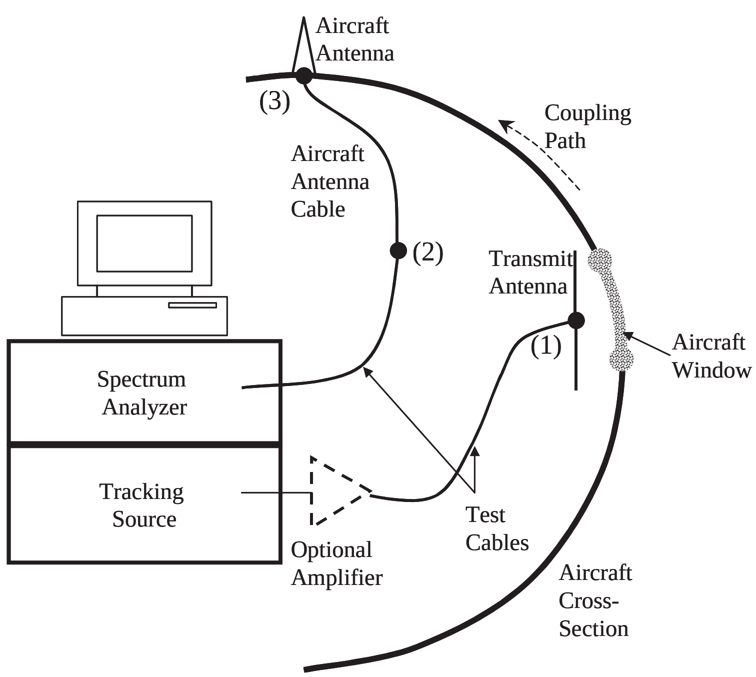

Figure 4.1-3: A typical setup for conducting an IPL measurement.

In Figure 4.1-3, IPL is defined to be the ratio, or the difference in dB, between the power radiated from the transmit antenna at location (1) to the power received at location (2). For GPS, IPL is defined to be the difference in power between location (1) and (3). Or,

$$IPL = P^T_{(1)} - P^R_{(2)} \quad \text{for most systems, and} \qquad \text{(Eq. 4.1-1)}$$

$$IPL = P^T_{(1)} - P^R_{(3)} \quad \text{for GPS,} \qquad \text{(Eq. 4.1-2)}$$

where $P^T_{(1)}$ is power transmitted at point (1), and $P^R_{(2)}$, and $P^R_{(3)}$ are power received at points (2) and (3), in dBm, respectively.

The transmit antennas used in the measurement typically include dipoles for frequencies in the GS band and below, and a dual-ridge horn antenna for the frequencies in the TCAS band and above. In this effort, no corrections are made to account for the transmit antenna gain. The close proximity between the transmit antenna and the surrounding (such as windows and passenger seats) could significantly alter the gain, and the free-space values may not be appropriate. Table 4.1-1 shows the relevant parameters for the measurement on the B747 and B737 IPL data reported in [2], Section 4.2 and Section 6. The free-space antenna gains for the source antenna used are also shown in the table.

Table 4.1-1: Transmit Antenna Free-Space Gain (dBi)

Aircraft Systems	Spectrum (MHz)	Measurement Frequency Range (MHz)	Transmit Antenna Type	Free-Space Antenna Gain (dBi)
VHF-Com	118 – 137	116-138	Dipole	2.1
LOC/VOR	LOC: 108.1 – 111.95 VOR: 108 – 117.95	108-118	Dipole	0.9
GS	328.6 – 335.4	325-340	Dipole	1.9
TCAS	1090	1080 – 1100	Dual-Ridge Horn	7.4
GPS (L1)	1575.42 ± 2	1565 – 1585	Dual-Ridge Horn	9.6
SatCom	1545-1559	1530 – 1561	Dual-Ridge Horn	9.6

For most systems, IPL included aircraft cable loss, since receiver susceptibility thresholds were specified at the receiver antenna port. For GPS, interference thresholds were specified at the output of a passive GPS antenna. Thus, IPL for GPS should not include the antenna cable loss. The test cable should connect directly to the GPS antenna output or very close to it, and the spectrum analyzer measured the power at the output of the antenna directly. If an aircraft active GPS antenna was powered with the help of a DC bias-tee, the bias-tee should be included in the total system loss measurement.

For GPS, interference threshold is specified at the output of a passive antenna, or at the output of an active GPS antenna, but before the pre-amplifier stage. Thus, the active GPS antenna pre-amplifier gain should be removed during post processing. This step was required in the GPS receiver's Minimum Operating Performance Standards (MOPS)

The measurement process for each system on each aircraft can involve the following steps:

1. Conduct 1-meter path loss measurement. IPL was measured with the transmit antenna positioned one meter from the aircraft antenna. This simple step established a baseline measurement and helped detect any excessive aircraft antenna cable loss. Excessive cable loss could indicate possible signs of connector corrosion in the path. These data were not needed to compute the IPL.

2. Configure the spectrum analyzer to the proper reference level, resolution bandwidth, attenuation level and desired measurement frequency band. Configure the tracking source to track the frequency sweep of the spectrum analyzer. Set the tracking source output to desired power level.

3. Measure test cable and aircraft cable "through" losses.

4. Position the transmit antenna at a desired location, typically near a window or door. Point the antenna to radiate toward a window or door seam.

5. Clear spectrum analyzer's trace. Set spectrum analyzer to "Trace Max Hold" and sweep continuously across the desired measurement band.

6. Scan the transmit antenna slowly along the door seam, while the spectrum analyzer is still set at "Trace Max Hold". No scanning was needed at the windows due to small window sizes.

7. Record trace and the peak marker value. For systems that experience narrowband peaks caused by strong local transmitters such as LOC, position the marker at the peak of the broadband envelope while avoiding the narrowband peaks. Record data at this marker location.

8. Change polarization and repeat from step 2 so that both vertical and horizontal polarizations of the transmit antenna are included.

9. Relocate the transmit antenna to another window/door and repeat from step 4.

Post processing helps remove the measured system "through" loss from the total path loss data. The system loss includes the effects of test cable losses, amplifier gains, and other types of losses/gains in the measurement path. Active GPS pre-amplifier gain is also removed in the final results.

Figure 4.1-4 shows a measurement being conducted with the transmit antenna at a window, and the computer and software used for data acquisition. Instruments and computers were located within the passenger cabin. Spurious emissions from the equipment were too low to be measurable or to affect the measurement. In contrast, the output signal from the tracking source was 10 dBm or higher depending upon whether an external amplifier was used.

Figure 4.1-4: IPL measurement at window locations. (a) A dipole was used as transmit antenna for LOC, VOR, GS and VHF-Com. (b) A dual ridge horn antenna was used for TCAS, GPS and SatCom. (c) A computer recorded data from the spectrum analyzer (located underneath the computer).

4.2 Interference Path Loss Results

Recent IPL results along with existing publicly available data are reported in this section. Section 4.2.1 reports the recent measured results using the described method. Section 4.2.2 discusses the results summarized from other efforts. The combined data are reported in Tables 4.2-1 to 4.2-7.

4.2.1 Recent Measured Results

Recent IPL data for several radio receivers on six B737-200 and four B747-400 aircraft are reported in Tables 4.2-1 to 4.2-7 [2]. In addition to the window and door locations, IPL measurements were also conducted at each of the seats, including one measurement between two adjacent seats on the left half of two B737 aircraft. As a result, each full-aircraft measurement provided approximately 160 locations (times two for two transmit antenna polarizations) rather than about 36 window and door locations. Statistics such as the minimum and the average IPL were also reported.

Comparing the window/door data against the full-aircraft data for these two B737s, it was recognized that the window/door measurements capture the *minimum* IPL for the systems on those aircraft. Also, the differences in *average* IPL values were not significant. The comparison validates the common understanding that the minimum IPL occurs at window and door locations, at which most measurements were made.

The same full-aircraft IPL data for the B737 aircraft were also used to provide a conservative estimate of the effects due to multiple PED devices. The approach computes the interference power at the receiver by first scaling each PED's emissions according to the IPL for its location. The total interference power is the sum of all contributions, reasonably assuming the signals are incoherent. Multiple equipment factor (MEF) is defined as the ratio, in dB, of total interference power at the receiver to the interference power due to one PED located at the worst case location for the lowest IPL. Additional details on the computation and results of MEF for several radio systems are shown in Section 6.

4.2.2 Other Interference Path Loss Data

There are also other IPL data previously reported in various documents. These documents consist of RTCA/DO-199 [6], RTCA/DO-233 [25], a Veda report [26], and those from the cooperative agreement between NASA and Delta Airlines [27]. Most of these data were previously summarized in the report on interference effects of wireless phones to aircraft radio-navigation receivers [1]. For completeness, they are again reported in Tables 4.2-1 to 4.2-7.

The main difference between the path loss definition in this document and the definition used in parts of RTCA/DO-199 and RTCA/DO-233 is whether the transmit antenna's free-space antenna factors are included in the path loss data provided. In this document, it is assumed that the environment is far from free space and that free-space antenna factors are not valid correction factors. The true transmit antenna factors are not known, and are not included in the path loss calculations. However, free-space antenna factors for the antennas used are provided in Table 4.1-1 if corrections are desired.

In the Appendix A of RTCA/DO-199, most reported papers used the same definition for IPL as shown in Eq. 4.1-1, but with a correction for transmit antenna gain. However, there were also test papers in RTCA/DO-199 with path-loss-factors calculated *without* the correction applied (paper SC156-110). In these cases, the path loss definition is the same as in this report.

In RTCA/DO-233, path-loss-factor calculations "may" include *Tx* antenna gain. Antenna factors were given for a dipole antenna used but not for other transmit antennas.

In Tables 4.2-1 to 4.2-7, IPL was reported for LOC, GS, VHF Comm., SatCom, TCAS, and GPS. Data were grouped into large, medium, and small aircraft categories. For each aircraft measured, the minimum IPL (MIPL), the average IPL and the standard deviation (StDev) were reported.

The number of measurement points and measurement frequency range were also reported when available. The number of measurement points was often reported as a *number times 2*, i.e. "*26x2*". This notation indicated that both transmit antenna polarizations, vertical and horizontal, were used at each measurement location, effectively doubling the number of data points. Thus, "26x2" indicated measurements were taken at 26 locations, with vertical and horizontal polarized source antenna, resulting in 52 data points.

The statistics of the MIPL for each large, medium and small aircraft category were also reported. In addition, statistics of the MIPL calculated using ALL available data were shown at the end of each table and again in Table 4.3-1. These statistics include the lowest MIPL and the average MIPL for the safety margin calculations in Section 5.

In the tables 4.2-1 to 4.2-7, the following symbols are used in identifying the sources for the measurement data:

{1} United Airlines, Eagle Wings Inc., and NASA LaRC cooperative effort

{2} Delta Airlines, Eagle Wings Inc., and NASA LaRC cooperative effort

{3} United Airlines and Eagle Wings Inc.

{4} RTCA/DO-233

{5} RTCA/DO-199

{6} RTCA/SC-177

{7} Aerospatiale

{8} Veda/FAA

Table 4.2-1: SatCom IPL

Recent Data	Aircraft & Model {Source}	Interference Path Loss (IPL) (dB)			No. of Meas.	Test Freq. Range (MHz)
		Min (MIPL)	Average	StDev		
	Large Aircraft					
✓	B747 Nose No. 8173 {1}	52.1	70.7	18.6	21x2	
✓	B747 Nose No. 8174 {1}	51.5	70.1	18.6	21x2	
✓	B747 Nose No. 8188 {1}	53.6	65.8	12.2	21x2	
✓	B747 Nose No. 8186 {1}	55.5	70.2	14.7	21x2	
	B747 {4}	87.0	96.8	5.0		
	Column Minimum	**51.5**	***65.8***			
	Column Average	**59.9**	***74.7***			
	Column Maximum	***87.0***	***96.8***			
	Column Standard Deviation	***15.2***	***12.5***			

Table 4.2-2: GPS IPL

Recent Data	Aircraft & Model {Source}	Interference Path Loss (IPL) (dB)			No. of Meas.	Test Freq. Range (MHz)
		Min (MIPL)	Average	StDev		
	Large Aicraft					
✓	B747 Nose No. 8173 {1}	65.7	73.5	4.0	21x2	1565-1585
✓	B747 Nose No. 8174 {1}	66.3	72.9	3.3	21x2	1565-1585
✓	B747 Nose No. 8188 {1}	64.7	70.6	2.9	21x2	1565-1585
✓	B747 Nose No. 8186 {1}	66.3	74.0	3.5	21x2	1565-1585
	Column Minimum	***64.7***	***70.6***			
	Column Average	***65.8***	***72.8***			
	Column Maximum	***66.3***	***74.0***			
	Medium Aircraft					
✓	B737 Nose No. 1989 {1}	64.9	75.0	4.0	36x2	1565-1585
✓	B737 Nose No. 1883 {1}	64.0	76.0	5.3	76x2	1565-1585
✓	B737 Nose No. 1879 {1}	71.2	77.1	3.9	33x2	1565-1585
✓	B737 Nose No. 1997 {1}	68.8	74.5	2.7	34x2	1565-1585
✓	B737 Nose No. 1994 {1}	67.4	74.4	3.9	34x2	1565-1585
✓	B737 Nose No. 1881 {1}	67.2	73.0	3.5	33x2	1565-1585
	CV-580 {8}	41.0				
	B727 N40 {5}	71.0	77.0		12	1575
	Column Minimum	***41.0***	***73.0***			
	Column Average	***64.4***	***75.3***			
	Column Maximum	***71.2***	***77.1***			
	Small Aircraft					
	Gulf G4 {4}	82.4	91.4	5.7		
	CRJ {2}	43.2	53.5	6.1	14x2	
	Column Minimum	***43.2***	***53.5***			
	Column Average	***62.8***	***72.5***			
	Column Maximum	***82.4***	***91.4***			
	All Aircraft Column Minimum	**41.0**	**53.5**			
	All Aircraft Column Average	**64.6**	**74.1**			
	All Aircraft Column Maximum	**82.4**	**91.4**			
	All Aircraft Standard Deviation	**10.6**	**8.0**			

Table 4.2-3: TCAS IPL

Recent Data	Aircraft & Model {Source}	Interference Path Loss (IPL) (dB)			No. of Meas.	Test Freq. Range (MHz)
		Min (MIPL)	Average	StDev		
	Large Aircraft					
✓	B747 Nose No. 8173 {1}	63.2	69.9	4.4	21x2	1080-1100
✓	B747 Nose No. 8174 {1}	61.7	67.3	3.3	21x2	1080-1100
✓	B747 Nose No. 8188 {1}	63.3	68.6	2.3	21x2	1080-1100
✓	B747 Nose No. 8186 {1}	64.2	71.0	3	21x2	1080-1100
	Column Minimum	***61.7***	***67.3***			
	Column Average	***63.1***	***69.2***			
	Column Maximum	***64.2***	***71.0***			
	Medium Aircraft					
✓	B737 Nose No. 1989 {1}	53.0	66.1	4.4	36x2	1080-1100
✓	B737 Nose No. 1883 {1}	52.8	64.8	4.3	36x2	1080-1100
✓	B737 Nose No. 1879 {1}	55.8	67.6	4.4	36x2	1080-1100
✓	B737 Nose No. 1997 Windows {1}	54.3	68.3	4.4	36x2	1080-1100
✓	B737 Nose No. 1997 Full Aircraft{1}	54.3	70.9	3.8	179x2	1080-1100
✓	B737 Nose No. 1994 {1}	56.6	69.3	4.2	36x2	1080-1100
✓	B737 Nose No. 1881 {1}	56.3	69.0	4.5	36x2	1080-1100
	B757 {4}	69.1	83.3	7.3		
	B757-TCAS-Top {2}	58.6	71.5	6.9	55x2	
	B757-TCAS-Bottom {2}	57.6	75.0	7.7	53x2	
	A320 -TCAS-T {4}	54.8	74.6	11.3		
	A320 -TCAS-B {4}	63.0	78.5	7.1		
	A320 {7}					
	Column Minimum	***52.8***	***64.8***			
	Column Average	***57.2***	***71.6***			
	Column Maximum	***69.1***	***83.3***			
	Small Aircraft					
	CRJ TCAS-Top {2}	53.1	59.2	4	14x2	
	CRJ TCAS-Bottom {2}	54.7	61.5	3.3	14x2	
	Emb 120 -TCAS-Top {2}	50.7	57.6	4.5	11x2	
	Emb 120 -TCAS-Bottom {2}	48.2	59.7	5.8	11x2	
	ATR72- TCAS-Top {2}					
	ATR72- TCAS-Bottom {2}					
	Column Minimum	***48.2***	***57.6***			
	Column Average	***51.7***	***59.5***			
	Column Maximum	***54.7***	***61.5***			
	All Aircraft Column Minimum	**48.2**	**57.6**			
	All Aircraft Column Average	**57.3**	**68.7**			
	All Aircraft Column Maximum	**69.1**	**83.3**			
	All Aircraft Standard Deviation	**5.3**	**6.4**			

Table 4.2-4: GS IPL

Recent Data	Aircraft & Model {Source}	Interference Path Loss (IPL) (dB) Min (MIPL)	Average	StDev	No. of Meas.	Test Freq. Range (MHz)
	Large Aircraft					
✓	B747 Nose No. 8173 {1}	49.3	67.6	8.4	26x2	325-340
✓	B747 Nose No. 8174 {1}	51.0	69.6	9.3	26x2	325-340
✓	B747 Nose No. 8188 {1}	49.3	68.8	7.9	26x2	325-340
✓	B747 Nose No. 8186 {1}	48.9	66.1	8.5	26x2	325-340
	B747 {4}	54.6	86.2	14.1		
	B747 {3}	53.0	71.0	8.0	36	
	DC10 {5}	77.0	91.0		24	329-335
	L1011 {4}	64.4	82.6	8.1		
	Column Minimum	***48.9***	***66.1***			
	Column Average	***55.9***	***75.4***			
	Column Maximum	***77.0***	***91.0***			
	Medium Aircraft					
✓	B737 Nose No. 1989 {1}	58.9	70.1	5.0	36x2	325-340
✓	B737 Nose No. 1883 {1}	60.2	75.1	6.5	36x2	325-340
✓	B737 Nose No. 1879 {1}	59.7	75.4	5.5	36x2	325-340
✓	B737 Nose No. 1997 Windows {1}	61.7	72.2	5.2	36x2	325-340
✓	B737 Nose No. 1997 Full Aircraft {1}	61.7	73.3	4.3	169x2	325-340
✓	B737 Nose No. 1994 {1}	61.4	73.9	6.5	36x2	325-340
✓	B737 Nose No. 1881 {1}	59.5	72.2	5.7	36x2	325-340
	B737 {4}	68.8	83.1	4.9		
	B757 {4}	57.5	83.0	9.9		
	B757 {2}	58.9	72.1	6.0	53x2	
	B727 {6}	68.0	83.0			
	B727 {5}	68.0	76.0		12	328
	CV-580 {8}	64.0				
	MD80 {4}	63.5	85.4	11.0		
	A320 {4}	64.6	84.2	10.0		
	A320 {7}	*56.0*	70.0			
	Column Minimum	***56.0***	***70.0***			
	Column Average	***62.0***	***76.6***			
	Column Maximum	***68.8***	***85.4***			
	Small Aircraft					
	Canadair RJ {2}	51.6	59.7	3.2	14x2	
	Emb 120 {2}	46.2	51.5	2.3	10x2	
	ATR72	57.5	68.0	5.4	26x2	
	Column Minimum	***46.2***	***51.5***			
	Column Average	***51.8***	***59.7***			
	Column Maximum	***57.5***	***68.0***			

Table 4.2-4: Concluded

All Aircraft Column Minimum	**46.2**	**51.5**
All Aircraft Column Average	**59.1**	**74.3**
All Aircraft Column Maximum	**77.0**	**91.0**
All Aircraft Standard Deviation	**7.2**	**8.8**

Table 4.2-5: VOR IPL

Recent Data	Aircraft & Model {Source}	Interference Path Loss (IPL) (dB) Min (MIPL)	Average	StDev	No. of Meas.	Test Freq. Range (MHz)
	Large Aircraft					
✓	B747 Nose No. 8173 {1}	51.8	68.8	9.4	26x2	108-118
✓	B747 Nose No. 8174 {1}	62.7	82.3	10.9	26x2	108-118
✓	B747 Nose No. 8188 {1}	55.0	77.7	11.6	26x2	108-118
✓	B747 Nose No. 8186 {1}	58.9	77.0	10.6	26x2	108-118
	B747 {4}	84.7	105.0	5.1		
	B747 {3}	76.0	80.0	3.0	8	
	DC 10 {5}	80.0	89.0		20	113-117
	L1011 {4}	70.3	79.0	2.0		
	Column Minimum	***51.8***	***68.8***			
	Column Average	***67.4***	***82.4***			
	Column Maximum	***84.7***	***105.0***			
	Medium Aircraft					
✓	B737 Nose No. 1989 Windows {1}	65.0	78.1	7.7	36x2	108-118
✓	B737 Nose No. 1989 Full Aircraft {1}	65.0	81.7	5.6	156x2	108-118
✓	B737 Nose No. 1883 {1}	56.5	73.0	9.8	36x2	108-118
✓	B737 Nose No. 1879 {1}	61.8	77.5	7.7	36x2	108-118
✓	B737 Nose No. 1997 {1}	74.2	87.3	6.2	36x2	108-118
✓	B737 Nose No. 1994 {1}	62.6	78.5	7.9	36x2	108-118
✓	B737 Nose No. 1881 {1}	67.0	78.6	6.0	36x2	108-118
	B737 {4}	76.0	90.0	5.0		
	B757 {4}	49.9	90.7	9.9		
	B757 {2}	46.7	65.8	6.8	56x2	
	B727-a {5}	70.0	74.0		6	112-117
	B727 -b {5}	30.0	56.0		86	112-117
	B727-c {5}	71.0	76.0		6	109-120
	B727 {6}	75.0	90.0			
	CV-580 {8}	45.0				
	MD80 {4}	66.2	87.8	9.4		
	A320 {4}	65.0	91.9	8.7		
	A320 {7}	59.0	84.0			
	Column Minimum	***30.0***	***56.0***			
	Column Average	***61.4***	***80.1***			
	Column Maximum	***76.0***	***91.9***			

Table 4.2-5: Concluded

Small Aircraft				
Canadair RJ {2}	57.9	71.6	6.6	14x2
Emb 120 {2}	41.8	56.3	4.5	11x2
ATR72 {2}	63.9	72.1	4.2	25x2
Column Minimum	***41.8***	***56.3***		
Column Average	***54.5***	***66.7***		
Column Maximum	***63.9***	***72.1***		
All Aircraft Column Minimum	**30.0**	**56.0**		
All Aircraft Column Average	**62.4**	**79.3**		
All Aircraft Column Maximum	**84.7**	**105.0**		
All Aircraft Standard Deviation	**12.2**	**10.6**		

Table 4.2-6: LOC IPL

Recent Data	Aircraft & Model {Source}	Interference Path Loss (IPL) (dB)			No. of Meas.	Test Freq. Range (MHz)
		Min (MIPL)	Average	StDev		
	<u>Large Aircraft</u>					
✓	B747 Nose No. 8173 {1}	51.8	68.8	9.4	26x2	108-118
✓	B747 Nose No. 8174 {1}	62.7	82.3	10.9	26x2	108-118
✓	B747 Nose No. 8188 {1}	55.0	77.7	11.6	26x2	108-118
✓	B747 Nose No. 8186 {1}	58.9	77.0	10.6	26x2	108-118
	B747 {4}	64.8	93.9	12.7		
	B747 {3}	55.0	61.0	2.0	38	
	DC10 {5}	82.0	91.0		10	108
	L1011 {4}	60.7	85.2	9.4		
	Column Minimum	***51.8***	***61.0***			
	Column Average	***61.4***	***79.6***			
	Column Maximum	***82.0***	***93.9***			
	<u>Medium Aircraft</u>					
✓	B737 Nose No. 1989 Windows {1}	65.0	78.1	7.7	36x2	108-118
✓	B737 Nose No. 1989 Full Aircraft {1}	65.0	81.7	5.6	156x2	108-118
✓	B737 Nose No. 1883 {1}	56.5	73.0	9.8	36x2	108-118
✓	B737 Nose No. 1879 {1}	61.8	77.5	7.7	36x2	108-118
✓	B737 Nose No. 1997 {1}	74.2	87.3	6.2	36x2	108-118
✓	B737 Nose No. 1994 {1}	62.6	78.5	7.9	36x2	108-118
✓	B737 Nose No. 1881 {1}	67.0	78.6	6.0	36x2	108-118
	B737 {4}	72.7	90.7	8.8		
	B757 {4}	51.5	86.1	11.4		
	B757 {2}	56.1	75.3	10.2	52x2	
	B727 -a {5}	63.0	67.0		6	108-112
	B727 -b {5}	35.0	53.0		86	108-112
	B727 {6}	72.0	90.0			
	A320 {4}	48.8	85.7	14.8		
	A320 {7}	54.0	75.0			
	Column Minimum	***35.0***	***53.0***			
	Column Average	***60.3***	***78.5***			
	Column Maximum	***74.2***	***90.7***			
	<u>Small Aircraft</u>					
	Canadair RJ {2}	57.9	71.6	6.6	14x2	
	Emb 120 {2}	41.8	56.3	4.5	11x2	
	ATR72 {2}	63.9	72.1	4.2	25x2	
	Column Minimum	***41.8***	***56.3***			
	Column Average	***54.5***	***66.7***			
	Column Maximum	***63.9***	***72.1***			

Table 4.2-6: Concluded

All Aircraft Column Minimum	**35.0**	**53.0**
All Aircraft Column Average	**60.0**	**77.5**
All Aircraft Column Maximum	**82.0**	**93.9**
All Aircraft Standard Deviation	**10.0**	**10.4**

Table 4.2-7: VHF Comm IPL

Recent Data	Aircraft & Model {Source}	Interference Path Loss (IPL) (dB)			No. of Meas.	Test Freq. Range (MHz)
		Min (MIPL)	Average	StDev		
	<u>Large Aircraft</u>					
✓	B747 Nose No. 8173 {1}	31.5	53.9	7.7	21x2	116-138
✓	B747 Nose No. 8174 {1}	32.3	56.3	6.7	21x2	116-138
✓	B747 Nose No. 8188 {1}	35.3	58.9	6.6	21x2	116-138
✓	B747 Nose No. 8186 {1}	35.3	59.5	7.9	21x2	116-138
✓	B747 Nose No. 8188 {1} (AC Pressurized)	43.2	61.5	5.9	21x2	116-138
	B747 -VHF1 {4}	40.5	79.2	12.0		
	B747 -VHF2 {4}	63.2	86.2	10.8		
	B747 -VHF3 {4}	71.5	92.9	7.4		
	DC 10 {5}	63.0	80.0		45	117-137
	L1011 -VHF1 {4}	56.2	72.9	6.1		
	L1011 -VHF2 {4}					
	L1011 -VHF3 {4}	62.2	77.2	4.2		
	Column Minimum	***31.5***	***53.9***			
	Column Average	***48.6***	***70.8***			
	Column Maximum	***71.5***	***92.9***			
	<u>Medium Aircraft</u>					
✓	B737 Nose No. 1989 {1}	52.3	61.9	5.2	36x2	116-138
✓	B737 Nose No. 1883 {1}	46.8	59.3	5.2	36x2	116-138
✓	B737 Nose No. 1879 {1}	50.1	61.6	4.7	36x2	116-138
✓	B737 Nose No. 1997 Windows {1}	<u>51.5</u>	61.9	5.8	36x2	116-138
✓	B737 Nose No. 1997 Full Aircraft {1}	<u>51.5</u>	65.8	4.3	173x2	116-138
✓	B737 Nose No. 1994 {1}	48.6	63.5	5.1	36x2	116-138
✓	B737 Nose No. 1881 {1}	52.6	61.2	4.5	36x2	116-138
	B737 -VHF1 {4}	52.9	69.0	7.6		
	B737 -VHF2 {4}	58.4	74.2	9.3		
	B737 -VHF3 {4}	53.2	76.2	9.6		
	B757 -VHF1 {4}	49.7	72.9	9.8		
	B757 -VHF2 {4}	38.0	64.7	8.7		
	B757 -VHF3 {4}	53.0	79.3	8.7		
	B757-VHF-Left {2}	36.3	52.8	7.4	56x2	
	B757-VHF-Right {2}	49.3	60.6	6.2	38x2	
	B757-VHF-Center {2}	50.3	64.0	6.7	55x2	
	B727 N40 -a {5}	67.0	71.0		6	118-135
	B727 N40 -b {5}	44.0	53.0		49	118-135
	B727 N40 -c {5}	76.0	<u>80.0</u>		6	109

Table 4.2-7: Concluded

MD80-VHF1 {4}	57.2	74.5	9.2	
MD80-VHF2 {4}	64.9	81.7	10.0	
MD80-VHF3 {4}	55.2	81.7	13.3	
A320 -VHF1 {4}	51.5	70.0	8.4	
A320 -VHF2 {4}	62.1	77.6	6.7	
A320 -VHF3 {4}	55.6	76.2	7.4	
Column Minimum	***36.3***	***52.8***		
Column Average	***53.1***	***68.6***		
Column Maximum	***76.0***	***81.7***		
Small Aircraft				
CRJ VHF-L {2}	36.7	53.7	7.6	14x2
CRJ VHF-R {2}	50.9	62.3	6.0	14x2
Emb 120 -VHF-L {2}	28.7	47.0	7.3	12x2
Emb 120 -VHF-R {2}	45.0	53.5	3.7	11x2
ATR72- VHF-L {2}	48.4	61.3	8.2	13x2
ATR72- VHF-R {2}	43.5	60.0	6.3	26x2
Column Minimum	***28.7***	***47.0***		
Column Average	***42.2***	***56.3***		
Column Maximum	***50.9***	***62.3***		
All Aircraft Column Minimum	**28.7**	**47.0**		
All Aircraft Column Average	**50.4**	**67.4**		
All Aircraft Column Maximum	**76.0**	**92.9**		
All Aircraft Standard Deviation	**10.9**	**10.6**		