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Evaluation of a Mobile Phone for Aircraft GPS Interference

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March 2004

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Acronyms and Symbols

CDMA	Code Division Multiple Access
CW	Continuous-wave
dBm	dB relative to 1 milliwatt
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
GHz	Gigahertz
GPS	Global Positioning System
IPL	Interference Path Loss
ITU	International Telecommunication Union
LaRC	Langley Research Center
MHz	Megahertz
MIPL	Minimum Interference Path Loss
NASA	National Aeronautics and Space Administration
PCS	Personal Communications System
PDA	Personal Digital Assistant
PEDs	Portable Electronic Devices
RTCA	RTCA, Inc. (formerly Radio Technical Commission on Aeronautics)
SC-202	Special Committee 202 of the RTCA
TM	Technical Memorandum
WLAN	Wireless Local Area Network

Abstract

Measurements of spurious emissions from a mobile phone are conducted in a reverberation chamber for the Global Positioning System (GPS) radio frequency band. This phone model was previously determined to have caused interference to several aircraft GPS receivers. Interference path loss (IPL) factors are applied to the emission data, and the outcome compared against GPS receiver susceptibility. The resulting negative safety margins indicate there are risks to aircraft GPS systems. The maximum emission level from the phone is also shown to be comparable with some laptop computer's emissions, implying that laptop computers can provide similar risks to aircraft GPS receivers.

Introduction

In July 2003, it was reported to the Federal Aviation Administration (FAA) that a cellular phone when turned on simultaneously interfered with three different aircraft GPS receivers, causing complete signal loss. The three GPS receivers were using three separate antennas, and were installed on a small aircraft. The phone was on, however, calls were not made during the incidents and subsequent tests.

In an email message to the FAA, the company who owned the airplane reported the subsequent tests taken to prove a clear and convincing direct relationship between the phone being in ON-mode, and interference with the three onboard GPS systems. The company verified several times, in multiple flights over different days, that the interference problem could be recreated reliably in the air by having the phone turned on. The interference disappeared when the phone was turned off or covered behind a metal object, and re-appeared when turned on or brought into the open again. In addition, the company conducted tests at two different places to ensure that it was not dependent on location, and were able to reproduce the interference effects at both. The interference occurred when the plane was in the air, but not on the ground. Tests using other phones did not create interference problems on the same aircraft and systems.

The company also provided measurement data of the radio frequency (RF) emissions from the phone in the GPS band. The results show wide-band emission bursts coming from the phone at level up to –54 dBm. The measurements were conducted using a spectrum analyzer, and the results provided were in form of equipment screen plot. Measurement technique, facility, and calibration details were not discussed. It is therefore suspected that the measurements were preliminary and simply for the purpose of demonstrating the existence of strong interference signal in the GPS band from the phone.

This finding was very significant in that the aircraft interference evidence was very conclusive and repeatable, as typically not the case with other aircraft incident reports. In addition, the scenario of phones being inadvertently left in ON mode during a flight is very possible, or even likely.

The email message to the FAA was later forwarded to members of the RTCA Special Committee 202 (SC-202). RTCA SC-202 was formed in early 2003 to address compatibility issues between intentionally transmitting Portable Electronic Devices (PEDs) and aircraft systems.

At the request of the FAA, National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) conducted spurious radiated emission measurements in the GPS RF band to accurately measure the levels using a proven and repeatable method and facility. A different mobile handset, of the same manufacturer and model type, was acquired for the testing. The results of the measurement were forwarded to the FAA and later to the RTCA/SC-202 as a data report that was then not publicly available. Due to the request of several RTCA/SC-202 members, the data report is now being converted to this publicly available NASA Technical Memorandum (TM) for future reference.

In this document, the identity of the company who first discovered the interference effects is omitted, as it is not relevant to the following analysis. In addition, the company requested that the original email message not to be disclosed without consideration that it contains proprietary information. The author would like to acknowledge the company's great efforts in identifying and demonstrating conclusively the source and interference effects on victim aircraft GPS systems.

The phone model was a Samsung SPH-N300. The manufacturer and model number are disclosed here for independent verification purposes only. As demonstrated later in this report, the phone is in compliance as its emissions in the GPS band are well under the corresponding Federal Communication Commission (FCC) regulatory test limits.

The Samsung SPH-N300 is a CDMA dual-band mobile phone. Samsung has advertised that the model was the first mobile handset with built-in E-911 capability. This technology helps to identify the location of the handset using a built-in GPS receiver, but with additional assistance from the network to overcome deficiencies in low signal strength areas such as inside buildings. The handset has menu options to allow the E-911 feature to be turned off to protect users privacy. The SPH-N300 model was no longer in production at the time of testing, thus a previously owned unit was acquired from an internet auction site for this study. This particular unit defaulted to the Personal Communications System (PCS) band upon registration with a local wireless network, and had logged approximately 150 hours of previous airtime use.

Objectives

The primary objectives of this report are to describe the measurement and results of emissions in the GPS RF band from the Samsung SPH-N300 mobile phone. The results are also compared against the corresponding FCC limits and the maximum emissions from standard laptop computers and personal-digital-assistants (PDAs) that are currently allowed for use on aircraft.

Measurements and Analysis

This section describes the emission measurement method, measurement results, safety margin calculations and the result comparison with emissions from laptop computers and PDAs whose use are allowed during flight.

Measurement Method

In a preliminary measurement, a dual-ridge horn antenna was used to measure the direct radiation from the phone. The results clearly indicated strong spurious emissions in the GPS band. The results warranted further and more accurate measurements to assess risks to aircraft GPS systems. In addition, lack of filters to prevent the handset's intentional PCS signals from possibly overloading the measurement equipment was a concern in the preliminary measurement.

In the follow-on measurement, a GPS survey antenna that had a built-in pre-amplifier and GPS band filters was used as the receive antenna. With this antenna, overloading of the measurement equipment by the PCS signal from the handset was not a concern. A reverberation chamber was used for the emission measurements for good accuracy, repeatability and speed. As a result of the reverberation method, the results were in actual radiated power (within the measurement resolution bandwidth) rather than Effective Isotropic Radiated Power (EIRP) as in the anechoic chamber method.

The reverberation chamber method is a relatively new method that compares the test chamber's power density statistics from an injected calibration signal against the same statistics resulting from unknown signals radiated by the test device. A pair of matched, in-band antennas is typically used to inject the calibration signal and to receive (or pick-up) RF signal from the chamber. A set of continuous rotating conducting paddles, called stirrers, is used to change the boundary conditions in the chamber while the receive antenna samples chamber power density for deriving field statistics. This helps eliminate the need to move the receive antenna around for the sampling.

The signal statistics typically include the peak receive-power or the average receive-power over a paddle rotation. For emission measurement, peak received power measurement is much faster, and is much more appropriate as spurious signals often do not exist long enough to be averaged over a paddle revolution. As with references [1] and [2], the peak received power approach is used in this measurement.

Test chamber calibration was first performed to determine the composite gain that was used to correct the measured received power data to arrive at the final emission results. The composite gain includes effects of chamber loss, antenna losses, cable losses, pre-amplifier gain and other losses that may exist along the RF propagation path. During calibration, a dual-ridge horn antenna was used to transmit a known power level into the chamber, while the spectrum analyzer measured the maximum (peak) signal coupling into the receive antenna. The difference, in dB, between the maximum received signal (after a stirrer revolution) and the calibration transmitted power resulted in the chamber's "composite gain".

The test unit was then introduced and exercised through various operating modes. The spectrum analyzer was used to measure the level of unknown emission signal coupled into the received antenna. The composite gain, and the transmit cable loss, was then applied to the measurement results to yield total radiated powers (within measurement resolution bandwidth). References [1] and [2] provide additional information on the method.

Chamber calibration was performed using a tracking source with the output set at –60 dBm. The calibration transmit cable had 2.3 dB loss in the GPS band. These losses and power levels were normalized out in the final results.

A tracking source was used to provide a calibration signal, and a spectrum analyzer was used for the measurements of power coupled into the received antenna. Their settings are listed in Table 1.

The dual-ridge horn used as the transmit antenna during chamber calibration was later used to re-radiate external wireless signal for phone communication. A MicroPulse L1/L2 GPS Survey Antenna was used as the receive antenna. In addition, a lowpass filter was installed in-line at the output of the GPS survey antenna to block the intended PCS signals from the phone. The filter was later found unnecessary as the GPS antenna already had high rejection ratio in the PCS band. However, the filter remained in the path through all measurements for consistency.

Table 1: Measurement Equipment and Settings

Spectrum Analyzer	Agilent E4407B
Center Frequency	1575 MHz
Span	80 MHz
Resolution Bandwidth	10 kHz
Video Bandwidth	10 kHz
Reference Level	0 dBm
Sweep Time	2 Sec
Number of Points	401
Tracking Source Output (for chamber calibration)	–60 dBm
Transmit Cable Loss	2.3 dBm

During tests, a pair of dual ridge horns was used to pick-up the external PCS signal and re-radiate inside the test chamber, and the phone was placed close to the re-radiation antenna for sufficient signal strength. The phone was also oriented with its extended antenna pointing toward the re-radiation antenna (dual-ridge horn) to minimize absorption by the horn antenna. External noise in the GPS band being re-radiated in the chamber was low and was not observable above the measuring equipment noise floor.

Three phone modes were considered for test: Stand-by, Phone-Active with GPS on and Phone-Active with GPS off. In the Phone-Active mode, the handset made repeated calls to a phone number. Each call resulted in a 40 second message from the operator (Sprint PCS) notifying of invalid subscription. In Standby mode, emission results were similar between GPS On and GPS Off modes, thus only one data set was reported.

Results

Figure 1 shows the results of all measurements after calibration and normalization. The data can be thought of as total radiated power (within the resolution bandwidth), integrated over all polarizations and directions around the mobile phone at a particular frequency.

Figures 2, 3 and 4 show raw data as recorded on a spectrum analyzer for the phone in Standby, Active with GPS on, and Active with GPS off.

Figure 5 shows chamber calibration raw data, with –60 dBm input power (with 2.3 dB transmit cable, the actual power delivered to the transmit horn antenna was –62.3 dBm).

Figures 6 and 7 demonstrate the selectivity of the receive antenna used for the measurements. This selectivity helps to filter out the intentional PCS signals from the mobile phone, reducing possible overloading effects. Figure 6 first shows the chamber calibration measurement using a standard passive wideband dual-ridge horn (1-18 GHz) as the receive antenna. In comparison, Figure 7 shows the same calibration performed using the GPS survey receive antenna with a built-in amplifier and filters. Note that

Figures 6 and 7 should not be compared with Figure 5 as measurement conditions and chamber loadings were not identical.

Figures 8 and 9 contain photos of the measurement set-up.

Safety Margin Calculations

Figure 1 indicates that the spurious emissions can be as high as –50 dBm. With the aircraft Minimum Interference Path Loss (MIPL) as low as 41 dB on a CV-580 (Veda/FAA) and 43 dB on a CRJ (Delta/Eagle Wings/NASA) ([1], table 4.2-7), the resulting signal can be as high as –91 to –93 dBm at the output of a passive GPS aircraft antenna.

GPS interference threshold is well defined and consistent across various standards [4][5]. These documents show that the lowest interference threshold is –126.5 dBm for a GPS system in acquisition-mode, with the interference signal being continuous-wave (CW) or having bandwidth up to 700 Hz. The threshold level would go higher for wider bandwidth interference signals. In track-mode, the interference threshold level is 6 dB higher.

As a result, the safety margin is about –35.5 dB. In this document, safety margin is defined as the difference in dB between the interference threshold and the interference signal level at the output of the GPS antenna.

The average MIPL among 14 different aircrafts reported in [1] was 65 dB for large, medium and small aircraft combined. Using the average MIPL results in a safety margin of −11.5 dB. Table 1 summarizes the calculations.

Table 2: Calculation of Safety Margins

Max. Emission (A)	**Aircraft Min. Interference Path Loss*** (B)	**Signal Level at GPS Antenna Output** (C)= (A)-(B)	**GPS CW Interference Threshold** (D)	**Safety Margin** =(D)-(C)
-50 dBm	41 dB (lowest)	-91 dBm	-126.5 dBm	-35.5 dB
	65 dB (average)	-115 dBm		-11.5 dB

* [1], table 4.2-7

It is important to note that high emissions, shown in Figure 1, occurred during active phone transmission, but not during standby mode. This characteristic strongly indicates that the emissions came from the transmission circuitry (analog or digital). Thus, FCC Part 24 out-of-band emission limits apply rather than FCC Part 15.

According to FCC Part 24.238 [3], the out-of-band limit for spurious and harmonics is 43+10log(P) dB below the maximum intentional transmitted power. Assuming the phone has 0.5W (or 27 dBm) maximum in-band power, the formula results in the attenuation of 40 dB. Thus the limit is –13 dBm (= 27dBm – 40 dB). This emission limit is much higher than the maximum measured emission data. Thus, the device complies with the FCC Part 24 emission limit in the GPS band by a large margin.

Comparisons with Laptop Computers' Emissions

It is worthwhile to compare the emission data in Figure 1 to emissions data from unintentionally transmitting devices such as laptop computers and PDAs. The significance of the comparison is that these laptops/PDAs are currently allowed for use on aircraft during certain phases of flight. Emissions in aircraft radio-navigation bands from such devices were previously measured using the same method and test facility, and the results were reported in [1]. Eight laptop computers, two PDAs, and a portable battery operated Bluetooth printer were considered. A summary of the results in the GPS band is shown in Figure 10, with the composite maximum of all 11 measured devices displayed in red.

As can be observed from Figure 10, a few of the devices (laptop computers and PDAs) can have strong emissions in the GPS band (or near it). The maximum emission was as high as –55 dBm as compared to –50 dBm for the Samsung SPH-N300. Thus, interference risks to GPS systems are comparable between the Samsung SPH-N300 and the measured laptop computer with the highest emissions. Since interference to GPS systems has been demonstrated with this mobile phone, some laptop computers in certain operating modes may also provide similar risk of interference.

Conclusions

The measured emission data show that the threat of interference from a particular mobile phone to aircraft GPS receivers is real, even though the handset satisfies the FCC Part 24 out-of-band spurious radiated emissions limit. However, the maximum emission was only 5 dB above the composite maximum emission from 11 non-intentional transmitters previously reported. More studies are needed to determine if other GPS-enabled mobile handsets provide similar emissions.

References

[1] "Portable Wireless LAN Device and Two-Way Radio Threat Assessment for Aircraft Navigation Radios," NASA/TP-2003-212438, July 2003.

[2] "Wireless Phone Threat Assessment and New Wireless Technology Concerns for Aircraft Navigation Radios," NASA/TP-2003-212446, July 2003.

[3] 47CFR, Chapter I - Federal Communication Commission, Part 24.238 "Personal Communications Services – Broadband PCS - Emission Limits", 10-1-2000 Edition.

[4] RTCA/DO-235A, "Assessment of Radio Frequency Interference Relevant to the GNSS," Dec. 5, 2002.

[5] International Telecommunication Union (ITU), Recommendations ITU-R M.1477 (2000).

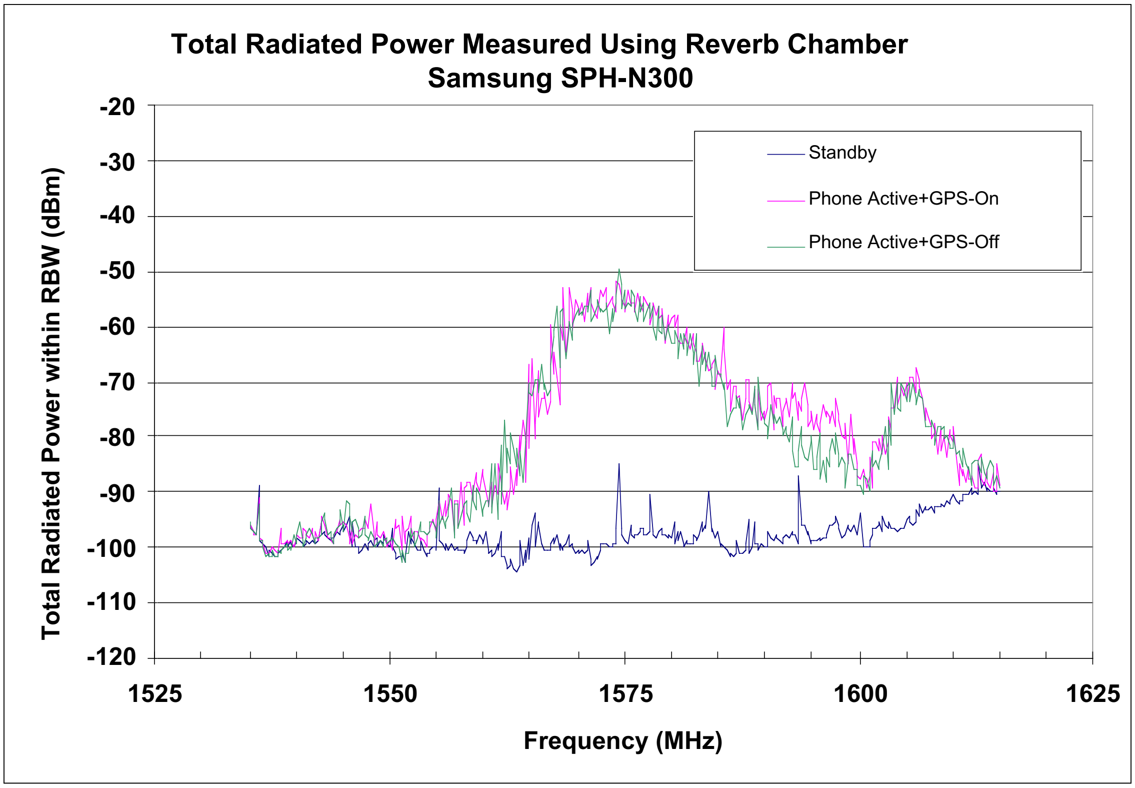

Figure 1: Composite results of emissions from the Samsung SPH-N300.

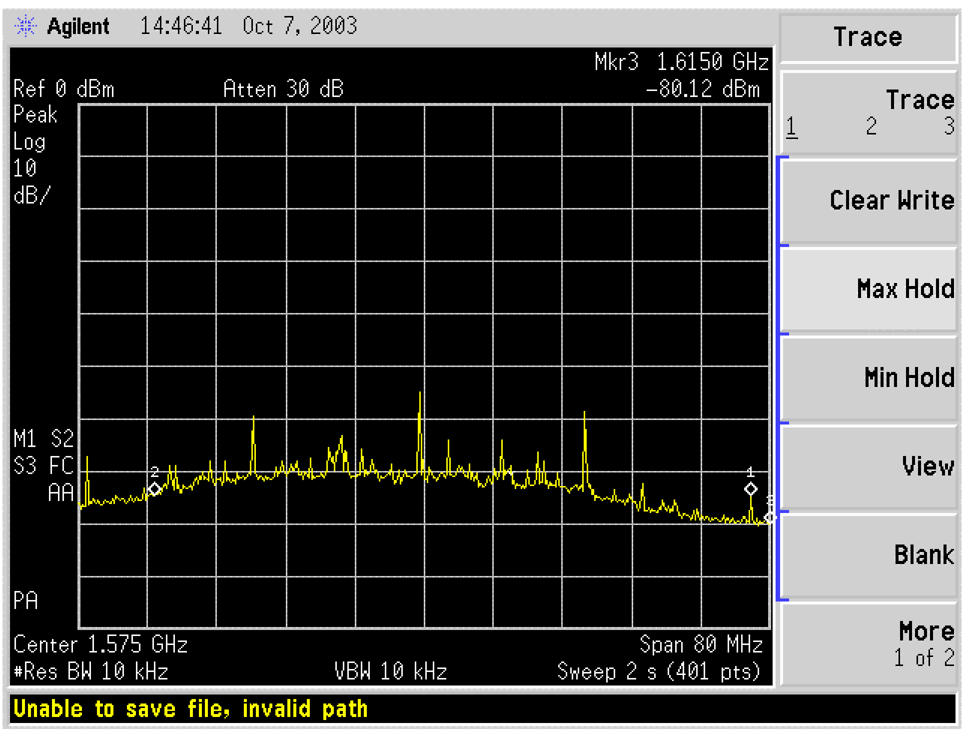

Figure 2: Raw spurious emission data. Phone in Standby mode.

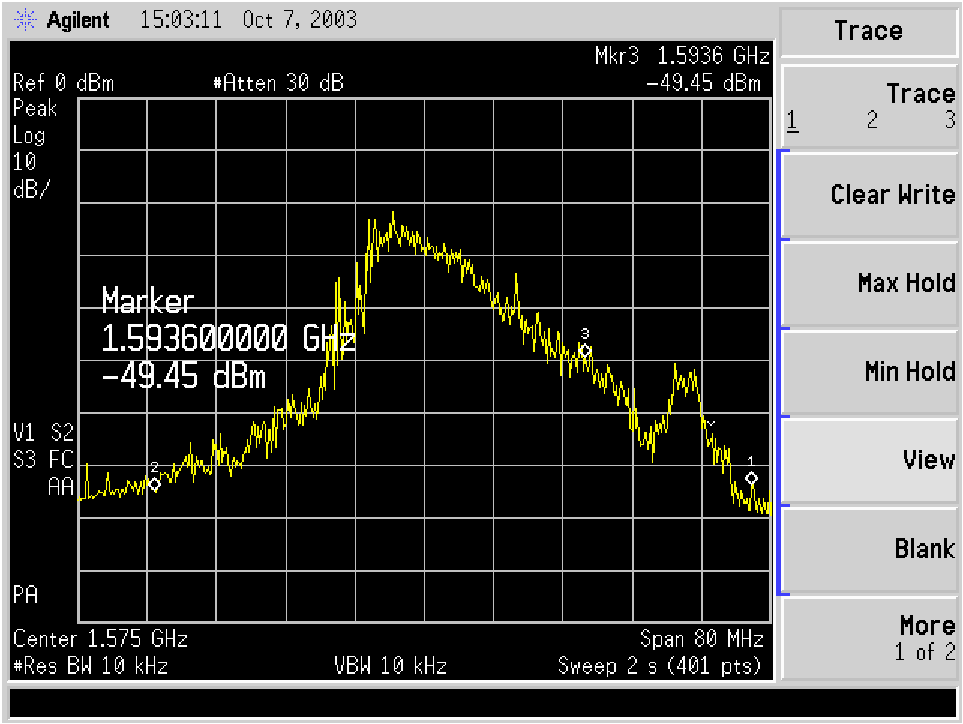

Figure 3: Raw spurious emission data. Phone-Active, GPS On.

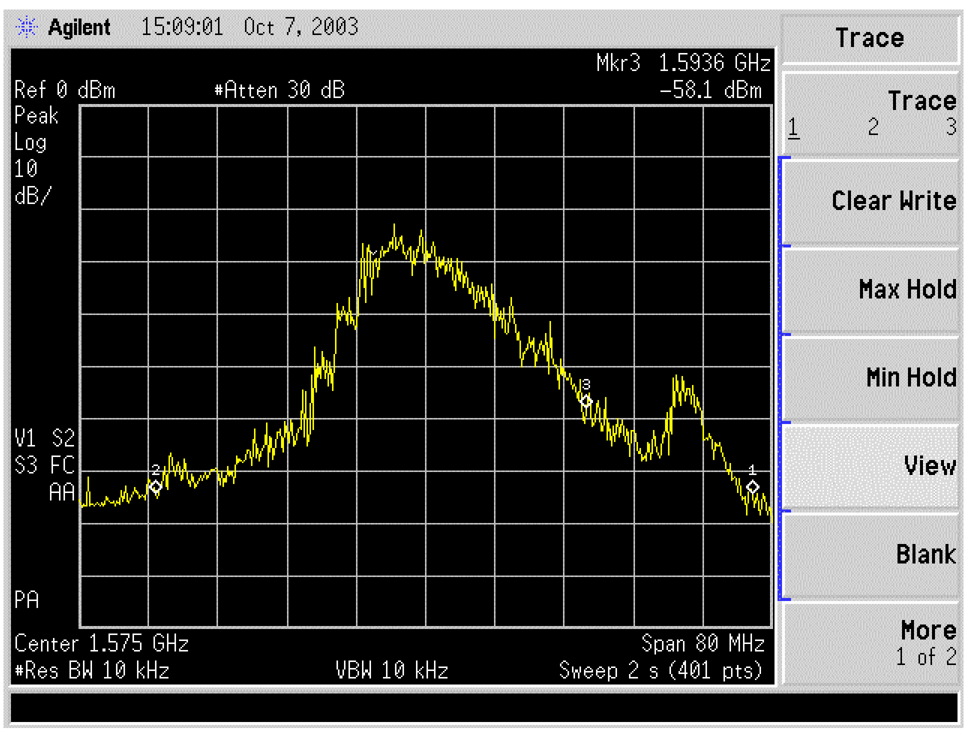

Figure 4: Raw spurious emission data. Phone-Active, GPS Off.

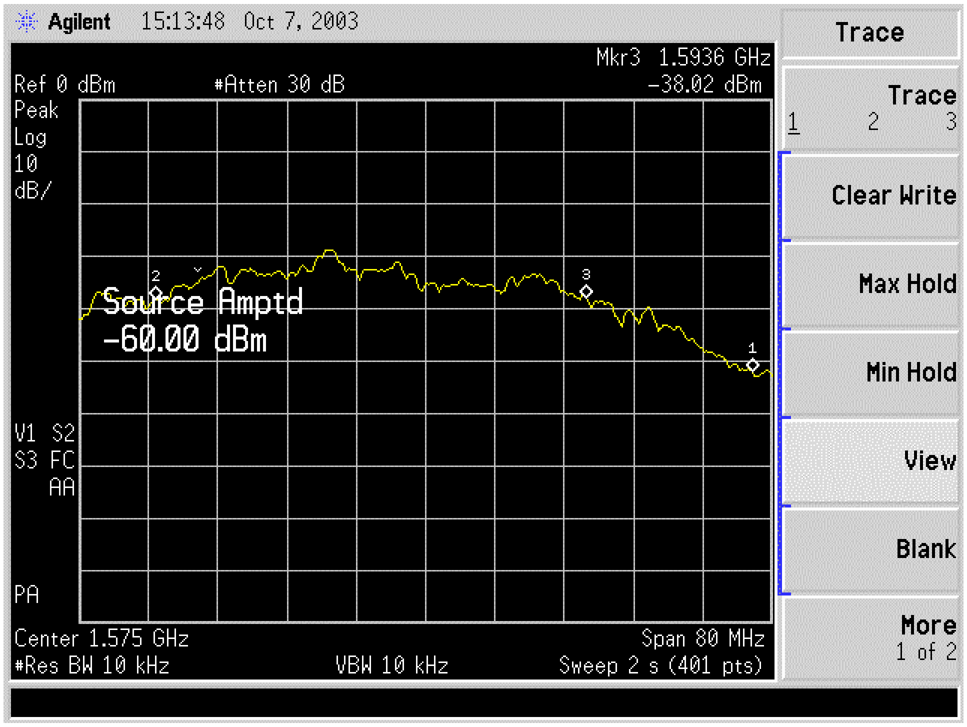

Figure 5: Chamber calibration (raw data) with –60dBm input power.

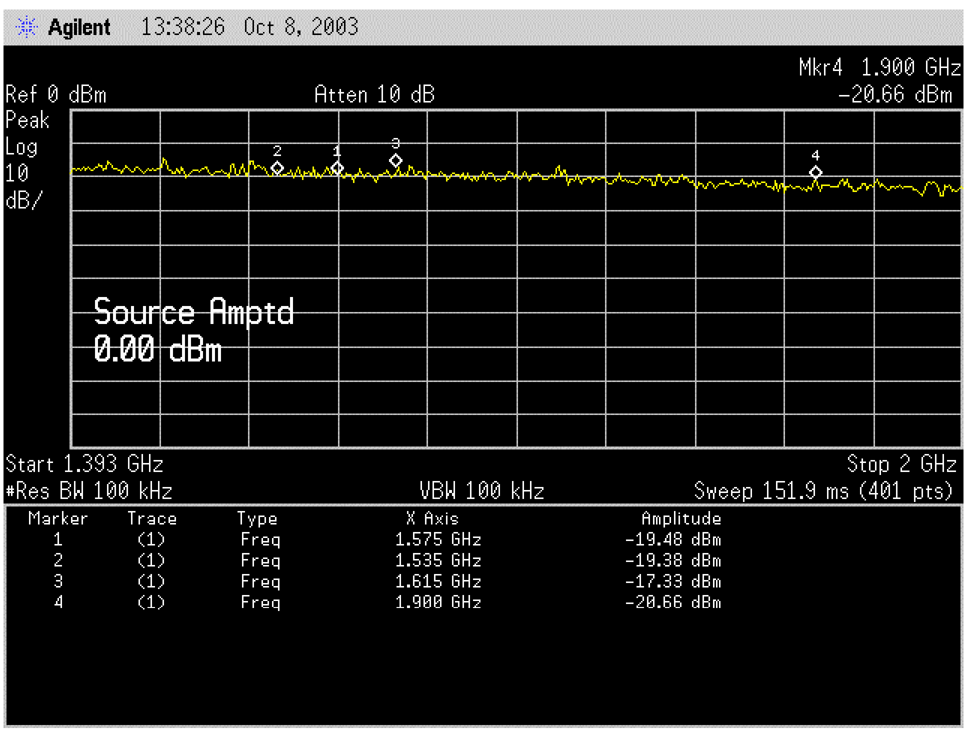

Figure 6: Chamber calibration (raw data) performed with reference wideband dual-ridge horns used as transmit and receive antennas.

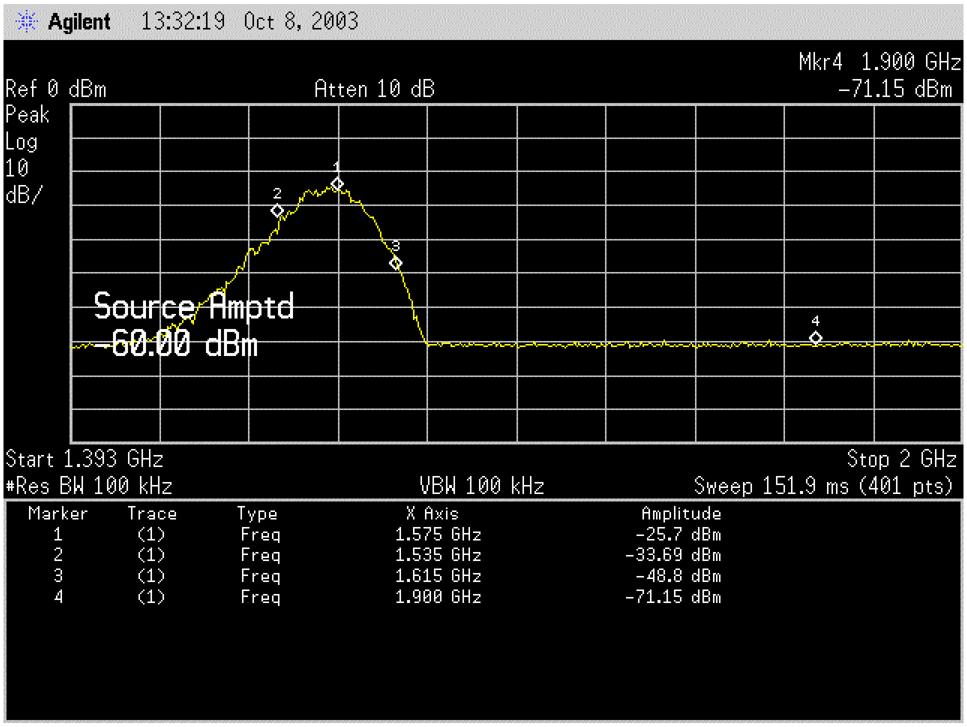

Figure 7: Chamber calibration (raw data) performed with a MicroPulse GPS survey antenna (and a GPS band low pass filter with negligible effects) and a wideband dual-ridge horn as transmit antenna. This plot demonstrates the selectivity of the GPS antenna with built-in filters/pre-amplifier as compared against Figure 6.

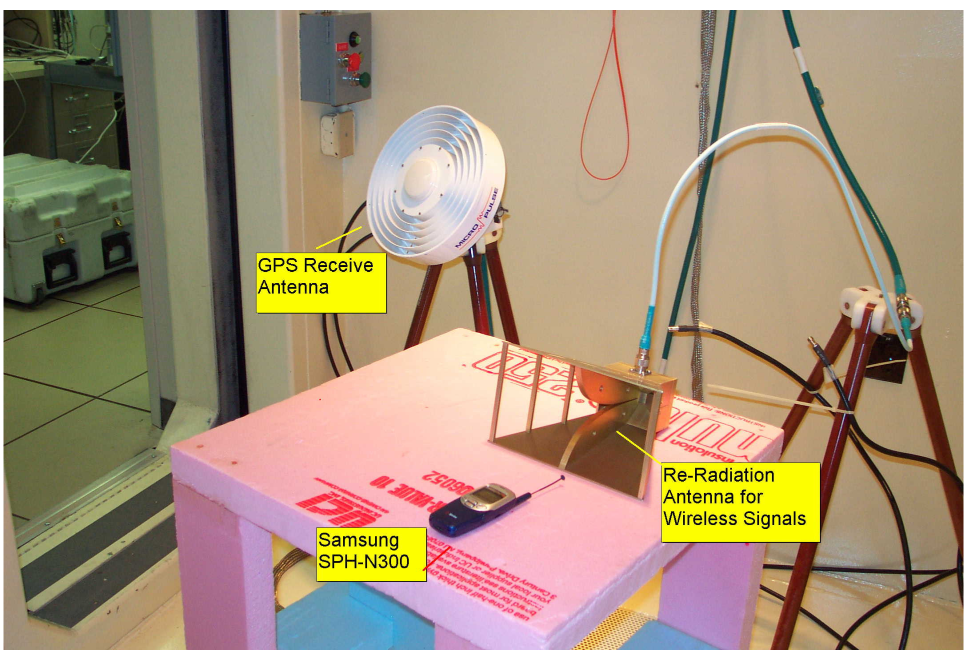

Figure 8: Inside test chamber a MicroPulse GPS survey antenna used as the receive antenna, the Samsung SPH-N300 phone, and a dual-ridge horn re-radiation antenna. The dual-ridge horn antenna was also used as the transmit antenna during chamber calibration.

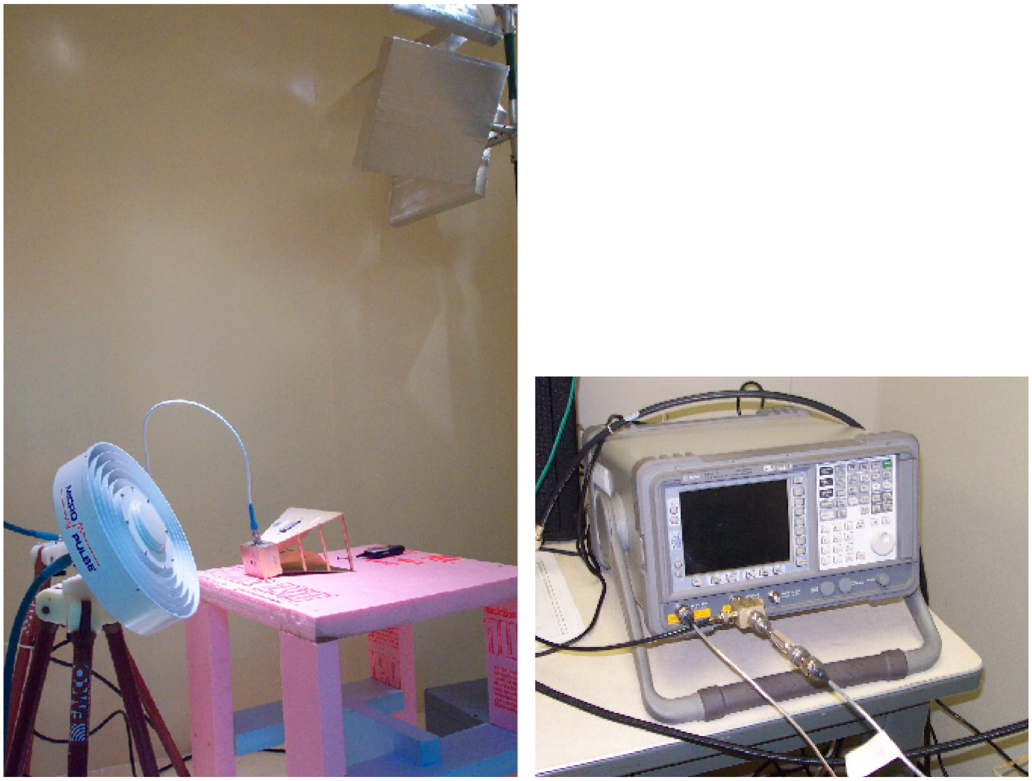

Figure 9: Set-up in a reverberation chamber with the stirrer partially visible in the upper right hand corner. A spectrum analyzer for data acquisition is shown with a low-pass filter and an in-line DC-bias Tee to power the active GPS antenna.

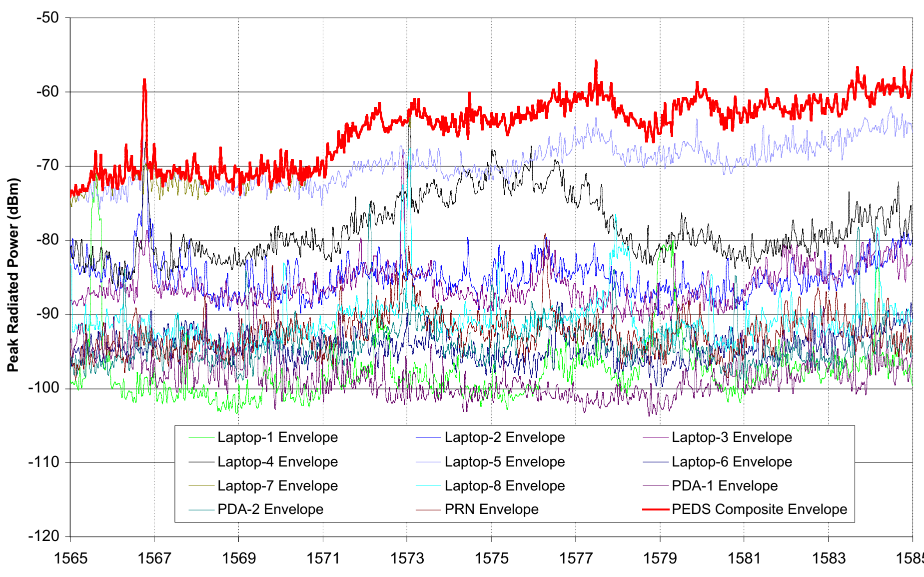

Figure 10: Maximum emissions from various laptop computers and PDA in the GPS band measured in a reverberation chamber.

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