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Evaluation of Mobile Phone Interference With Aircraft GPS Navigation Systems

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Acronyms and Symbols

CDMA	Code Division Multiple Access
CW	Continuous-wave
dBm	dB relative to 1 milliwatt
dBuV/m	Electric field strength relative to 1 microvolt
EIRP	Effective Isotropic Radiated Power
EMC	Electro Magnetic Compatibility
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
GHz	Gigahertz
GPS	Global Positioning System
ITI	Interference Technology International
ITU	International Telecommunication Union
KHz	Kilohertz
LaRC	Langley Research Center
LO	Local Oscillator
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 (non-intentionally transmitting)
RF	Radio Frequency
RTCA	RTCA, Inc. (formerly Radio Technical Commission on Aeronautics)
SC-202	Special Committee 202 of the RTCA
TM	Technical Memorandum
T-PED	Transmitting Portable Electronic Devices (intentionally transmitting)
VCO	Voltage Controlled Oscillator
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Network

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Abstract

This report compiles and analyzes tests that were conducted to measure cell phone spurious emissions in the Global Positioning System (GPS) radio frequency band that could affect the navigation system of an aircraft. The cell phone in question had, as reported to the FAA (Federal Aviation Administration), caused interference to several GPS receivers on-board a small single engine aircraft despite being compliant with data filed at the time with the FCC by the manufacturer. NASA (National Aeronautics and Space Administration) and industry tests show that while there is an emission in the 1575 MHz GPS band due to a specific combination of amplifier output impedance and load impedance that induces instability in the power amplifier, these spurious emissions (i.e., not the intentional transmit signal) are similar to those measured on non-intentionally transmitting devices such as, for example, laptop computers. Additional testing on a wide sample of different commercial cell phones did not result in any emission in the 1575 MHz GPS Band above the noise floor of the measurement receiver.

1. Introduction

In July 2003 the FAA received a report about a cellular phone on a small single engine aircraft that, when turned on, it simultaneously interfered with three different aircraft GPS receivers causing loss of GPS lock. The three GPS receivers were using three separate receivers on-board a small aircraft (a Piper Cherokee 6), two of them with two separate antennas near the front of the fuselage, and the third one with an antenna about ten feet behind the other two. Even though the phone was on, 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 appeared to show a direct and repeatable relationship between the phone being in ON-mode and interference with the three on-board GPS systems. 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. The company also conducted tests at two different locations in the aircraft and reproduced the same phenomenon. The interference occurred when the plane was in the air and tests using other phones did not cause the GPS phenomenon. Preliminary measurement data of the radio frequency (RF) emissions from the phone was obtained using a spectrum analyzer and the results provided in the form of equipment screen plot.

At the request of the FAA, the 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. Preliminary test results and analysis are publicly available as a NASA Technical Memorandum (Ref. 1).

Concerns were raised within RTCA Special Committee 202 (Portable Electronic Devices) regarding the emission profiles of GPS-enabled phones, and whether there is something inherent in mobile phone designs that would result in high level emissions within the GPS band when the transmitter is enabled. A mobile phone manufactured by Samsung (model number SPH-N300) was presented to the committee for review following the detection of an emission in the GPS 1575 MHz, which is a band used for commercial aircraft navigation. QUALCOMM conducted a series of tests to verify regulatory compliance of this product and investigated the origin of the emission (Ref. 2). In addition, QUALCOMM sampled 11 randomly selected commercially available GPS-enabled mobile phones to measure their emission profiles in the 1575 MHz GPS band (Ref. 3).

NASA Headquarters and QUALCOMM subsequently agreed to consolidate their test results and conduct an in-depth analysis, to be released as an official NASA Technical Publication.

The objective of this report is to evaluate a specific instance of interference, reported to the FAA, of an FCC-compliant cellular phone with an aircraft GPS navigation system. This report does not evaluate potential interference with other on-board navigation systems (e.g. glide slope indicator, magnetic compass, etc.).

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2. Objectives and Methodology

2.1 NASA Samsung Test

The primary objectives of the test were to describe the measurement and results of emissions in the GPS RF band from the Samsung SPH-N300 mobile phone, and to compare the results against the corresponding FCC (Federal Communications Commission) limits and the maximum emissions from standard laptop computers and Personal Digital Assistants (PDAs) currently allowed for use on aircraft.

A dual-ridge horn antenna was used for a preliminary measurement of the direct radiation from the phone. The results indicated strong spurious emissions in the GPS band and the need for more accurate measurements to assess the risk to aircraft GPS systems. There were also concerns about the lack of filters to prevent intentional Personal Communications System (PCS) signals from the handset from overloading the measurement system.

In the follow-on measurement, a GPS survey antenna with a built-in pre-amplifier and a GPS band filter was used to avoid overloading of the measurement equipment by the PCS signal from the handset. A reverberation chamber was used and, thus, results were in actual radiated power, within the measurement resolution bandwidth, rather than Effective Isotropic Radiated Power (EIRP) as would be the case with 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 pickup) RF signal from the chamber. A set of continuously 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 (Figure A.1 – see Appendices). 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 4 and 5, 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 4 and 5 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 (the settings are listed in Table 1).

The dual-ridge horn used as the transmit antenna during chamber calibration was later used to reradiate external wireless signal for phone communication. A MicroPulse L1/L2 GPS Survey Antenna was used as the receive antenna (Figure A.2). In addition, a low-pass 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 to be 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 reradiate inside the test chamber, and the phone was placed close to the reradiation antenna for sufficient signal strength. The phone was also oriented with its extended antenna pointing toward the reradiation antenna (dual-ridge horn) to minimize absorption by the horn antenna. External noise in the GPS band being reradiated in the chamber was low and not observable above the measuring equipment noise floor. Three phone modes were considered for test: Standby, Phone-Active with GPS on, and Phone-Active with GPS off. The GPS on/off modes are selected from the phone's user interface menu and determine whether GPS data is always sent to the PCS network or only sent during emergency calls. The status of the GPS receiver circuitry is not known for this particular model of phone when the user setting is set to "on" or "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.

2.2 Qualcomm Samsung Conducted Emissions Test

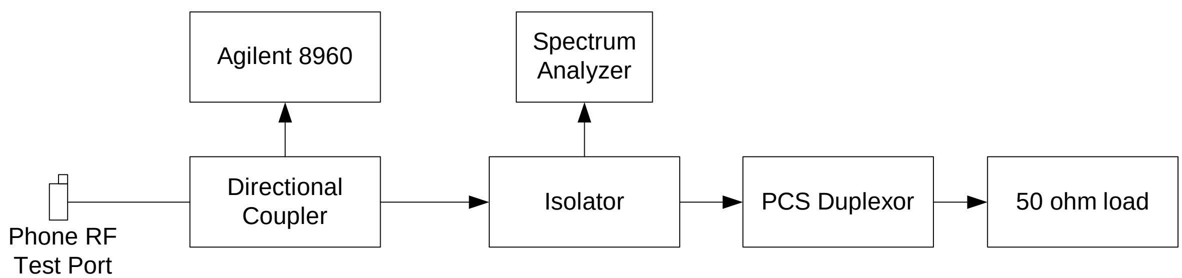
Qualcomm desired to find the source and cause of the observed GPS emissions with the Samsung N300 phone. A conducted setup is best suited to evaluate the GPS emissions since the phone's circuit board can be probed to identify the source and characteristics of the emissions while maintaining a controlled RF environment with a continuous test call. The N300 incorporates a RF test port for testing conducted transmitter RF emissions, so this port was utilized to perform conducted experiments.

As shown in Figures 1 and A.3, an Agilent 8960 was connected to the phone's RF test port through a 10 dB directional coupler and configured to support a maximum power test call. The through-path of the coupler was connected to the measurement equipment RF chain that consisted of an isolator, a PCS duplexor, and a 50-ohm load. The isolator and load were used to reduce the level of the PCS transmit signal at the input of the measurement spectrum analyzer to prevent saturation of the spectrum analyzer's RF front end. It was verified with a network analyzer that the isolator had low attenuation in the GPS band of interest as shown in Figure C.1. This test setup would not support a full broadband emissions test due to the frequency limitation of the isolator. Test was limited to GPS band evaluation.

Using this test setup, the phone was investigated at the circuit board level to identify the emission's source. Once the source of the emission was identified, modifications to the board were performed to understand why the emission was generated and how the emission could be modified. The majority of measurements and changes were performed using PCS Code Division Multiple Access (CDMA) channel 25 (1851.25 MHz) while transmitting at maximum power, but other experiments were performed with other power levels and different RF channels to help investigate the emission.

Equipment: Agilent 8960, Agilent E4402B Spectrum Analyzer, PCS Duplexer, Isolator, 50-ohm load, RF test connector, Samsung N300 Phone.

Figure 1: Conducted GPS Emission Test Setup



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2.3 Qualcomm Emission Measurements in the GPS Band

The Electro Magnetic Compatibility (EMC) tests were performed in the Qualcomm EMC Test Facility. This facility is accredited and listed in the Interference Technology International (ITI) lab network. A lab assessment was performed in accordance with ISO 25, defining the general international requirements for the competence and testing laboratories and with ITI assessment criteria LACO196. Under this accreditation scheme, the Qualcomm EMC Test facility has been assigned the certificate number 7069**.**

In order to identify if there is am inherent design characteristic of mobile phones that produces spurious emissions in the GPS band, 11 random phones were obtained and tested for emissions in frequency band of interest. Figure A.6 shows the sample of phones used in the testing.

The test phone was placed on a turntable inside a 3-meter semi-anechoic chamber as shown in Figure A.5. Figure A.6 shows the samples of phones used in this testing. Outside of the chamber, an Agilent 8960 Base Station simulator was configured to support PCS and Cellular test calls with the phone. Coaxial cable was routed from the 8960 through bulkhead connectors in the chamber to an antenna inside the chamber. The 8960 was configured to support maximum transmit power test calls with the phone using the registration channels as defined in Table 2.

Table 2: Registration / Call Parameters

Verizon: SID = 4, NID = 8, ch 384
Sprint: SID = 4145, NID = 65535, ch25
PCS channel 600 = 1880 MHz
US Cellular channel 384 = 836.52 MHz

A horn antenna was used as the measurement antenna. The horn was cabled outside the semi-anechoic chamber to a GPS bandpass filter, where the filtered signal was passed through a preamp and then to a spectrum analyzer as shown in Figure A.4. The measured attenuation through the bandpass filter was 2.8 dB. An initial measurement bandwidth of 30 KHz was used for each measurement. If a signal was detected, the appropriate bandwidth was used per Part 15 (1 MHz), Part 22 (30 KHz), or Part 24 (1 MHz).

If an emission signal was detected, the EUT was rotated 360 degrees and the receive antenna was raised up and down from 1 to 3 meters to find the peak emission level from the EUT. This peak level was recorded as the measured signal level. All plots have a reference display line at 54 dBuV/m indicating the Part 15 unintentional radiated emissions 3-meter limit.

A commercially available laptop was used in the EMC laboratory as test support equipment was inadvertently found to have an emission at 1575 MHz. After the discovery, a Part 15 measurement was performed on this laptop with the purpose of demonstrating that all Portable Electronic Devices (PEDs) have the potential for generating emissions within the GPS band.

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3. Results

3.1 NASA Samsung Test

Test Results

Figure B.1 (NASA Samsung test results are included in Appendix B) 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 B.2, B.3, and B.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 B.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 B.6 and B.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 B.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 B.7 shows the same calibration performed using the GPS survey receive antenna with a built-in amplifier and filters. Note that Figures B.6 and B.7 should not be compared with Figure B.5 as measurement conditions and chamber loadings were not identical.

Analysis – Safety Margin Calculations

Figure B.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) (Ref. 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 (References 7 and 8). 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 Reference 4 was 65 dB for large, medium and small aircraft combined. Using the average MIPL results in a safety margin of -11.5 dB. Table 3 summarizes the calculations.

Table 3: 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

* Reference 4, table 4.2-7

It is important to note that high emissions, shown in Figure B.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 (Ref. 6) 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 (= 27 dBm – 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.

Analysis - Comparisons with Laptop Computers' Emissions

It is worthwhile to compare the emission data in Figure B.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 Reference 4. 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 B.8, with the composite maximum of all 11 measured devices displayed in red.

As can be observed from Figure B.8, a few of the devices (laptop computers and PDAs) can also have strong emissions in the GPS band (or near it). The maximum emission from other devices 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 a GPS system in one specific configuration has been demonstrated with this mobile phone, laptop computers in certain operating modes could also interfere with a GPS system in the same configuration due to the comparable emissions levels in the GPS band.

3.2 Qualcomm Samsung Conducted Emissions Test

Test Results

Figure 2 is the conducted emissions data submitted to the FCC as part of the approval documentation in September 2001. The data shows the intentional signal at maximum power in the PCS band and a spurious emission at 1585 MHz with a compliance margin of approximately 15 dB. The difference in frequency is likely attributed to the marker frequency error associated with the 2.5 GHz span used in the plot. In the Qualcomm measured conducted data shown in Figure 3, the amplitude correlates with the FCC filed data.

Figure 2: FCC Database Plot (original chart is tilted)

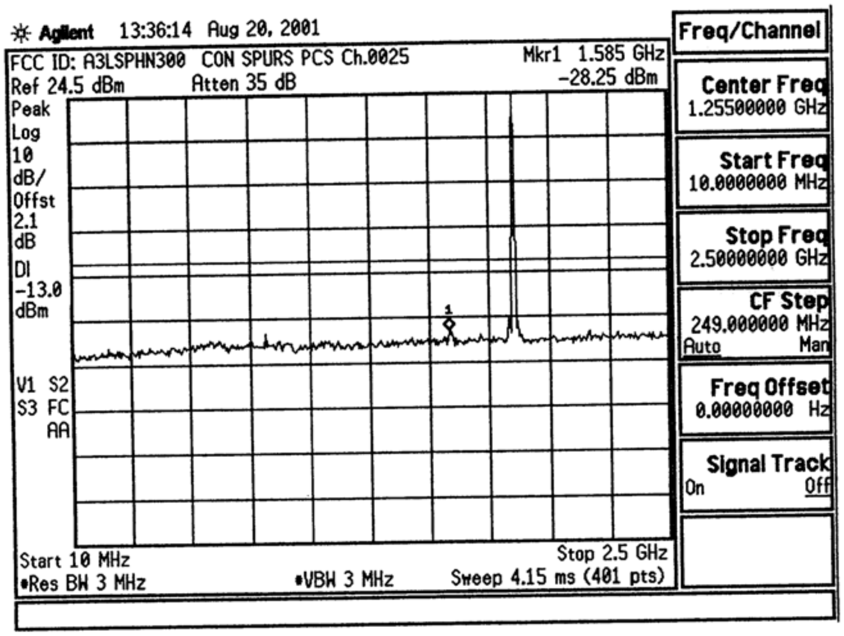
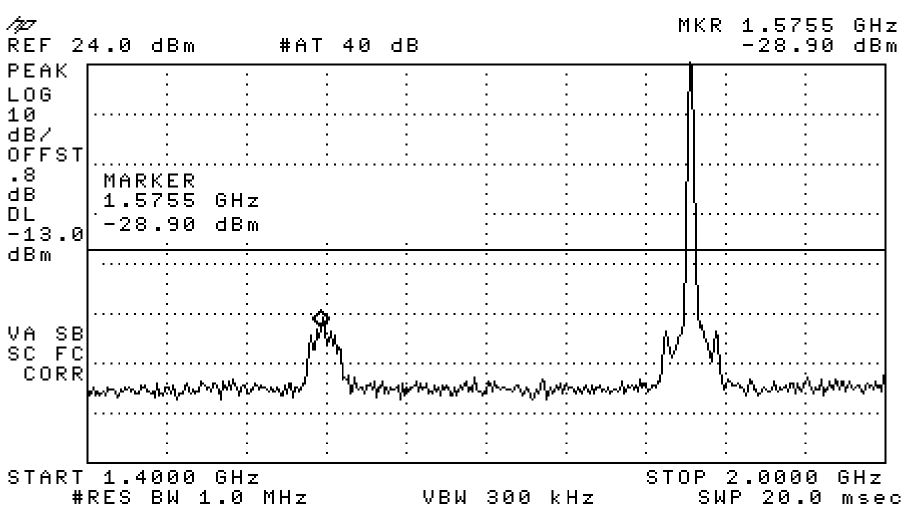


Figure 3: Qualcomm Measured Data. (ch80-max power, FCC limit = -13 dBm)



Figures C.1 through C.6 in Appendix C depict the Impedance Matching experiments for different configurations.

Experiment Observations and General Mobile Phone Design Discussion

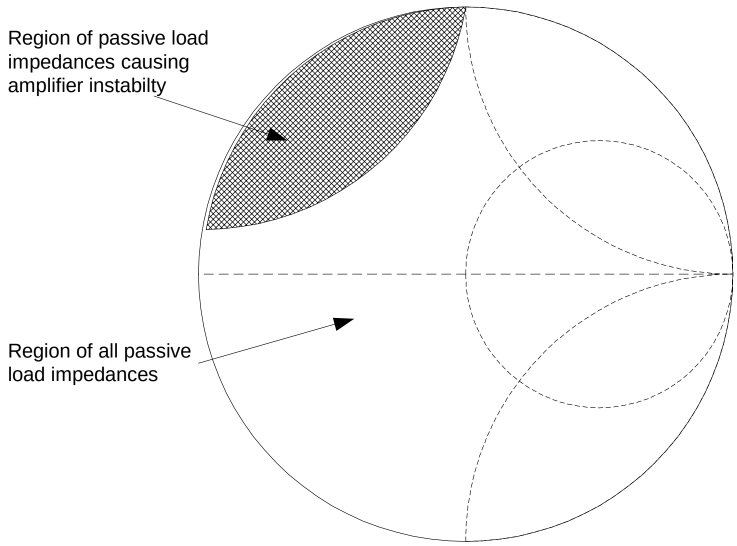
The following ten points summarize the observations resulting from the conducted test investigation of the GPS band emission.

1. All GPS circuitry is turned off when GPS is not in use. GPS is only active with this chipset when the transmitter is turned off.
2. This phone uses a superhetrodyne design for the GPS receiver circuit. The Local Oscillator (LO) is a minimum of 83 MHz off GPS, and typically 183 MHz.
3. The GPS and PCS band share a common Voltage Controlled Oscillator (VCO). The VCO is operating on one frequency or the other, never at the same time. This was verified through experiment.
4. The spur is not present in an 800 MHz call.
5. Spur is variable with transmit power. This is a common attribute with PA oscillations.
6. The spur changes amplitude and shape as the transmitter frequency changes. The highest emissions occurred with the transmitter operating on the lower frequencies of the PCS band.
7. Modifying the PA matching network shifted and reduced emissions level. Experiments were performed to demonstrate that changes in the match would affect the amplitude and frequency of the spur.
8. The spur changed shape when the phone was fully assembled. This indicates interaction with the rear housing, which has metal paint.
9. The spur was only present when the phone was transmitting (call or paging). The spur was not present in idle mode.
10. The transmit power was checked after each modification. With the modifications installed, the transmit power was reduced approximately 1 dB. The conclusion is that the modifications did not destroy the PA performance, but did modify the PA oscillation.
11. It was verified that turning GPS location “On” and “Off” had no effect on the spur. The phone display tells you that the “Off” mode means that location will be hidden from the network. “On” tells you the Service provider will have access to location information.

Analysis

From the S-parameter theory governing 2-port amplifier operation, it is well known (Ref. 9 and 10) that specific combinations of amplifier output impedance and load impedance can induce instability. This condition is termed conditional stability. The unstable load impedances typically lie within a locus of complex impedances bounded by the intersection of two circular sections in complex impedance space. Figure 4 (next page) is a graphical depiction of this concept for an arbitrary amplifier. Note the unstable region typically encompasses load impedances with high reflection coefficient, but is limited to a specific phase range. The unstable region is defined by the amplifier’s S-parameters and terminating impedances. As the amplifier operating output power climbs to within ~10 dB of its maximum output, the amplifier’s S-parameters begin to vary as a function of output power. Hence, the instability region also varies vs. output power, and with a great enough S-parameter change can exit the passive impedance locus leaving the amplifier unconditionally *stable*.

Figure 4: Smith Chart Depiction of Amplifier Stability



The Samsung SPH-N300 1900 MHz TX power amplifier operates into a load impedance defined by a series inductor connected to its 1900 MHz duplexer TX port. The duplexer provides a bandpass filtering function, so the reflection coefficient is low (<-9 dB) over the 1850-1910 MHz TX band and very high (>-2 dB) at 1575 MHz. The load impedance presents a reflection coefficient magnitude and phase that lies within the power amplifier's instability region and results in the spurious measured at the phone output.

- The observed spurious output resembles behavior commonly seen in load impedance induced amplifier instability.
- The spurious output center frequency changes with minor changes in the amplifier output impedance matching circuit component values.
- The spurious output spectra is wideband, not sinusoidal as would be expected with an LO signal.
- The spurious output power magnitude increases with phone output power, in a nonlinear fashion (not dB-for-dB).

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3.3 Qualcomm Emission Measurements in the GPS Band

Test Results

Table 4 lists the 11 phones evaluated for emissions in the GPS band, centered on 1575 MHz.

Table 4: Cellphones Evaluated

Carrier	Manufacturer	Model	FCC ID	Band	Tech	GPS
Verizon	Audiovox	CDM8600	PP4TX-55C	Dual	CDMA1x	Yes
Verizon	Motorola	V60p	IHDT56DC1	Dual	CDMA1x	Yes
Verizon	Motorola	T730	IDHT56CG1	Dual	CDMA1x	Yes
Verizon	Motorola	T720	IHDT56CG1	Dual	CDMA1x	Yes
Sprint	Sanyo	SCP-8100(W)	AEZSCP-81H	Dual	CDMA1x	Yes
Sprint	Sanyo	SCP-7200	AEZSCP-72H	PCS only	CDMA1x	Yes
Sprint	Sanyo	SCP-5400	AEZSCP-54H	Dual	CDMA1x	Yes
Sprint	Samsung	SPH-A620	A3LSPHA620	Dual	CDMA1x	Yes
Sprint	Samsung	SPH-A600	A3LSPHA600	Dual	CDMA1x	Yes
Verizon	Samsung	SCH-A530	A3LSCHA530	Dual	CDMA1x	Yes
Verizon	LG	VX6000	BEJVX6000	Dual	CDMA1x	Yes

Figures D.1 through D.21 in Appendix D depict the radiated data for the phones that were evaluated.

Figures D.22 through D.32 in Appendix D depict, for comparison, a sample of the conducted emission profiles taken from the FCC online database.

Please note that there are no radiated or conducted emission profiles for the Sanyo SCP-7200. The phone does not support CDMA Cellular communications. These figures were left as placeholders for the purpose of readability.

Analysis

No emissions in the GPS band were detected above the noise floor of the measurement receiver in all cases.

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4. Conclusions

NASA testing on the Samsung SPH-N300 mobile phone verified compliance with data that was filed with the FCC by the manufacturer in September 2001. The measured emission data shows 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. It should be noted, however, that there could be a measurement uncertainty of +/- 5 dB (Ref. 5). Should this be the case, it could bring the Transmitting Portable Electronic Devices (T-PED) emission levels in line with those measured on a sample of PEDs, such as laptops, in the GPS band.

Follow-on testing by Qualcomm indicates the emission at 1575 MHz was due to a specific combination of amplifier output impedance and load impedance that induced instability in the power amplifier. The resulting spurious emission complied with the mandatory regulatory emissions limits by a large margin, and thus the manufacturer pursued no further design improvements. This type of amplifier instability can occur in any transmitting device and is independent of technology (Wireless Local Area Network -WLAN- or Wireless Wide Area Network -WWAN-).

In any case, Qualcomm determined the Samsung model SPH-N300 mobile phone was discontinued, not withdrawn, from the market because of potential emissions- by the service provider (Sprint) in favor of newer models.

In addition, emissions testing of 11 available commercial mobile phone models from five different phone manufacturers resulted in no detectable emissions above the noise-floor measurements in the 1575 GPS band. These results confirm that the emissions in the GPS band from the Samsung N300 are specific to that phone model and are not indicative of inherent emissions characteristics for all mobile phones.

It should be noted, however, that signals below the thermal noise floor could still impact GPS signals, which are themselves below the thermal noise floor. Therefore, good receiver measurements are needed to be confident that no emission detected implies there is no impact to GPS.

The objective of this report was to analyze potential interference with the on-board GPS navigation system, not other standard navigation systems such as, for example, the glide slope indicator or magnetic compass.

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Appendices

Appendix A. Test Setup

Figure A.1: NASA Samsung Test. 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 A2: NASA Samsung Test. 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.

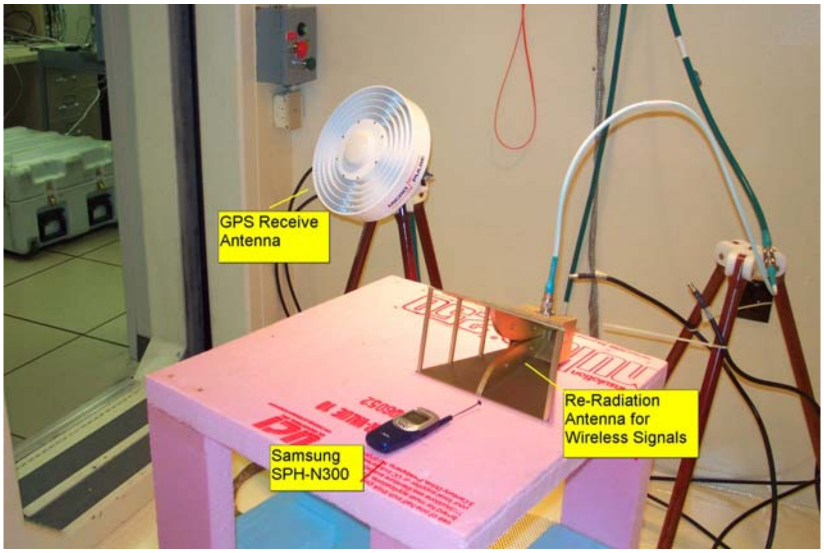


Figure A.3: QUALCOMM Samsung Conducted Emissions Test Setup

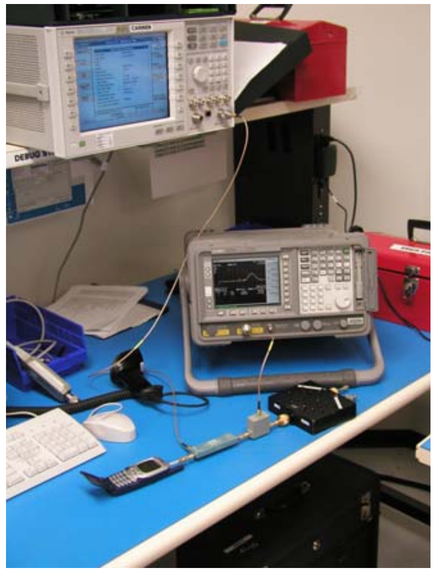


Figure A.4: QUALCOMM Radiated Emissions Test Setup in GPS Band Test Setup

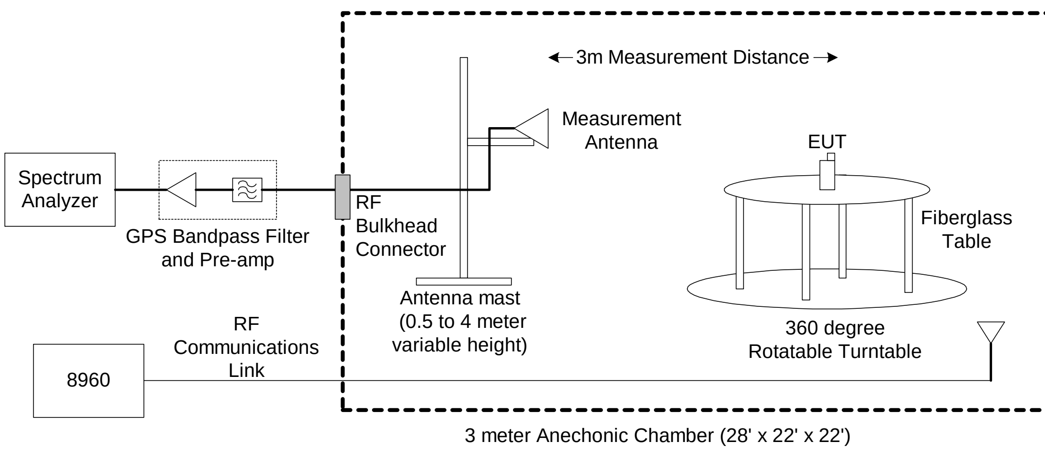


Figure A.5: QUALCOMM Emissions in GPS Band Test Setup (2)

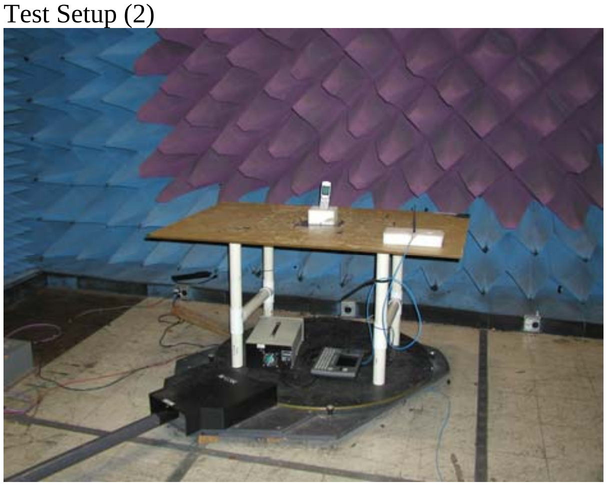


Figure A.6: QUALCOMM Emissions in GPS Band – Commercial Test Phones

Appendix B. Results – NASA Samsung Test

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

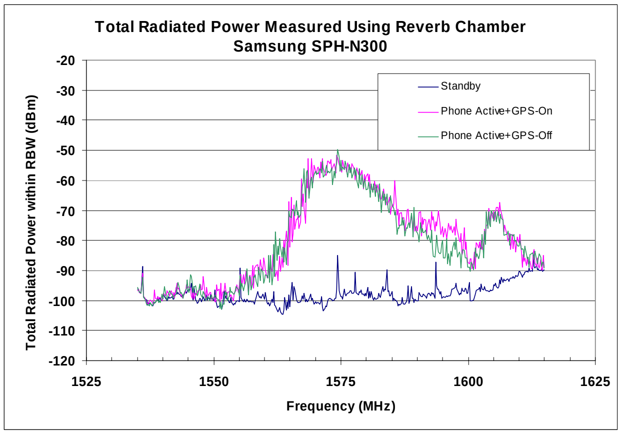


Figure B.2: Raw spurious emission data. Phone in Standby mode.

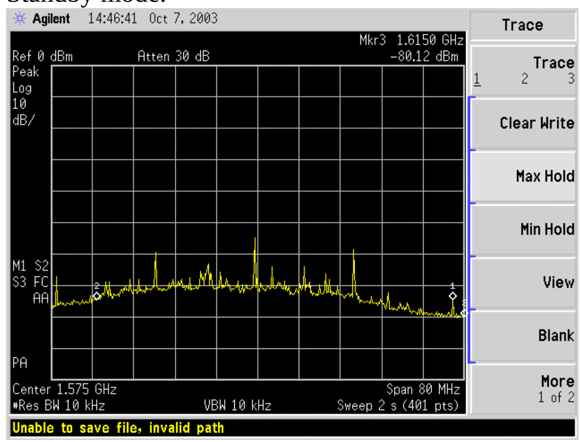


Figure B.3: Raw spurious emission data. Phone-Active, GPS On.

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

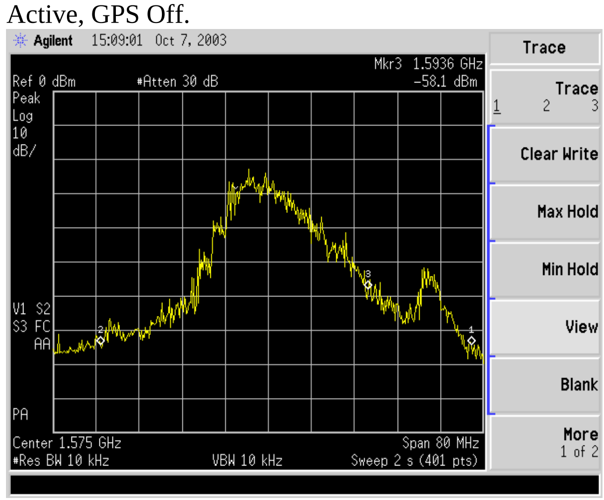


Figure B.5: Chamber calibration (raw data) with –60 dBm input power.

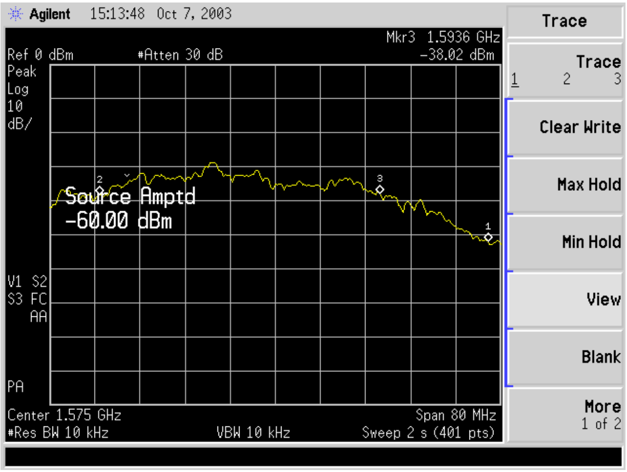


Figure B.6: Chamber calibration (raw data) performed with reference wideband dual-ridge horns used as transmit and receive antennas

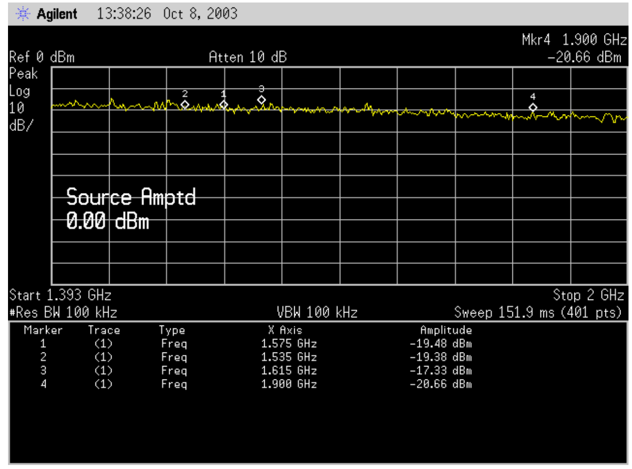


Figure B.7: Chamber calibration (raw data) performed with a MicroPulse GPS survey antenna (and a GPS band low-pass filter with negligible effects) and a wideband dual-ridge horn as transmit antenna. This plot demonstrates the selectivity of the GPS antenna with built-in filters/pre-amplifier as compared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

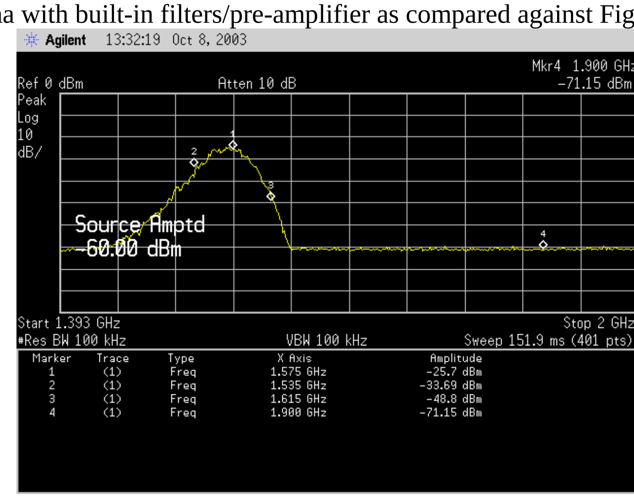
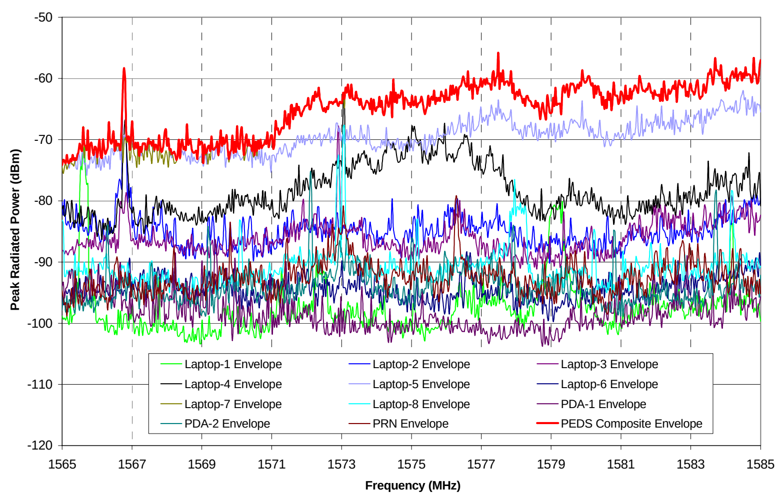


Figure B.8: Maximum emissions from various laptop computers and PDA in the GPS band measured in a reverberation chamber.



Appendix C. Results - Qualcomm Samsung Conducted Testing

Figure C.1: Frequency response of isolator/duplexer setup to pass GPS but absorb PCS TX.

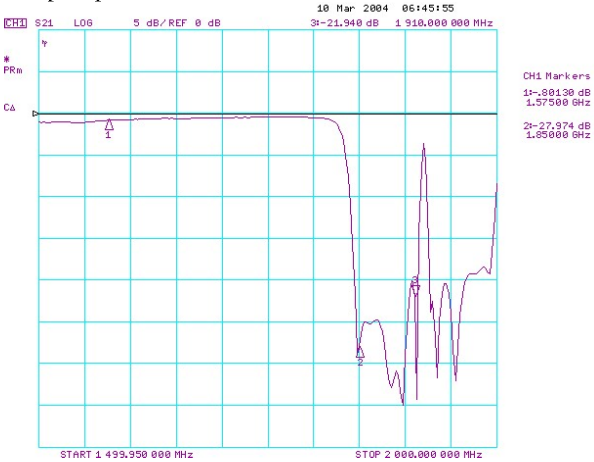


Figure C.2: Bare board, stock, no tuning applied.

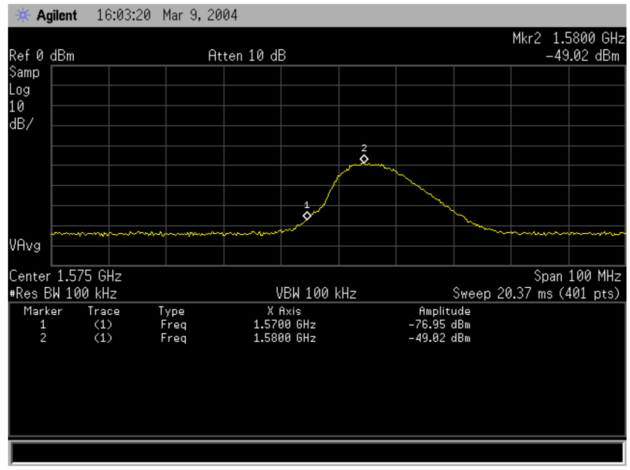


Figure C.3: 1.2pF cap at PCS PA output after series inductor. Use PCS duplexer + isolator combination to absorb TX energy before output to spectrum analyzer. Phone in a PCS call at CH25, max TX power. Recorded +23 dBm. Bare board.

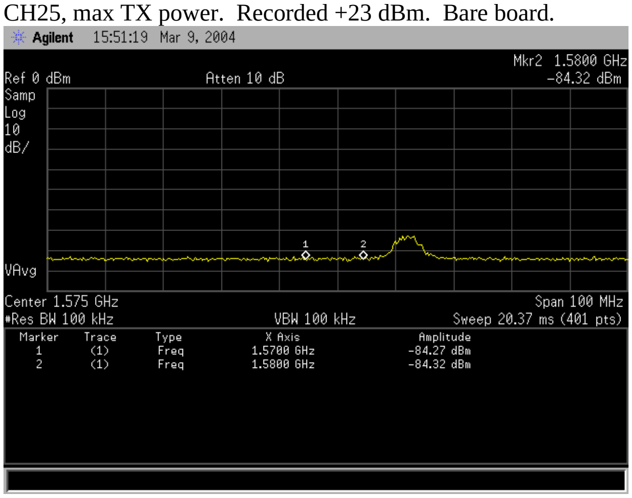


Figure C.4: Assembled phone, stock, no cap or tuning at PA output.

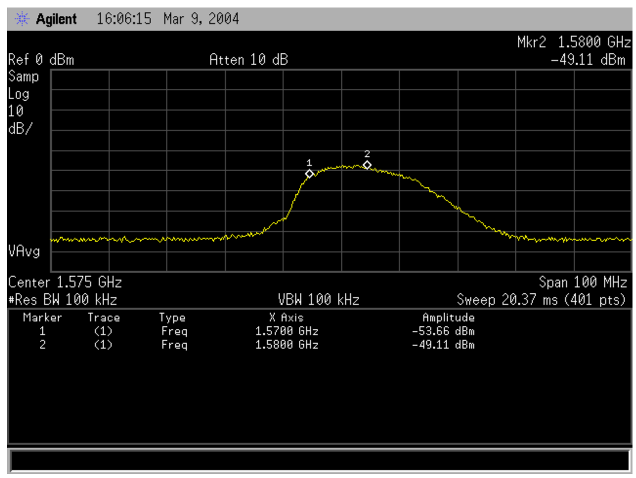


Figure C.5: Assembled phone, shunt 1.2pF cap at PA output after stock inductor.

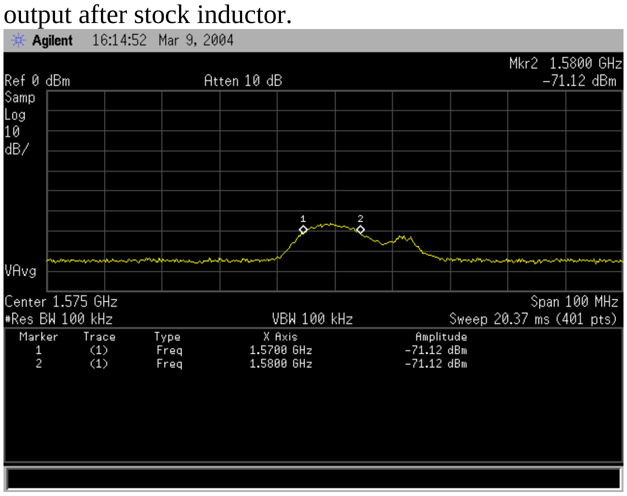
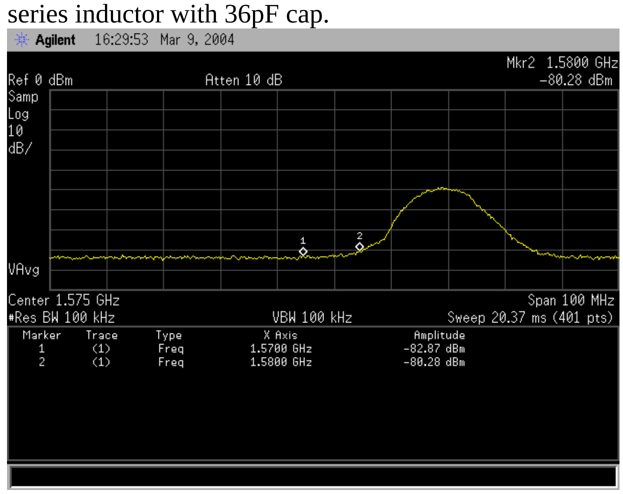


Figure C.6: Assembled phone, no shunt match. Replace series inductor with 36pF cap.



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Appendix D. Results – Radiated Emissions in GPS Band Test

Figure D.1: Audiovox CDM8600 - Radiated PCS Ch 600 (1880 MHz)

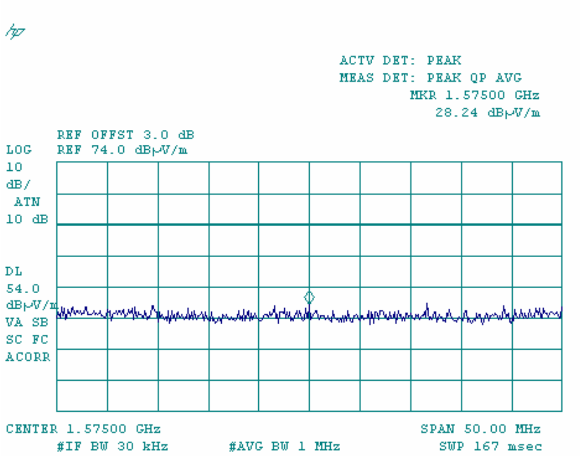


Figure D.2: Audiovox CDM8600 - Radiated Cellular Ch 384 (836 MHz

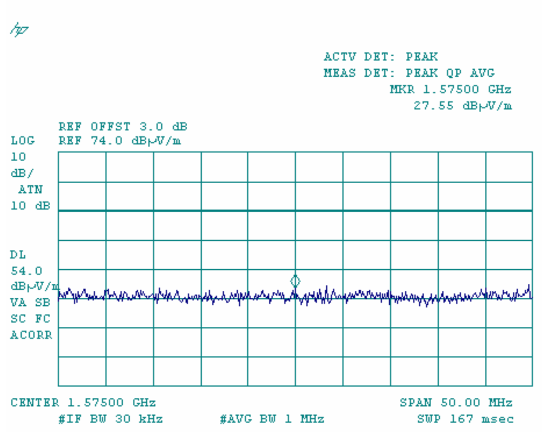


Figure D.3: Motorola V60p - PCS Ch 600 (1880 MHz)

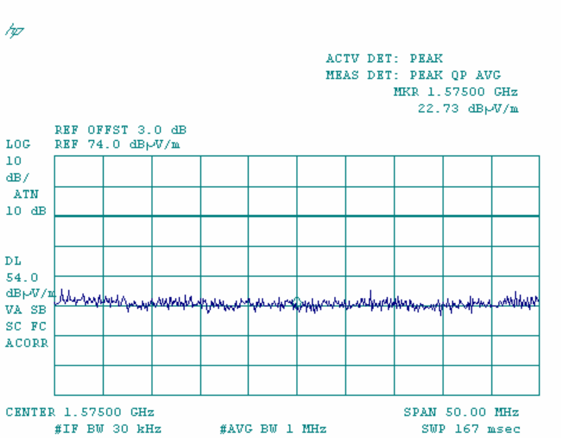


Figure D.4: Motorola V60p - Cellular Ch 384 (836 MHz

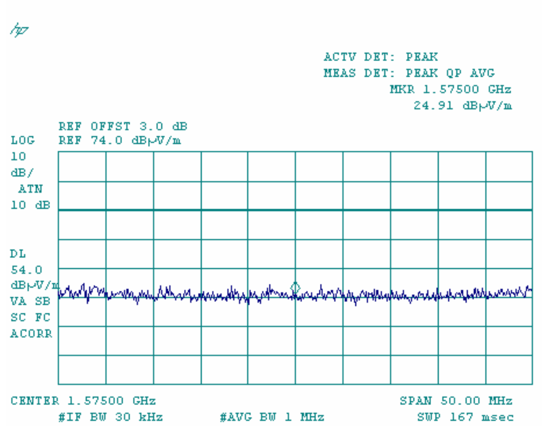


Figure D.5: Motorola T730 - PCS Ch 600 (1880 MHz

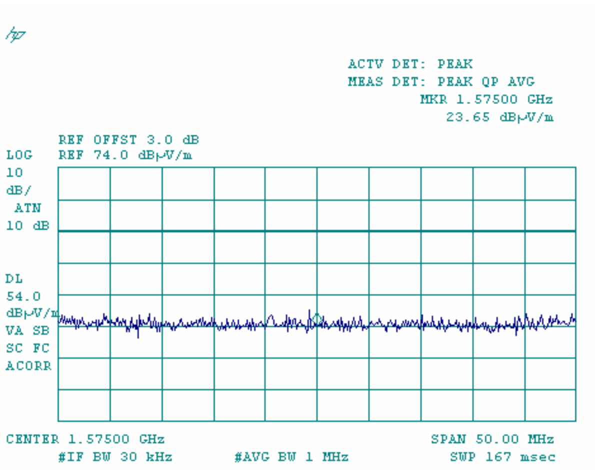


Figure D.6: Motorola T730 - Cellular Ch 384 (836 MHz)

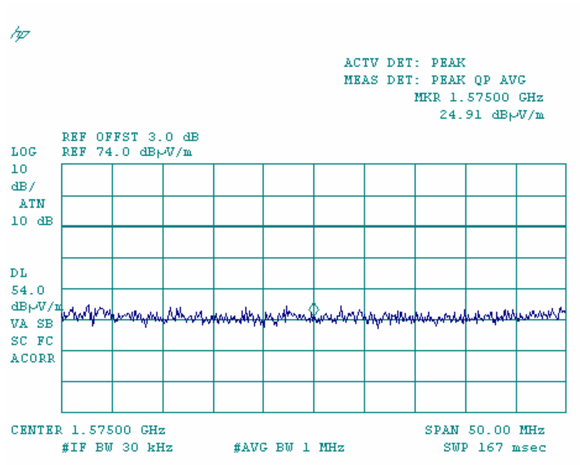


Figure D.7: Motorola T720 - PCS Ch 600 (1880 MHz)

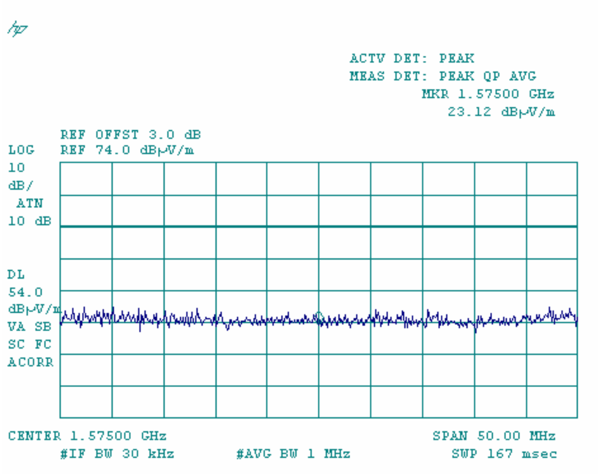


Figure D.8: Motorola T720 - Cellular Ch 384 (836 MHz)

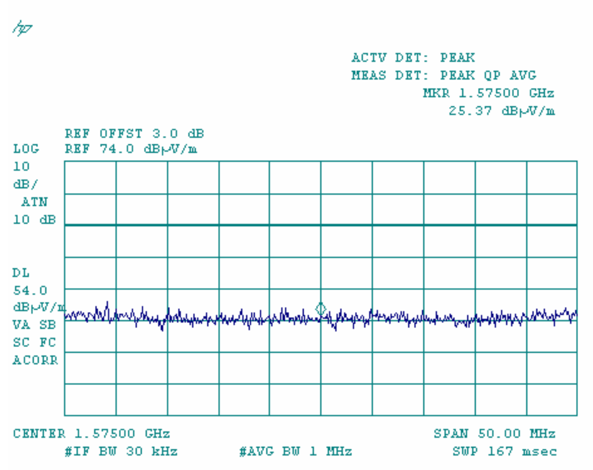


Figure D.9: Sanyo SCP-8100(W) - Radiated PCS Ch 600 (1880 MHz)

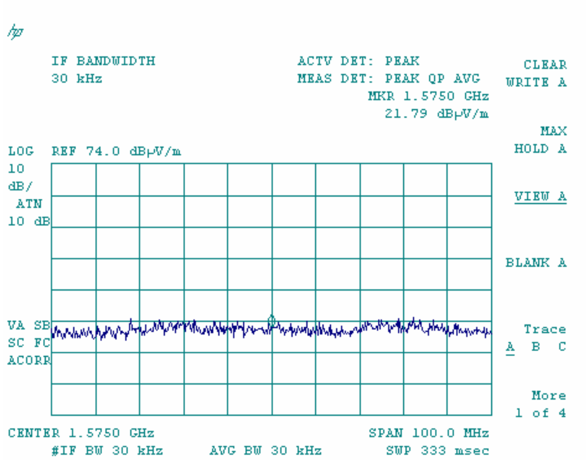


Figure D.10: Sanyo SCP-8100(W) - Radiated Cellular Ch 384 (836 MHz)

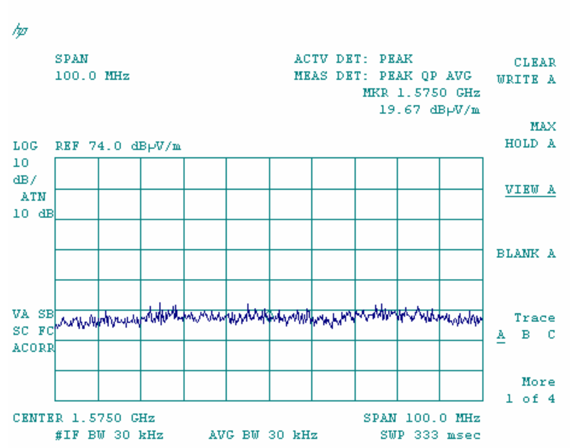


Figure D.11: Sanyo SCP-7200 - Radiated PCS Ch 600 (1880 MHz)

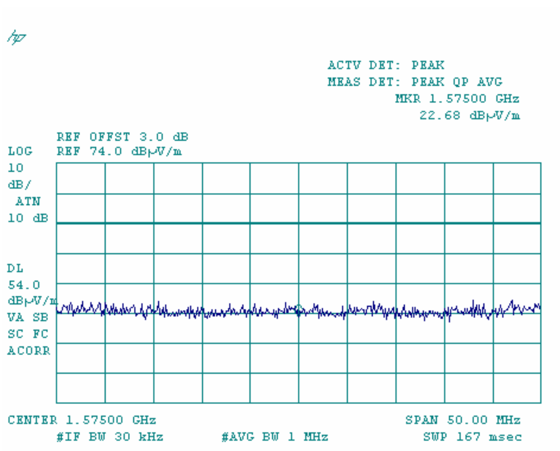


Figure D.12: Sanyo SCP-7200 - Radiated Cellular Ch 384 (836 MHz)

Does not support 800 MHz band.

Figure D.13: Sanyo SCP-5400 - Radiated PCS Ch 600 (1880 MHz)

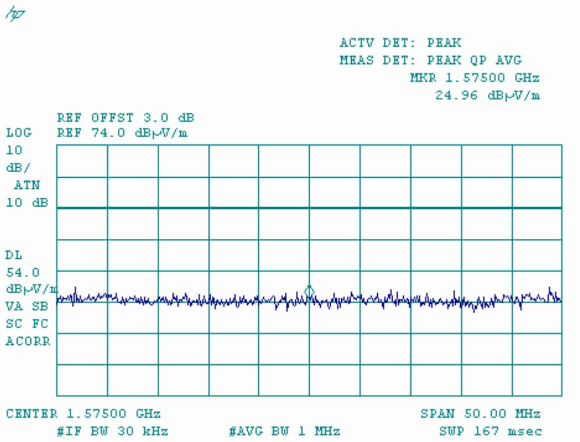


Figure D.14: Sanyo SCP-5400 - Radiated Cellular Ch 384 (836 MHz)

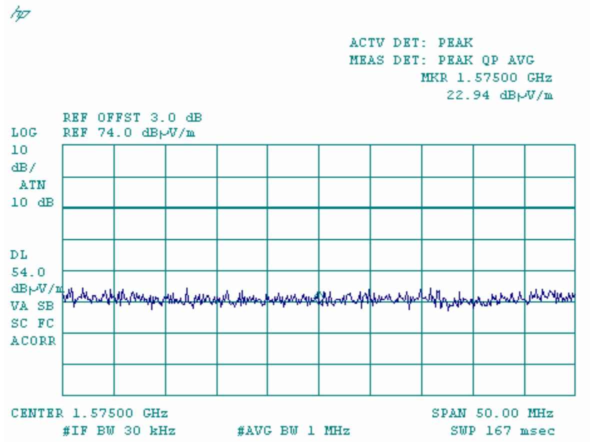


Figure D.15: Samsung SPH-A620 - Radiated PCS Ch 600 (1880 MHz)

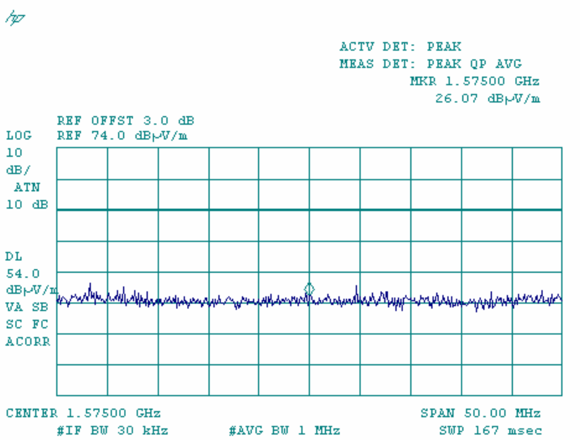


Figure D.16: Samsung SPH-A620 - Radiated Cellular Ch 384 (836 MHz)

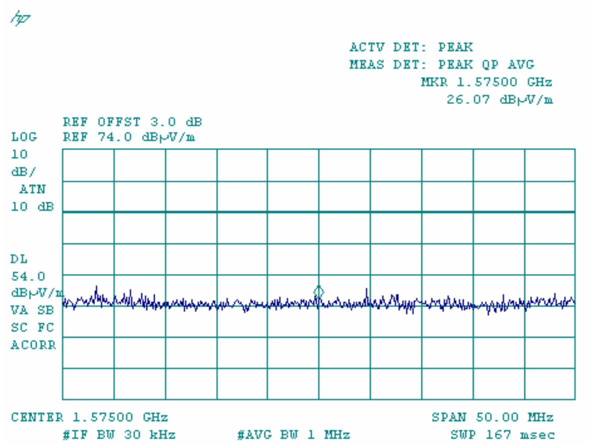


Figure D.17: Samsung SPH-A600 - Radiated PCS Ch 600 (1880 MHz)

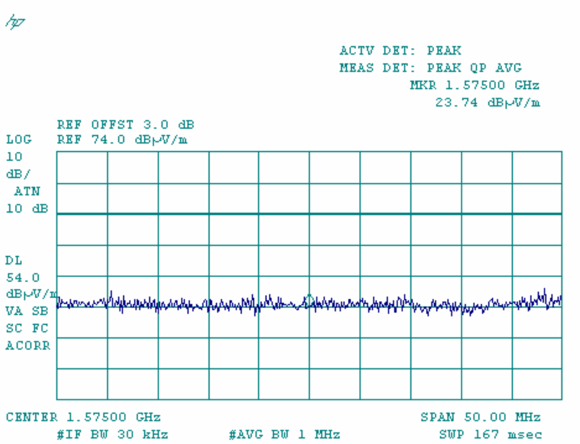


Figure D.17: Samsung SPH-A600 - Radiated Cellular Ch 384 (836 MHz)

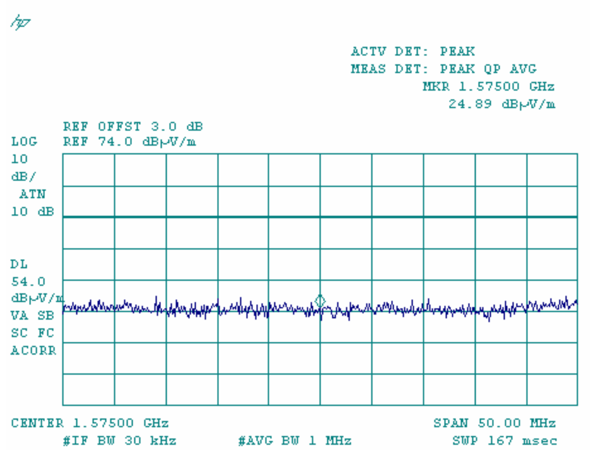


Figure D.18: Samsung SCH-A530 - Radiated PCS Ch 600 (1880 MHz)

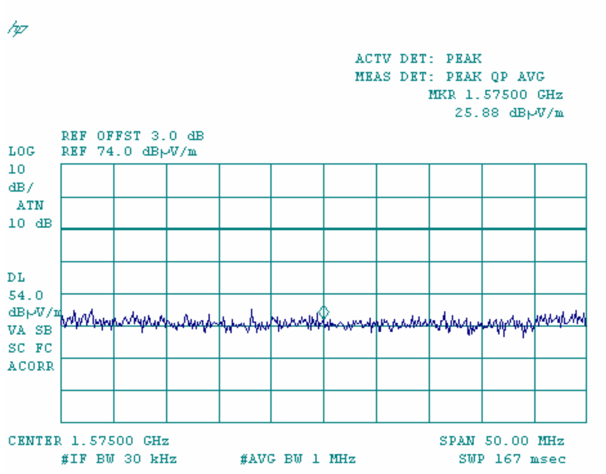


Figure D.19: Samsung SCH-A530 - Radiated Cellular Ch 384 (836 MHz)

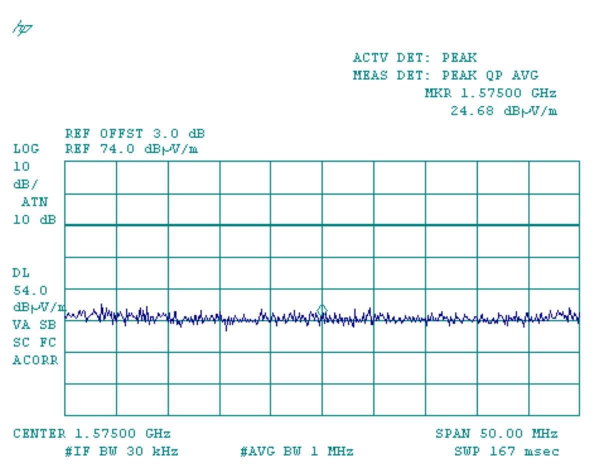


Figure D.20: LG VX 6000 - Radiated Cellular Ch 384 (836 MHz)

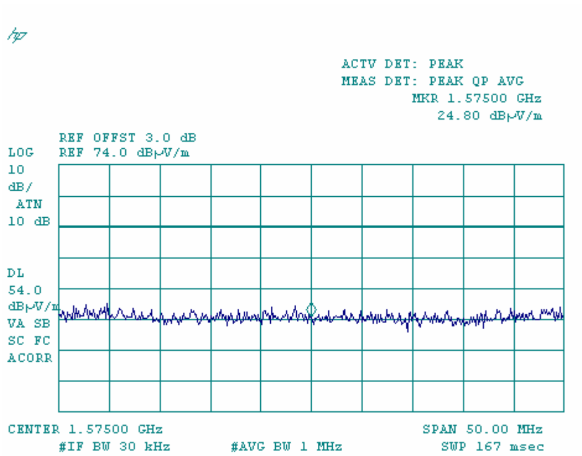


Figure D.21: LG VX 6000 - Radiated PCS 600 (1880 MHz)

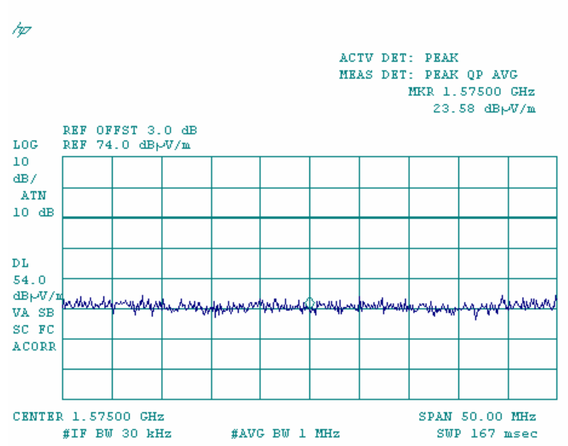


Figure D.22: Audiovox CDM8600 - Conducted PCS Ch 600

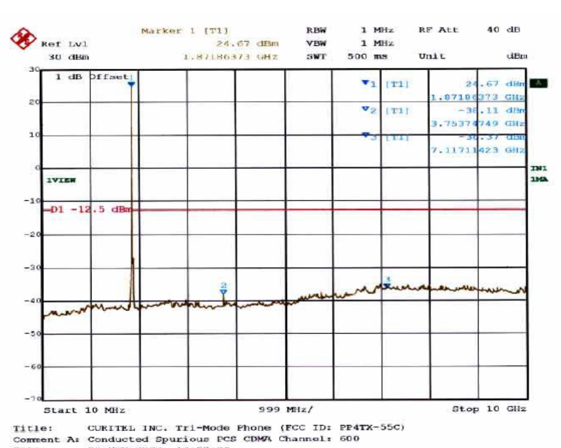


Figure D.23: Audiovox CDM8600 - Conducted Cellular Ch 363 (835.89 MHz)

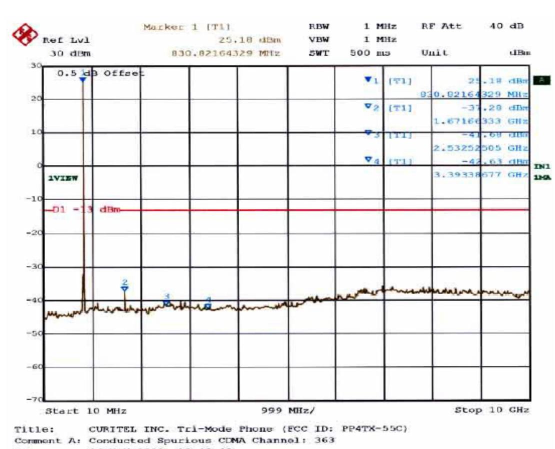


Figure D.24: Sanyo SCP-8100(W) - Conducted PCS Ch 600

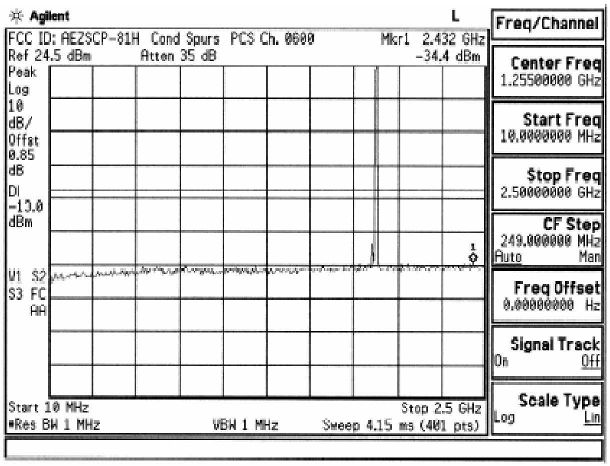


Figure D.25: Sanyo SCP-8100(W) - Conducted Cellular Ch 383

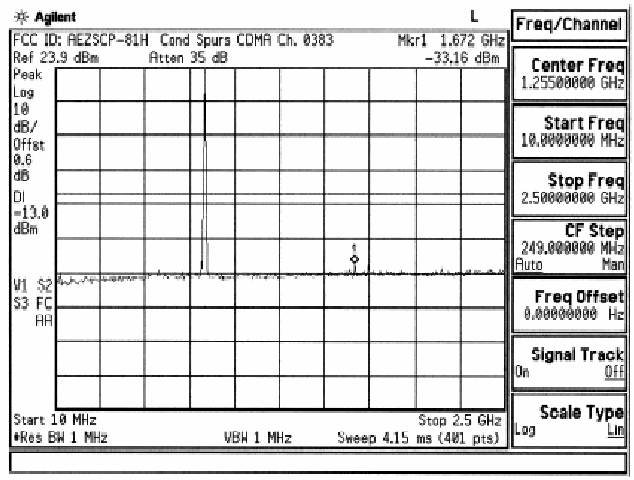


Figure D.26: Sanyo SCP-7200 - Radiated Cellular Ch 384 (836 MHz)

Does not support CDMA cellular.

Figure D.27: Sanyo SCP-7200 - Conducted PCS Ch 600

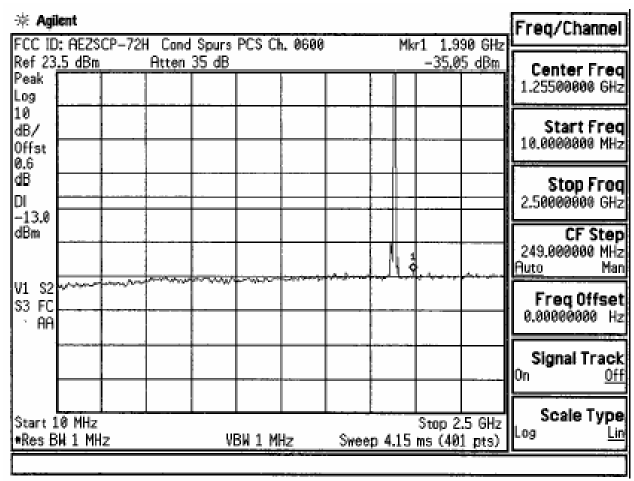


Figure D.28: Sanyo SCP-7200 - Conducted Cellular Ch 384

Does not support CDMA cellular.

Figure D.29: Sanyo SCP-5400 - Conducted PCS Ch 600

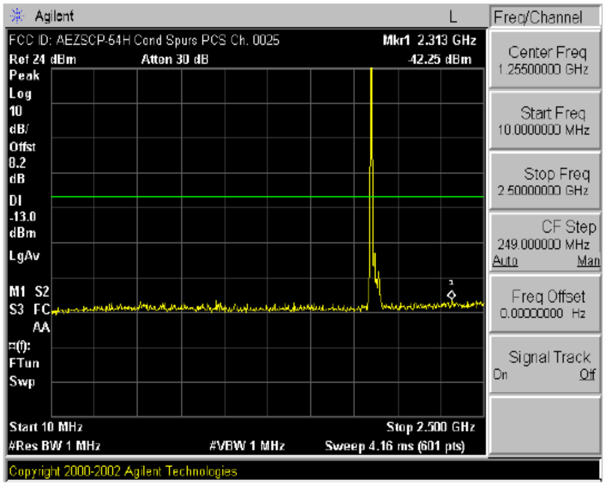


Figure D.30: Sanyo SCP-5400 - Conducted Cellular Ch 384

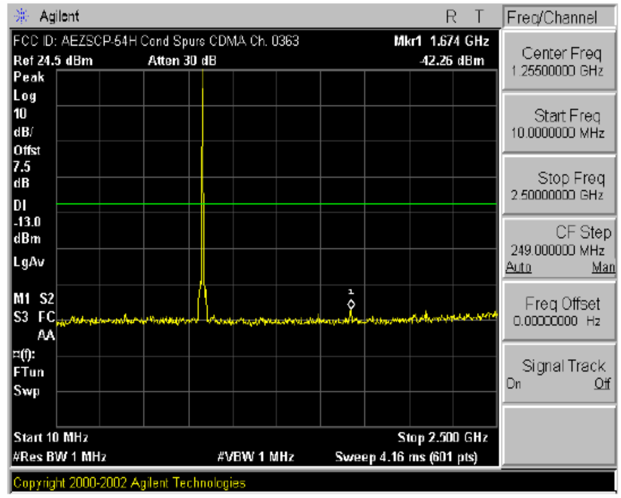


Figure D.31: Samsung SPH-A620 - Conducted PCS Ch 600

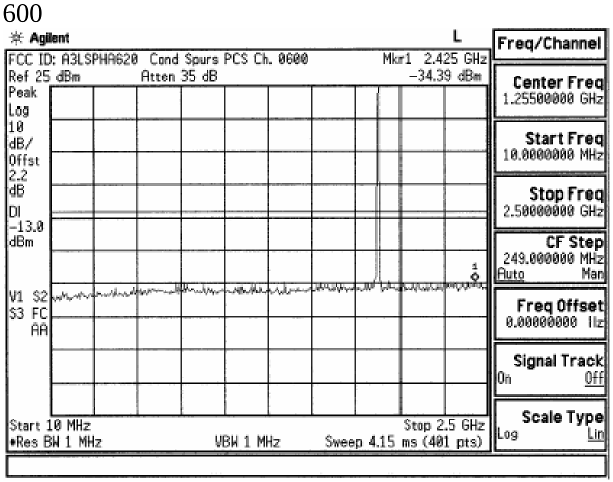


Figure D.32: Samsung SPH-A620 - Conducted Cellular Ch 363

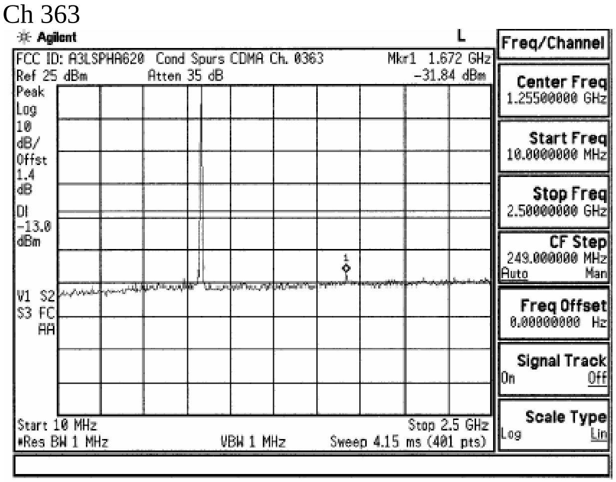


Figure D.33: Samsung SPH-A600 - Conducted PCS Ch 600

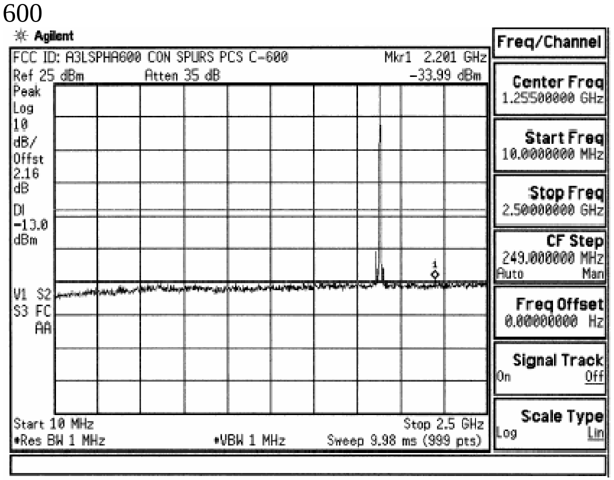


Figure D.34: Samsung SPH-A600 - Conducted Cellular Ch 363

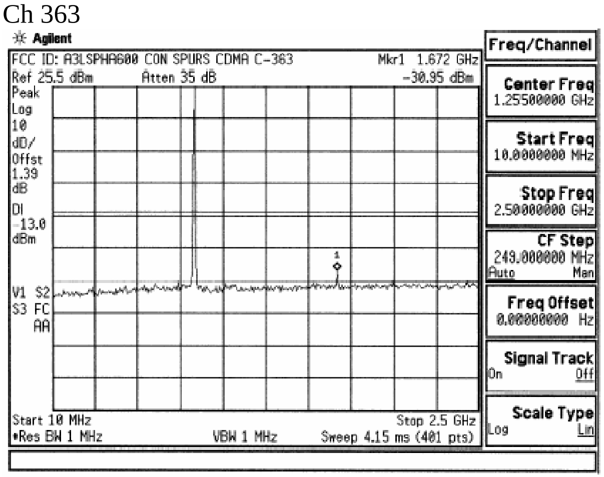


Figure D.35: Samsung SCH-A530 - Conducted PCS Ch 600

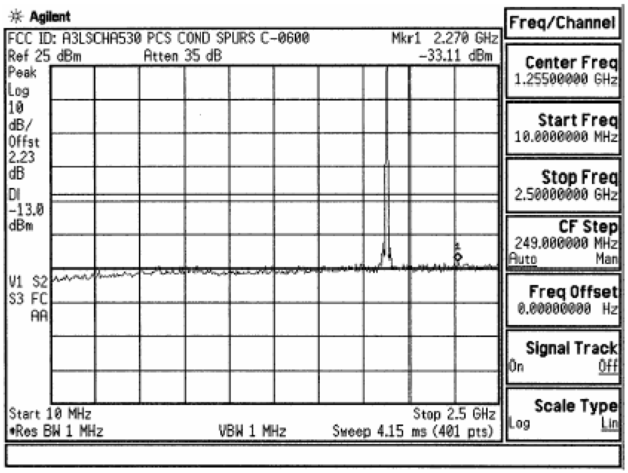


Figure D.36: Samsung SCH-A530 - Conducted Cellular Ch 362

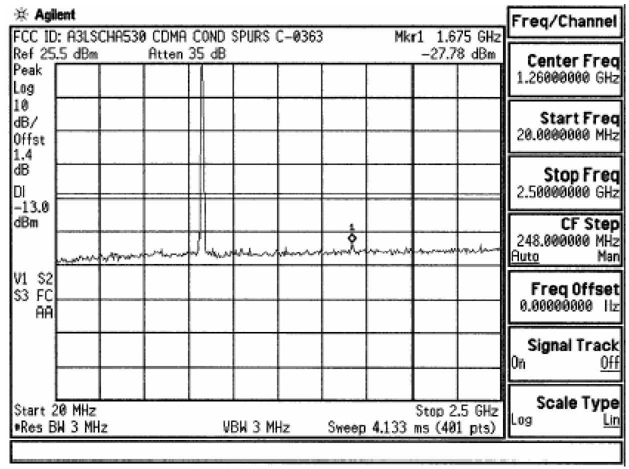


Figure D.37: LG VX 6000 - Conducted PCS Ch 25

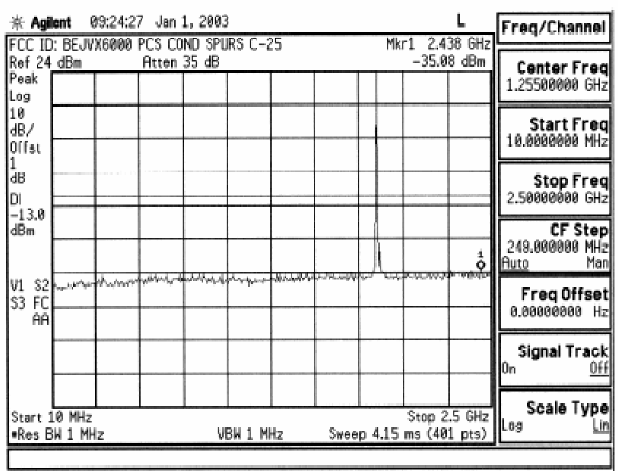
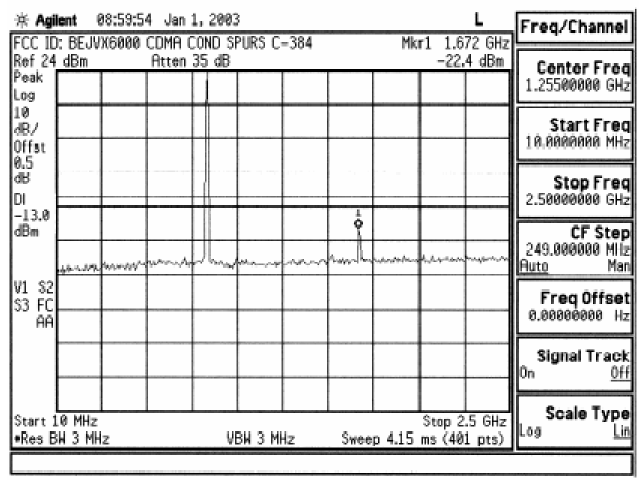


Figure D.38: LG VX 6000 - Conducted Cellular Ch 384



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13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report compiles and analyzes tests that were conducted to measure cell phone spurious emissions in the Global Positioning System (GPS) radio frequency band that could affect the navigation system of an aircraft. The cell phone in question had, as reported to the FAA (Federal Aviation Administration), caused interference to several GPS receivers on-board a small single engine aircraft despite being compliant with data filed at the time with the FCC by the manufacturer. NASA (National Aeronautics and Space Administration) and industry tests show that while there is an emission in the 1575 MHz GPS band due to a specific combination of amplifier output impedance and load impedance that induces instability in the power amplifier, these spurious emissions (i.e., not the intentional transmit signal) are similar to those measured on non-intentionally transmitting devices such as, for example, laptop computers. Additional testing on a wide sample of different commercial cell phones did not result in any emission in the 1575 MHz GPS Band above the noise floor of the measurement receiver.

15. SUBJECT TERMS
GPS, cellular phone, interference

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