MEASURED EMISSIONS DATA FOR USE IN EVALUATING THE ULTRA-WIDEBAND (UWB) EMISSIONS LIMITS IN THE FREQUENCY BANDS USED BY THE GLOBAL POSITIONING SYSTEM (GPS)

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EXECUTIVE SUMMARY

On February 14, 2002, the Federal Communications Commission (FCC) adopted the First Report and Order (R&O) authorizing the limited use of Ultra-Wideband (UWB) devices on an unlicensed basis under Part 15 of the FCC rules. UWB devices operate by employing very narrow or short-duration pulses that result in an extremely wideband frequency spectra. UWB technology holds great promise for a vast array of new applications with the potential for providing significant benefits to public safety operations, as well as business and consumer applications.

The UWB R&O establishes average limits for UWB emissions in the form of application-based emission masks. In the 960-1610 MHz frequency range, the emissions limits defined by these masks are predicated on the protection of current and future Global Positioning System (GPS) operations. Many of the parties providing public comments within the UWB proceeding have expressed concerns over the aggregation of conservative assumptions used in the derivation of these emissions limits.

The Commission recognizes the growing importance of GPS in everyday life and is committed to ensuring that the GPS signals are not degraded or interrupted as a result of radio frequency interference. However, the Commission is also committed to fostering the development and implementation of promising new radio communications technology. As such, the Commission must carefully balance the need to protect critical services like GPS from interference without placing unnecessary burdens on developing technologies such as UWB.

The following statement was included in the text of the R&O: “It is our belief that the standards contained in this Order are extremely conservative. These standards may change in the future as we continue to collect data regarding UWB operations.” This measurement effort represents a first step in collecting data to assist in an assessment of these standards in accordance with the Commission’s commitment to re-examine the UWB rules within six to twelve months of the initial release of the R&O. Since very few UWB devices had actually reached the marketplace at the time this effort was initiated, it was decided that this first step assessment would focus on an evaluation of some of the assumptions that were integral to the derivation of the emission limits for UWB devices. In particular, this effort concentrates on an examination of pre-existing emissions and associated amplitude (power density) levels present in those frequency bands that were identified as requiring extreme protection from UWB operations.

A measurement approach was developed to determine the existing level of ambient RF activity within these specific frequency bands. A set of locations was

identified from which to perform the measurement of existing ambient RF activity based on the likelihood of UWB-to-GPS interactions. These locations are separated into two distinct categories, outdoor locations and indoor locations. Seven outdoor sites were identified for performing these measurements, including airports, seaports, train yards, and industrial sites. These sites were selected primarily because GPS has been cited as a key navigational component for use in aviation, maritime, rail, and automotive transportation systems.

Eight measurement sites were selected for the indoor ambient environment measurements consisting primarily of office buildings and factory installations. These locations were selected as representative of environments in which E-911 enabled handsets (using enhanced GPS technology) are anticipated to operate coincident with UWB devices.

A measurement system was designed to measure and record the existing ambient RF activity at each of the candidate measurement locations. This system was designed to detect RF emissions down to the very low-amplitude levels necessary to compare with the conservative GPS receiver susceptibility threshold assumed in the derivation of the UWB emissions limits. The measurement system was transported to an assortment of locations where existing ambient RF emissions were measured and recorded for subsequent analysis.

The measurement results show that the GPS L1 and L2 frequency bands are quiet with respect to existing ambient emissions at those outdoor locations where tests were conducted. However, the data also reveals that in at least some locations, particularly indoor locations similar to those assumed in the derivation of the UWB emission limits, the ambient noise environment, rather than the GPS receiver thermal noise density, may actually be the limitation to the reception of the low-amplitude GPS signals.

The measurement system developed for the ambient tests was also used at the FCC Laboratory facility to measure and record radiated emissions and associated power levels produced in the GPS frequency bands by common consumer electronic/electrical devices.

These measurement results show that although many of the devices tested radiate emissions into the GPS frequency bands, the associated amplitudes were at much lower levels than permitted by the applicable limits. However, it was also determined that the amplitudes associated with these emissions were frequently in excess of the limits established for UWB emissions.

As part of this measurement effort, the ambient noise environment in the lower ARNS (960-1160 MHZ) frequency band was also examined. This band is not used to support GPS operations nor is it identified for use in the GPS modernization plan. Rather this frequency band is used to support terrestrial-based navigational aids such as the Distance Measuring Equipment (DME) and the Air Traffic Control Radio Beacon (ATCRBS). NTIA stated that "the operational limits required for the protection of the

GPS will also be adequate to protect DME operations."[1] The measurement results show that the ambient emissions in this band are generally above the adopted UWB emission limits. Thus it appears that the limiting factor in this band will also be the ambient noise environment rather than the limit based on the GPS receiver thermal noise density. In addition, Table 6 in the NTIA letter shows that a maximum EIRP of -64 dBm/MHz is required to protect the DME system under the most conservative assumptions, which is well above both the adopted UWB limit and the ambient noise environment for this band."[2]

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[1] Letter from United States Department of Commerce, National Telecommunications and Information Administration/William T. Hatch to Federal Communications Commission, Office of Engineering Technology/Edmond J. Thomas, dated 13 February 2002 (hereinafter "NTIA Letter") at pp. 13 and 14.
[2] See NTIA Letter, Table 6.

ACKNOWLEDGEMENTS

The author would like to recognize the following people for their contributions in the completion of this effort. Many thanks go to Mr. Michael Nicolay of the FCC Laboratory for his technical guidance and efforts in coordinating access to many of the sites at which data was collected. Mr. David Means of the FCC Laboratory was also instrumental in coordinating measurement locations for this effort. Thanks go to Mr. Joe Piekarski of Agilent Technologies for his efforts in providing the sensitive measurement instrumentation necessitated by this effort. Finally, thanks to all of those who permitted access to their facilities in support of the data collection phase of this project.

SECTION ONE
INTRODUCTION

BACKGROUND

On February 14, 2002, the Federal Communications Commission (FCC) adopted the First Report and Order (R&O) authorizing the limited use of Ultra-Wideband (UWB) devices on an unlicensed basis under Part 15 of the FCC rules.[3] UWB devices operate by employing very narrow or short-duration pulses that result in an extremely wideband frequency spectra. UWB technology holds great promise for a vast array of new applications with the potential for providing significant benefits to public safety operations, as well as business and consumer applications.

The UWB R&O establishes average limits for UWB emissions in the form of application-based emission masks. In the 960-1610 MHz frequency range, the emissions limits defined by these masks are predicated on the protection of current and future Global Positioning System (GPS) operations

In an effort to determine appropriate UWB emissions limits in those frequency bands in which GPS operates, the Commission, within the Notice of Proposed Rulemaking (NPRM), encouraged the undertaking of measurement efforts to assess the susceptibility of GPS receivers to UWB emissions.[4] Several parties performed measurement programs to assess this interference potential and provided the data and analyses as a part of the record in this proceeding.[5]

General agreement was obtained from each of these studies with respect to the interference susceptibility of GPS receivers to various categories of UWB emissions (broadband noise, CW, and pulsed). In addition, the results from these tests were consistent with GPS protection criteria used by the International Telecommunications Union-Radiocommunications Sector (ITU-R) and by various aeronautical standards organizations e.g., International Civil Aviation Organization (ICAO), Federal Aviation Administration (FAA), RTCA Inc, etc.

NTIA has indicated that additional protection may be required to address potential interference to emerging GPS receiver technology. Enhanced GPS is intended for use in

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[3] FCC 02-48, *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, First Report and Order, ET Docket 98-153, April, 2002, (hereinafter "UWB R&O").
[4] FCC 00-163, *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, Notice of Proposed Rulemaking, ET Docket No. 98-153, May 11, 2000, (hereinafter "UWB NPRM").
[5] See NTIA Special Publications 01-45 and 01-47, *Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers,* February 2001 (initial report) and November 2001 (addendum), (hereinafter "NTIA Report" and "NTIA Report Addendum"), University of Texas at Austin Applied Research Laboratories, *Final Report Data Collection Campaign for Measuring UWB/GPS Compatibility Effects*, Feb. 26, 2001, Stanford University, *Potential Interference to GPS from UWB Transmitters Phase II Test Results*, March 16, 2001, and Johns Hopkins University/Applied Physics Laboratory, *Final Report UWB-GPS Compatibility Analysis Project*, March 8, 2001.

providing location information as a solution for implementing enhanced 911 (E-911) services in mobile telephone handsets. Since this technology was not available at the time, none of the test efforts considered the potential for interference from UWB emissions to this type of GPS receiver.

To protect for this new GPS technology, NTIA proposed an analytically derived protection criterion based on the thermal noise floor of a typical GPS receiver. Specifically, NTIA recommended a receiver susceptibility mask based on constraining undesired UWB emissions to levels 6 dB below the thermal noise floor of a GPS receiver.[6] In addition, NTIA proposed an operational scenario assumed to be representative of a worst-case interference interaction between a UWB emitter and a GPS receiver. This scenario was utilized in the link-budget calculation to determine the maximum UWB emission level tolerable by this class of GPS receiver. The scenario assumes an enhanced GPS receiver (activated by placing an E-911 call) and a UWB device are simultaneously operating with an unobstructed signal propagation path at a separation distance of two meters.

The Commission recognizes the growing importance of GPS in everyday life and is committed to ensuring that the GPS signals are not degraded or interrupted as a result of radio frequency interference. However, the Commission is also committed to fostering the development and implementation of promising new radio communications technology. As such, the Commission must carefully balance the need to protect critical services like GPS from interference without placing unnecessary burdens on developing technologies such as UWB. It is in the public interest that appropriate limits be developed to provide adequate protection but not overprotect these services, particularly to an extent that overly encumbers the development of new technologies.

The following statement was included in the text of the R&O: "It is our belief that the standards contained in this Order are extremely conservative. These standards may change in the future as we continue to collect data regarding UWB operations."[7] This measurement effort represents a first step in collecting the data necessary to assess these standards in accordance with the Commission's commitment to re-examine the UWB rules within six to twelve months of the initial release of the R&O. Since very few UWB devices had actually reached the marketplace at the time this effort was initiated, it was decided that this first step assessment would focus on an evaluation of some of the assumptions that were integral to the derivation of the emission limits for UWB devices. In particular, this effort concentrates on an examination of pre-existing emissions and associated amplitude (power density) levels present in those frequency bands that were identified as requiring extreme protection from UWB operations.

OBJECTIVE

[6] NTIA Letter at page 2.

[7] NTIA Letter at page 2.

The objective of this effort is to acquire and analyze the data necessary to assess existing radio frequency emissions and associated power density levels within specific frequency bands in the 960-1610 MHz portion of the electromagnetic spectrum.

APPROACH

Since the UWB emission limits in the 960-1610 MHz band are based on protection of GPS receivers to levels below their thermal noise floor, an obvious question is "will a GPS receiver realize its thermal noise floor in existing electromagnetic environments?" A secondary question that arises as a result of the small separation distance assumed in the derivation is "what emission levels are currently produced within the GPS frequency bands by common electronic and electrical devices at a distance of two meters?" In an effort to address these questions, the FCC Laboratory examined existing RF emission levels within those frequency bands over which the GPS interference susceptibility mask was applied in the derivation of the UWB emission limits.

In order to address the first question, a measurement approach was developed to determine the existing level of ambient RF activity within these specific frequency bands. A set of locations was identified from which to perform the measurement of existing ambient RF activity based on the likelihood of UWB-to-GPS interactions. These locations are divided into two distinct categories; outdoor locations and indoor locations. The outdoor sites identified for performing these measurements include airports, seaports, train yards, and industrial sites. These sites were selected primarily because GPS has been cited as a key navigational component for use in aviation, maritime, rail, and automotive transportation systems.

The measurement sites selected for the indoor ambient environment measurements include office buildings and factory installations. These locations were selected as representative of those environments in which enhanced GPS would be anticipated to operate in E-911 applications coincident with UWB operations.

A measurement system was designed to measure and record the existing ambient RF activity at each of the candidate measurement locations. This system was designed to detect RF emission levels down to the very low amplitudes necessary to facilitate a comparison to the conservative GPS receiver susceptibility threshold used in the derivation of the UWB emissions limit. The measurement system was transported to an assortment of locations where existing ambient RF emissions were measured and recorded for subsequent analysis.

To address the second question, a measurement system was developed capable of detecting radiated emissions from existing electronic/electrical devices down to levels equivalent to the UWB emission limit. This measurement system was used at the FCC Laboratory facility to measure and record spurious emissions and associated power levels produced by these types of devices in the frequency bands of interest.

Subsequent to the data collection portion of this effort, an analysis was performed for each data set. Comments are provided with regard to any identifiable trends observed within the data sets.

SECTION TWO
DESCRIPTION AND USE OF THE FREQUENCY BANDS EXAMINED

GPS APPLICATIONS

The Global Positioning System is an integral component in a wide range of position determination and timing applications worldwide. GPS has become an essential element in aviation and maritime navigation systems and is also routinely being implemented in navigational systems used by trains, automobiles, and many other transportation and vehicular applications. The telecommunications, banking, and power distribution industries have become reliant on the ability of GPS to provide very precise timing information necessary for managing capacity and distribution of their services.

Since a major consideration in the derivation of the UWB limits applicable to the 960-1610 MHz was the protection of GPS receivers (both existing and future implementations), this effort was limited to an assessment of the existing RF activity in those frequency bands in which GPS either currently operates or plans to operate in the future. Additionally, since the UWB emission limit, although predicated on the protection of GPS receivers, is also applied to spectrum that is not currently used or planned for use in GPS operations, it was determined that these particular band segments should also be examined. Specifically, the lower Aeronautical Radio Navigation Service (ARNS) band between 960 and 1160 MHz was selected for examination in addition to the three GPS frequency bands. The following paragraphs briefly discuss characteristics associated with each of the frequency bands examined within this measurement effort.

GPS L1 FREQUENCY BAND

The GPS L1 frequency band is contained within the 1559-1610 MHz restricted band of operation. The 1559-1610 MHz band is allocated on a co-primary basis to the Aeronautical Radio Navigation Service (ARNS) and the Radio Navigation Satellite Service (RNSS). The upper portion of the band is used to host downlinks (space-to-Earth) from the Russian GLONASS satellite navigation system. The European Union is finalizing plans to build and launch a new satellite radio navigation system, called Galileo, which will also provide one or more downlink signals within this band.

The GPS L1 signal is transmitted from the orbiting GPS satellites on a center frequency of 1575.42 MHz. The total bandwidth registered to the GPS L1 signal is 24 MHz (i.e., 1575.42 ± 12 MHz); however, typical GPS receivers process only 2-12 MHz of the signal. The L1 signal provides a Standard Positioning Service (SPS), a Precise Positioning Service (PPS), and a navigation message. The L1 carrier is modulated with a coarse acquisition (C/A) code to provide the SPS and is the only signal presently guaranteed to be available to civil users of GPS. The L1 carrier is also modulated with a longer precision (P) code, in phase quadrature with the C/A-code, to provide the PPS.

This service is available to those users who require greater precision, with the use of specialized GPS receivers, but is subject to being made unavailable to civil users at any time by modulation with the encrypted Y-code.

The FAA and other international aeronautical administrations are planning to launch geo-stationary orbiting satellites to augment the GPS constellation. This is being done to provide the satellite availability required to certify GPS for use as a sole-means of aeronautical radio navigation. The domestic augmentation system is known as the Wide Area Augmentation System (WAAS). Similar systems are also being planned in Europe and Japan. Additionally, the FAA is planning to locally augment GPS at select airports with a system know as the Local Area Augmentation System (LAAS). This system will consist of terrestrial-based transmitters to augment the space-based GPS signal for use in the precision landing of aircraft. Both of these systems are planned for operation in the GPS L1 frequency band.

As a result of the GPS signals originating from a distant point in space (approximately 20,000 km), the signal levels are very low when they reach a terrestrial user. The minimum guaranteed GPS signal power specification for the C/A-code is -130 dBm into a 0 dBic gain antenna;[8] however, the actual signal levels are known to be 7-10 dB greater than the minimum level. Nonetheless, the signals are very weak and necessitate the use of signal processing techniques in order to recover a usable signal. The GPS signal strength can be further reduced before arriving at a user receiver from signal attenuation associated with foliage, terrain and/or building shielding.

Because the GPS L1 band is within a restricted band of operation that is currently used exclusively for radio navigation satellite downlinks, there are no authorized frequency assignments to terrestrial-based systems. Therefore it is hypothesized that any existing emissions in the GPS L1 band will be a result of spurious (out-of-band and/or harmonic) emissions from intentional radiators, and/or low-level unintentional or incidental emissions from electronic and electrical devices (i.e., no fundamental emissions are expected to be observed).

GPS L2 FREQUENCY BAND

The GPS L2 signal is contained within the 1215-1240 MHz restricted band of operation, which is allocated on a co-primary basis to the Radiolocation Service and the RNSS. In addition to the L2 signal, this frequency band hosts the Joint Surveillance System (JSS) radar system, shared by the Department of Defense (DoD) and the FAA. These radar systems, in particular the Air Route Surveillance Radars (ARSRs), are used by the FAA for en-route surveillance of commercial aircraft and by the DoD for early warning air defense. To accommodate the relatively weak GPS signal, the radar systems operating in the band avoid frequency assignments on the L2 center frequency.

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[8] ARINC Research Corporation, *Navstar GPS Space Segment/Navigation User Interfaces*, Sept. 25, 1997, at page 13.

The GPS L2 signal is transmitted on a center frequency of 1227.60 MHz. The registered bandwidth of the GPS L2 signal is also 24 MHz (1227.60 ± 12 MHz). Currently, only the P-code (unencrypted) or Y-code (encrypted) is modulated onto the GPS L2 carrier.

Ongoing GPS modernization efforts include the addition of a new civil signal to the GPS L2 carrier providing an additional channel for utilization of the SPS.[9] This new signal will be implemented by modulating a C/A-code in phase-quadrature with the existing P- or Y-code, similar to the structure of GPS L1.

GPS L5 FREQUENCY BAND

The implementation of a GPS L5 signal is also part of the ongoing GPS modernization effort. At the most recent World Radio Conference (WRC-2000) an allocation to RNSS was adopted in the 1164-1215 MHz segment of the 960-1215 MHz ARNS frequency band. The 1164-1188 MHz segment will be used to host a new GPS aviation-specific signal. The new signal is denoted L5 and will be transmitted on 1176.45 MHz with a registered bandwidth of 24 MHz (1176.45 ± 12 MHz).[10] The upper segment (1188-1215 MHz) will be used to host a Galileo downlink signal. The new GPS L5 signal has been specifically designed to support aviation applications and will improve on known shortcomings of the existing L1 signal. As a result, the L5 signal is anticipated to be a more robust signal (e.g., 6 dB higher power, longer code, etc.) and less susceptible to both noise-like and spectral line interference than the existing L1 signal.

ARNS FREQUENCY BAND

Prior to WRC-2000, the 960-1215 MHz band was allocated exclusively to the ARNS. Traditionally, this band has been used to support navigational aids such as the FAA's Distance Measuring Equipment (DME) and the military Tactical Aeronautical Navigation (TACAN) systems. The FAA also operates the Air Traffic Control Radio Beacon System (ATCRBS) on two discrete frequencies (1030 and 1090 MHz) within this band. In addition, the military Joint Tactical Information Distribution System (JTIDS) operates in this frequency band. At WRC-2000, a co-primary allocation was granted to RNSS in the 1164-1215 MHz portion of the band as discussed above. In this measurement effort, the 960-1164 MHz portion of the band is also of interest, particularly since the UWB emission limit, although based on the protection of GPS receivers, is applied, although GPS does not currently utilize nor has plans to utilize this part of the spectrum.

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[9] Press Release from The White House, Office of the Vice President, "*Vice President Gore Announces New Global Positioning System Modernization Initiative*," January 25, 1999.
[10] Hegarty, C., and Van Dierendonck, A.J., "*Civil GPS/WAAS Signal Design and Interference Environment at 1176.45 MHz: Results of RTCA SC159 WG1 Activities.*"

SECTION THREE
DERIVATION OF THE UWB EMISSION LIMIT

In this section, the methodology and assumptions that were incorporated in the derivation of the emission limits applicable to UWB devices operating over the 960-1610 MHz region of the electromagnetic spectrum will be presented and discussed. In this measurement effort, elements of this derivation, particularly the GPS receiver susceptibility threshold, are used as a basis for comparison to existing ambient and spurious emission levels.

As previously stated, the derived UWB limits applicable in the 960-1610 MHz frequency band are predicated on the protection GPS receivers from harmful interference. Several parties to the UWB rulemaking performed measurements of GPS receiver susceptibility to UWB emissions. General agreement was observed in the results from each of these test efforts. Additionally, these results were shown to be consistent with GPS interference protection criteria developed by the United States delegation to WRC-2000 within the ITU-R[11] and by RTCA[12] for use in performing GPS interference analyses. The threshold for broadband noise interference developed within these groups is based on maintaining a minimum GPS carrier-to-noise density (C/N_0) of 34 dB-Hz, necessary for satellite acquisition (a 30 dB-Hz C/N_0 is required to maintain tracking of an already acquired satellite), assuming the minimum specified GPS signal strength of -130 dBm.[13] The broadband noise interference criterion defined in these documents is -110.5 dBm/MHz. This criterion was developed for an aviation scenario that assumes a GPS receive antenna gain of -4.5 dBi. When adjusted for use in land-based GPS analyses (i.e., the undesired emitter is constrained to a hemispherical volume with respect to the GPS receiver resulting in a minimum GPS antenna gain of 0 dBi), the equivalent threshold is -106 dBm/MHz.

In the measurement effort undertaken by NTIA to assess the interference susceptibility of GPS receivers to UWB emissions, the broadband noise interference threshold was determined to range between -106 and -100 dBm/MHz when the interference metric considered was satellite break-lock. When the interference metric considered was a degradation in reacquisition time the interference threshold ranged between -106 and -104.5 dBm/MHz.[14] Regardless of the interference metric assumed, the most conservative threshold determined from the NTIA measurements was

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[11] ITU-R Recommendation M.1477, *Technical and Performance Characteristics of Current and Planned Radionaviagation-Satellite Service (Space-to-Earth) and Aeronautical Radionavigation Service Receivers to Be Considered in Interference Studies in the Band 1559-1610 MHz*, 2000, (hereinafter "ITU-R M.1477").

[12] RTCA/DO-229B*, Minimum Operational Performance Standard for GPS/Wide Area Augmentation System Airborne Equipment*, January, 1996.

[13] See ITU-R M.1477.

[14] See NTIA Report Addendum, Tables 2-4 through 2-6.

-106 dBm/MHz, the same threshold as determined by RTCA and ITU. In the initial NTIA analyses, the interference susceptibility threshold used to perform the link budgets was consistent with their measured data.[15]

NTIA has indicated that additional protection may be required to address potential interference to an emerging GPS receiver technology. This technology, enhanced GPS, is intended for use in providing location information as a solution for implementing enhanced 911 (E-911) services in mobile telephone handsets. Since this technology was not available at the time, none of the test efforts considered the potential for interference from UWB emissions to this type of GPS receiver. Thus, NTIA proposed an analytically derived protection criteria based on the thermal noise floor of a typical GPS receiver. Specifically, NTIA requested a receiver susceptibility threshold based on constraining undesired UWB emissions to levels 6 dB below the thermal noise floor of a GPS receiver ($I/N \leq -6$ dB).[16] This requirement was said to be necessary to protect the indoor use of GPS where the available C/N_0 may be 20 dB or less, possibly even as low as 10 dB[17]. Presumably, this 14-24 dB reduction in the available GPS C/N_0 inside of a building is due solely to building attenuation, since the receiver noise density is assumed constant.

The thermal noise floor of a GPS receiver is determined from:

$$N_0 = 10 \log (kTB) + NF \qquad (1)$$

where,

N_0 = thermal noise floor of a typical GPS receiver, dBW/Hz,
k = Boltzmans constant = 1.38×10^{-23} watts/Hz,
T = system temperature = 290 K,
B = receiver bandwidth = 1×10^{6} Hz, and
NF = receiver noise figure = 2.5 dB (typical).

Applying Equation 1 and converting to units of dBm/MHz, the thermal noise floor of a typical GPS receiver was determined to be –111.5 dBm/MHz. Therefore, the UWB power received by a GPS receiver must be limited to –117.5 dBm/MHz (6 dB below the thermal noise floor).

In all subsequent link budget analyses, a receiver susceptibility threshold of -117.5 dBm/MHz was used to determine the UWB limits in the 960-1610 MHz frequency range.[18,19] Additionally, NTIA recommended that an operational scenario, said to be representative of a worst-case interference interaction between a UWB emitter and an enhanced GPS receiver, be used in performing the link-budget calculation to determine

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15 See UWB R&O, Table 1 and NTIA Letter, Table 1.
16 See NTIA Letter at p 10.
17 See UWB R&O at par. 103 and NTIA Letter at p.10.
18 See NTIA Letter, Tables 2-5.
19 See UWB R&O, tables 3-5. Note: Although the receiver susceptibility threshold shown in these tables is -114.5 dBm/MHz, paragraph 111 specifies a 3 dB uncertainty margin that makes the effective receiver susceptibility threshold equal to -117.5 dBm/MHz.

the maximum level of UWB emissions tolerable to this class of GPS receiver. This scenario assumes an enhanced GPS receiver (activated by placing an E-911 call) and a UWB device are simultaneously operating with an unobstructed signal propagation path at a separation distance of two meters[20].

Under these assumptions, the link budget for indoor UWB applications is:

Parameter	Value
Receiver Susceptibility Mask (dBm/MHz) (Broadband Noise)	-117.5
GPS Antenna Gain in Direction of RFI Source (dBi)	0
Propagation Loss (dB) (Minimum Distance Separation (meters))	42.2 (2)
Noise-Like RFI Emission Limit (dBm/MHz)	-75.3
47 C.F.R.§15.209 Emission Limit (dBm/MHz)	-41.3
Additional Attenuation Required (dB)	34.0

Thus, the average emission limit applicable indoor UWB devices in the 960-1610 MHz frequency range is an equivalent isotropic radiated power (EIRP) of -75.3 dBm/MHz. This limit is applicable in the 960-1610 MHz band to the following UWB applications: Indoor UWB Applications (Section 15.517), Handheld UWB Applications (Section 15.519), and Vehicular Radar Systems (Section 15.515).

In this measurement effort, the GPS interference susceptibility threshold, -117.5 dBm/MHz, is used as a basis for comparison in both the ambient and spurious emissions measurements. A display line is used to depict this limit on the spectrum analyzer plots included in this report.

For the ambient emission measurements, the display line at –117.5 dBm/MHz is used as the basis for comparison to the measured ambient power levels. Since the source of the ambient emissions is not always known, the distance between the source and the measurement antenna cannot be determined. Thus, an EIRP cannot be calculated to compare directly to the UWB limits as they are defined in the rules. However, since the limits were derived based on a GPS receiver susceptibility threshold of -117.5 dBm/MHz, a comparison to this level is equivalent to a comparison with the emission limit. The underlying assumption is that the measured ambient emissions directly correspond to what would be detected by a GPS receiver at the same location as the measurement system antenna.

For the spurious radiated emission measurements, the display line value (-117.5 dBm/MHz) directly represents the UWB emission limit of –75.1 dBm/MHz (EIRP), when measured at a distance of 2 meters within a 1 MHz measurement bandwidth.

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[20] See NTIA Letter, Table 2.

SECTION FOUR
MEASUREMENT SYSTEM AND PROCEDURES

MEASUREMENT SYSTEM DESCRIPTION

The measurement system used to acquire the data in this effort is shown in Figure 4-1 below.

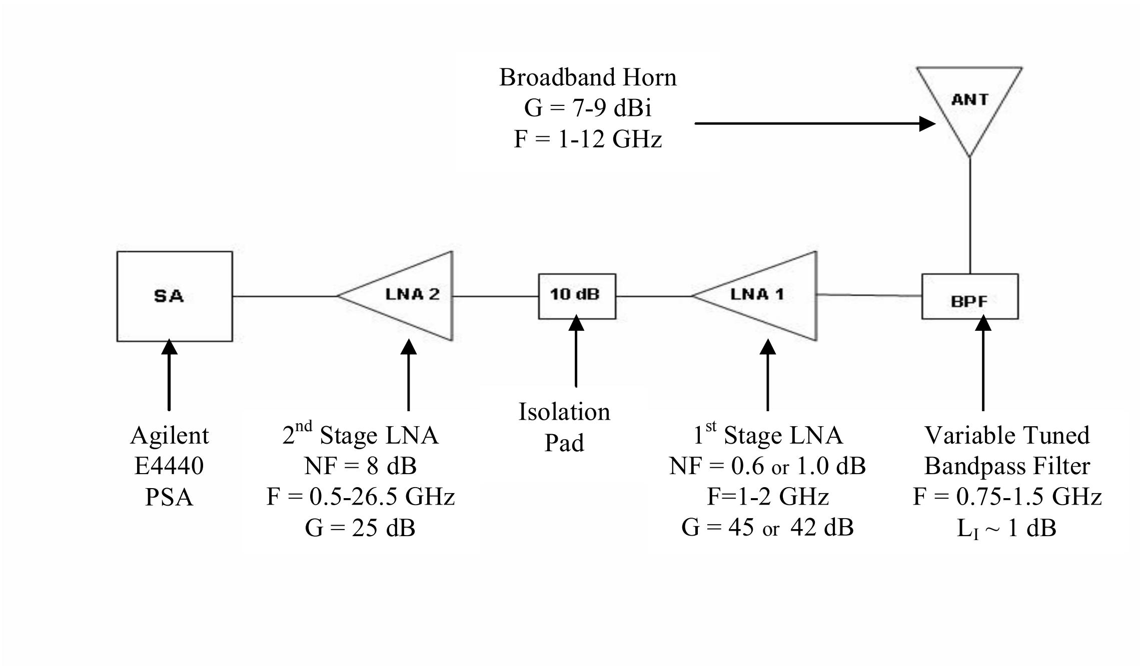


Figure 4-1. Measurement System Block Diagram.

An Agilent model E4440 PSA spectrum analyzer was the primary measurement instrument used to collect the data in this effort. This analyzer incorporates a true RMS detector providing a means to acquire, display, and store a continuous trace of RMS average power levels across the frequency bands under examination.

A pair of low noise amplifiers (LNAs) was cascaded to enable the detection of emissions to the very low levels necessary to compare with the UWB limit. Two different measurement systems were used over the duration of this effort, differing only by the first stage LNA employed. Measurement system A utilized an octave-tuned (1-2 GHz), pre-amplifier with a very low noise figure (NF) of 0.6 dB. Measurement system B also utilized an octave tuned (1-2 GHz) pre-amplifier but with a NF equal to 1.0 dB. In both systems, the first stage amplifier effectively establishes the noise figure of the entire measurement system. The second stage amplifier is a broadband amplifier of the type typically used in a compliance measurement set-up. A 10-dB attenuator was inserted between the two LNAs to provide isolation.

A tunable band-pass filter (BPF) was included in the measurement system ahead of the first stage LNA to filter out signals originating outside of the frequency band under examination.

The measurement antenna was a double-ridge broadband horn calibrated for use in the 1-12 GHz frequency range. This type of antenna was determined to provide the greatest flexibility with respect to polarization and broadband frequency characteristics, while also producing sufficient gain to accommodate the measurement of emissions to the low levels necessary to compare to the UWB limits. It should be noted that normalizing the data collected with this antenna to equate to a GPS antenna can result in an under estimate of the ambient levels that would actually be seen by a GPS receiver, particularly when the emission source is located outside the main beam of the measurement antenna.

Specific information for each component of the measurement system and the equipment used for calibration is presented below in Table 4-1.

TABLE 4-1. Test and Calibration Equipment Specifications.

EQUIPMENT	MANUFACTURER and MODEL	RELEVANT SPECIFICATIONS
Spectrum Analyzer	Agilent E4440A	3 Hz to 26.5 GHz
Signal Generator	Agilent E4437B	250 kHz to 4 GHz
LNA 2	Hewlett-Packard HP83017A	0.5-26.5 GHz Gain = 25 dB (Min) NF = 8 dB (Max)
LNA 1 (System A)	MITEQ AFS3-01000200-06-10P-6	1.0-2.0 GHz Gain = 45 dB (Min) NF = 0.6 dB (Max)
LNA 1 (System B)	MITEQ AMF-3B-010020-10-25P	1.0-2.0 GHz Gain = 42 dB (Min) NF = 1.0 dB (Max)
Tunable Band Pass Filter	Texscan 5VF750/1000-5AA	0.75-1.5 GHz
Receive Antenna	EMCO 3105 Double Ridge Guide Horn	1.0-12.0 GHz

MEASUREMENT SYSTEM CALIBRATION

The data obtained from the calibration of the measurement system components between the spectrum analyzer and the measurement antenna is presented in APPENDIX A. The following tables summarize the data relevant to characterizing the measurement system.

Tables 4-2 and 4-3 summarize the external gain as measured at the center of each of the frequency bands under examination for each of the two measurement systems used in this effort. The external gain reported in the tables is the sum of the cascaded LNA gains less the attenuation in the coaxial cables, connectors and the isolation pad, and the insertion loss of the band pass filter.

TABLE 4-2. Measurement System External Gain (System A).

CENTER FREQUENCY (MHz)	MEASUREMENT SYSTEM EXTERNAL GAIN (dB)
1575.4	64.8
1227.6	66.7
1176.0	66.4
985.0	68.0
1035.0	67.7
1085.0	67.3
1135.0	67.0

TABLE 4-3. Measurement System External Gain (System B).

CENTER FREQUENCY (MHz)	MEASUREMENT SYSTEM EXTERNAL GAIN (dB)
1575.4	63.5
1227.6	64.7
1176.0	64.9
985.0	67.4
1035.0	66.7
1085.0	66.6
1135.0	66.2

MEASUREMENT ANTENNA CALIBRATION

TABLE 4-4 lists the calibrated antenna gain provided by the manufacturer of the double-ridge guide horn antenna used in the measurement system.

TABLE 4-4. Measurement Antenna Gain.

FREQUENCY (MHz)	ANTENNA GAIN (dBi)
1575.4	8.6
1227.6	7.2
1176.0	7.1
985.0	6.1
1035.0	6.4
1085.0	6.7
1135.0	6.9

OVERALL MEASUREMENT SYSTEM GAIN

In order to determine the true amplitude of the signals impinging on the measurement antenna, adjustments to the displayed amplitude levels are necessary to account for the amplification in the measurement system, external to the spectrum analyzer. This amplification is necessary to detect low-amplitude signals but must be removed from the data to reveal the true signal level. The spectrum analyzer used in these measurements provides the capability to perform these corrections internally, but the user must enter the applicable gain values in order to adjust the data.

Tables 4-5 and 4-6 list the gain values determined for measurement systems A and B, respectively. The overall system gain reported in these tables are the values that were input to the spectrum analyzer to facilitate the internal correction to the data so that the displayed amplitudes accurately depict the actual signal levels impinging on the measurement antenna. The overall system gain was determined by adding the measurement system external gain of each of the measurement systems and the antenna gain for each frequency range examined as a part of this effort.

TABLE 4-5. Total System Gain (System A).

FREQUENCY (MHz)	EXTERNAL GAIN (dB)	ANTENNA GAIN (dBi)	OVERALL SYSTEM GAIN (dB)
1575.4	64.8	8.6	73.4
1227.6	66.7	7.2	73.9
1176.0	66.4	7.1	73.5
985.0	68.0	6.1	74.1
1035.0	67.7	6.4	74.1
1085.0	67.3	6.7	74.0
1135.0	67.0	6.9	73.9

TABLE 4-6. Total System Gain (System B).

FREQUENCY (MHz)	SYSTEM GAIN (dB)	ANTENNA GAIN (dBi)	OVERALL SYSTEM GAIN (dB)
1575.4	63.5	8.6	72.1
1227.6	64.7	7.2	71.9
1176.0	64.9	7.1	72.0
985.0	67.4	6.1	73.5
1035.0	66.7	6.4	73.1
1085.0	66.6	6.7	73.3
1135.0	66.2	6.9	73.1

MEASUREMENT PROCEDURES

The procedures implemented for measuring both existing ambient emissions and spurious emissions from consumer devices are defined in Appendix B of this document.

SECTION FIVE
MEASURED DATA

AMBIENT EMISSIONS MEASUREMENTS

Field surveys were performed at those locations deemed consistent with the list of candidate sites, i.e., airports, shipyards, train yards, industrial areas (outdoor sites), office buildings and factory floors (indoor sites). These surveys were performed to determine the presence of existing ambient emissions and the associated power levels within the frequency bands under examination.

These measurements were intended to determine the amplitude of existing ambient emissions as would be experienced at the measurement location by a GPS receiver. The measured levels were then compared to the theoretical GPS interference criterion supported by NTIA and used in establishing the emission limit applicable to UWB devices. To facilitate this comparison the measurement system was configured to simulate the RF front-end of a GPS receiver. The resolution bandwidth of the measurement receiver (spectrum analyzer) was set to 1 MHz, the same as the RF bandwidth of many GPS receivers and also to give results in dBm/MHz, consistent with the specified interference threshold units. The spectrum analyzer was tuned to the center frequency in each of the GPS frequency bands, as would a GPS receiver, but was also used to span the entire registered bandwidth of the GPS signal. The ambient emissions were measured in terms of RMS average, consistent with the results of studies performed by NTIA and others showing that GPS receivers are most susceptible to average power interference. Conventional GPS receivers employ an integration time on the order of 20 milliseconds; however, enhanced GPS receivers, for which the extreme protection criteria was deemed necessary, were said to "…integrate the satellite signal over a longer time period, allowing the receiver to obtain a 20 to 30 dB higher processing gain than a conventional GPS receiver."[21] For these measurements, an effective integration time of 100 milliseconds was utilized in performing the RMS averaging (one-hundred 1-msec sweeps). The primary distinction between the measurement system and the RF chain of a GPS receiver was the receive antenna. The measurement system utilized an antenna that is more directional than a GPS antenna in order to provide sufficient gain to accommodate measurements to the extremely low levels necessary to compare to the UWB emission limits (i.e., below thermal noise). The data is adjusted to equate to the 0-dBi gain assumed for a GPS antenna in the UWB-to-GPS receiver interaction link budget analyses of UWB interference potential. It is noted that this normalization of the antenna gain can lead to an underestimate of the measured ambient signal amplitudes, particularly when the emission source(s) are located outside of the measurement antenna main beam.

In these ambient measurements no concerted effort was made to identify the source of the emissions observed. Such efforts would be very difficult, particularly since many of the emissions present in these frequency bands are likely to be spurious, rather

[21] See UWB R&O at paragraph 99 and NTIA Letter at p. 8.

than fundamental emissions. Therefore, since neither the emission source nor its physical location is known, it is not possible to determine the EIRP relative to the source emitter(s). Thus, an EIRP cannot be calculated that could be compared directly to the UWB limits as they are defined in the rules. However, since the limits were derived based on a GPS receiver susceptibility threshold of -117.5 dBm/MHz, a comparison to this level represents an equivalent metric. The underlying assumption is that the measured ambient emissions directly correspond to what would be detected by a GPS receiver at the same location as the measurement system antenna. Thus, any emissions in excess of the susceptibility threshold would be expected to degrade the performance of those GPS receivers considered in the link budget analyses.

Ambient Emissions Measurement Locations

Table 5-1 provides a list of the outdoor locations where the ambient emissions measurements were performed as a part of this effort. Table 5-2 lists the indoor locations where ambient emissions measurements were performed.

Table 5-1. Outdoor Ambient Emissions Measurement Sites.

SITE	DESCRIPTION	COORDINATES
BWI Airport	Aircraft Observation Area	39º 09.771' N 076º 39.815' W
Dulles International Airport	Paige General Aviation Terminal	38º 57.170' N 077º 26.638' W
Reagan National Airport	General Aviation Parking Lot	38º 50.748' N 077º 02.668' W
Port of Baltimore	Security Office Parking Lot	39º 15.083' W 076º 33.415' W
U.S. Coast Guard Yard	Buoy Maintenance Facility	39º 12.027'N 076º 34.370'W
Train Yard	AMTRAK Maintenance Facility	38º 55.055'N 076º 59.286'W
Industrial Location	Tyson's Corner, VA	38º 55.326'N 077º 14.008'W

Table 5-2. Indoor Ambient Emissions Measurement Sites.

SITE	DESCRIPTION	COORDINATES
Office Building #1	Debt Consolidation Firm Workspace Area	39º 11.547' N 076º 49.014' W
Office Building #2	FCC Portals Large LAN Server Room	38º 52.967' W 077º 01.578' W
Office Building #3	Scientific Research Facility Central Corridor	38º 55.326' N 077º 14.008' W
Office Building #4	Engineering Research Company Small LAN Sever Room	38º 47.917' N 077º 11.480' W
Office Building #5	Engineering Research Company Typical Office Work Space	38º 47.917' N 077º 11.480' W
Factory Location #1	Electro-Optics Manufacturer Factory Floor	39º 10.948' N 076º 48.767' W
Factory Location #2	Compact Disc (CD) Manufacturer Factory Floor	39º 10.686' N 077º 15.047' W
Factory Location #3	Automotive Assembly Plant Factory Floor	39º 16.024' N 076º 32.695' W

Ambient Emissions Measurement Data

The spectrum analyzer plots depicting the data collected at each measurement site are presented in Appendices C (outdoor sites) and D (indoor sites).

A sample spectrum analyzer plot is presented below as an aid in providing an explanation of how to read and interpret the data presented in the appendices. In these plots, the upper (yellow) trace depicts the ambient emissions measured in the subject frequency band using a peak detector and the maximum hold function (i.e., no averaging employed) over a fifteen-minute period. This trace was generated mainly as a tool for orienting the measurement antenna and for determining the maximum likely emission amplitudes to facilitate decisions pertaining to the necessity of adding additional attenuation in the measurement system so as to prevent overdriving of components. This data was not used for any analytical purposes. The lower (blue) trace represents the measured RMS average emission level over one hundred one-millisecond analyzer sweeps across the measurement band. This is the data used to compare to the assumed interference threshold for enhanced GPS receivers. The constant display line (green) at -117.5 dBm is used as the basis for comparing the measured data to the theoretical enhanced GPS interference threshold.

All external measurement system parameters (e.g., amplifier gains, cable loss, and antenna gain) are accounted for in the spectrum analyzer display and are provided on each plot under the tag Ext PG located at the top of the display. At some measurement locations, it was necessary to add additional attenuation in the measurement system due to the presence of relatively high-amplitude signals. In those cases where additional external attenuation was required, the Ext PG value was adjusted accordingly. Thus, the levels shown on the amplitude axis of the spectrum analyzer plots represent the actual RMS average power as measured in a 1 MHz bandwidth at the measurement system antenna.

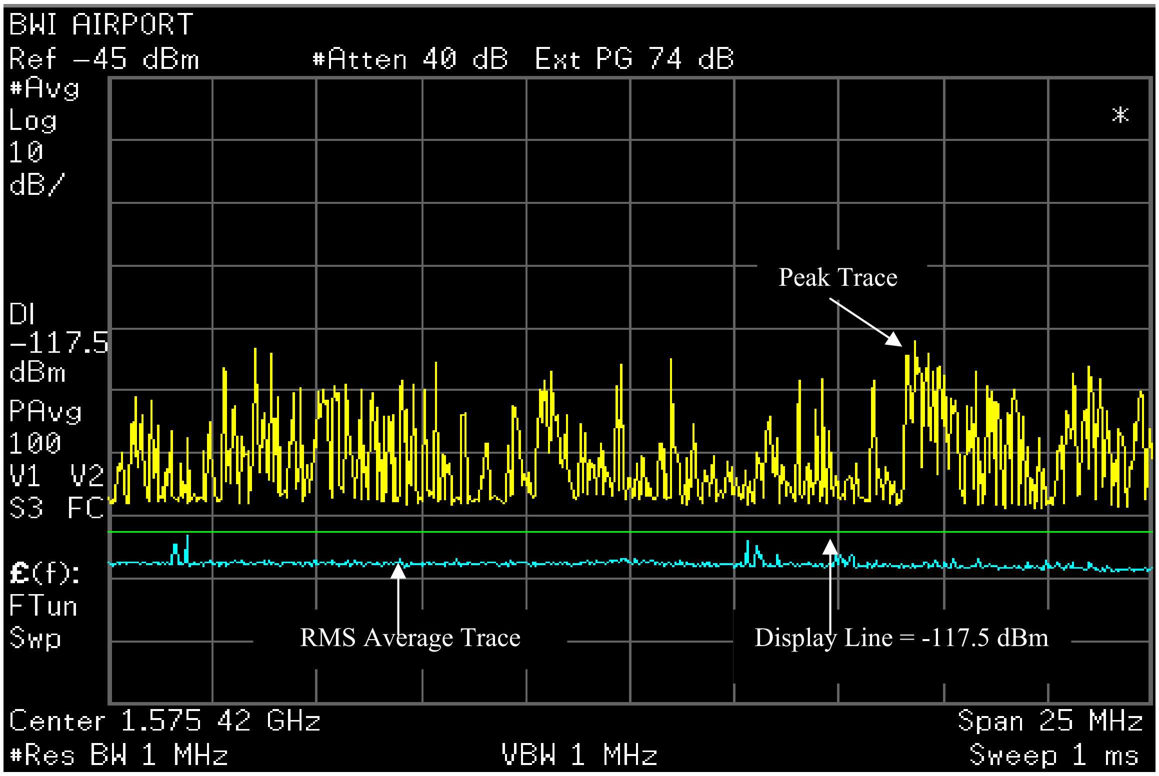


Figure 5-1. Sample Spectrum Analyzer Plot from Ambient Emissions Measurement.

In these plots, the horizontal axis represents frequency and the vertical axis represents amplitude. For measurements in the GPS frequency bands, a span of 25 MHz was used to encompass the 24 MHz registered frequency band. For a 25 MHz span, each vertical graticule line represents a 2.5 MHz deviation in frequency (25 MHz/10 graticule lines). For example, in the sample plot of Figure 5-1, the center vertical graticule line represents the center frequency of 1575.42 MHz. Each vertical graticule line to the left of the center represents a decrement from the center frequency of 2.5 MHz and each graticule line to the right of the centerline represents a 2.5 MHz increment relative to the center frequency. For the measurements performed in the 960-1160 MHz (ARNS) band, a span of 50 MHz was used, the maximum that could be achieved within the pass band of the pre-select filter. In these plots, each vertical graticule line represents a frequency deviation of 5 MHz (50 MHz/10 graticule lines).

On the amplitude axis, each horizontal graticule line represents a 10 dB decrement from the reference level amplitude shown in the upper left-hand corner of the plot. As an example, to determine the maximum amplitude level from the RMS average trace, begin with the reference level amplitude of -45 dBm and count 7.25 graticule lines down to the highest emission level shown by the trace. Since each graticule line is 10 dB (indicated in the upper left-hand margin of the plot by 10 dB/), the measured level is 72.5 dB (7.25 x 10) down from -45 dBm, or -117.5 dBm.

RADIATED EMISSIONS MEASUREMENTS

In this set of measurements, spurious emissions generated by common consumer electronic and electrical devices are examined within the GPS L1, L2, and L5 frequency bands. The ARNS band was not examined primarily due to questions regarding the usefulness of this type of measurement in assessing those assumptions used to establish the UWB limits within this band. As discussed in Section 2 of this report, GPS does not operate, nor has plans to operate in this frequency band. Thus, the relevance of a comparison of spurious emissions generated from consumer devices to the theoretical GPS interference threshold is not immediately clear. Further, it seems questionable that the types of consumer devices considered in this effort will routinely operate within two meters of the aviation and military systems that utilize this frequency band (see Section 2 for a description of these systems).

The radiated spurious emissions measurements were performed with the measurement system described previously. The measurement system was configured as it would be to determine compliance with the UWB emission limits. The device under test (DUT) was placed at a distance of two meters from the measurement antenna. This distance was selected to maintain consistency with the interaction distance assumed in the derivation of the UWB emission limit (see Section Three for details). At a distance of 2-meters, the display line at –117.5 dBm directly relates to the EIRP limit of -75.3 dBm/MHz defined within the rules.

Immediately preceding each measurement of the DUT-radiated spurious emissions, the measurement system was used to perform a check of the background or ambient RF environment in which the DUT was tested. This background measurement was performed using the same settings as used in the radiated emissions test. The resultant data was displayed using one of the three available traces of the spectrum analyzer. The DUT was then turned on and the radiated spurious emissions measurement was performed. The data from this measurement is displayed using another of the available analyzer traces. A single spectrum analyzer plot showing both traces was generated for each measurement band. The lower (yellow) trace represents the ambient (background) emission levels and the upper (blue) trace represents the sum of the ambient emissions and the spurious emissions originating from the DUT.

An important consideration in the interpretation of this data is the fact that the radiated spurious power captured by the measurement system is actually the sum of the ambient emissions already present and those spurious emissions introduced when the DUT is turned on. Since the emissions under consideration in this study are often very close to the ambient noise floor, the contribution of the noise floor to this sum can be significant. Within this study, if the difference between the measured ambient level and the corresponding radiated-plus-ambient level is 3 dB, then the DUT emission amplitude level is interpreted as being equivalent to the ambient level. Accordingly, if the difference between the DUT radiated-plus-ambient emission level and the corresponding ambient emission level is less than 3 dB, then the DUT emission level is interpreted as being less than the ambient level. Emissions that are more than 3 dB above the corresponding ambient level are attributed to spurious emissions from the DUT.

Consumer Device Sample Set

Table 3-2 lists the consumer electronic/electrical devices measured as a part of this effort.

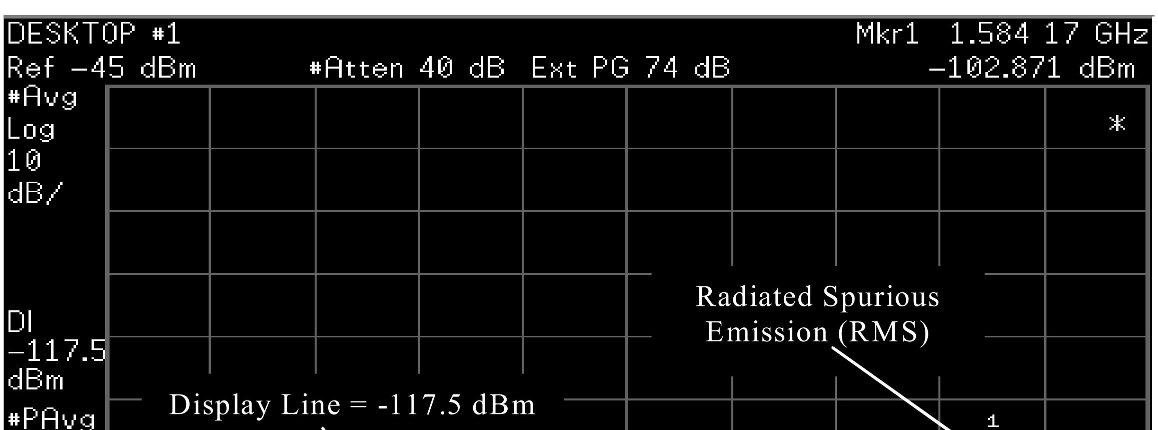
Table 3-2. Consumer Electronic/Electrical Devices Tested.

DEVICE	DESCRIPTION
Desktop Computer 1	Pentium IV
Desktop Computer 2	Pentium II
Desktop Computer 3	Pentium III w/ WLAN hub
Laptop Computer 1	Pentium III
Laptop Computer 2	Pentium I
Laptop Computer 3	Pentium II
Laptop Computer 4	Pentium II
Personal Digital Assistant	
Pendant Transmitter	Automotive Remote Keyless Entry Device
Electric Drill #1	Variable speed AC motor
Electric Drill #2	Variable speed DC motor (cordless)
Electric Hairdryer #1	Single speed AC motor
Electric Hairdryer #2	Two speed AC motor
Electric Vacuum Cleaner	Single speed AC motor

Consumer Device Radiated Emissions Measurement Data

Appendix E presents the spectrum analyzer plots depicting the data collected from the measurement of radiated spurious emissions generated by those electronic/electrical devices contained in the sample set identified above for each of the GPS frequency bands. A sample plot from these measurements is presented below and used to facilitate the following explanation of how to read and interpret the represented data.

The instructions provided earlier in this section for reading the ambient emission measurement analyzer plots are also applicable to reading the data represented in these plots. The following discussion highlights subtle differences between these plots and those depicting the ambient emissions measurements.



plot. This is set to a level of -117.5 dBm to represent the received power equivalent to the UWB EIRP limit of -75.3 dBm/MHz at a distance of two meters. Some of the plots presented in Appendix E use other than 10 dB per vertical division (graticule line). This was done to facilitate better resolution of the signals under examination. These plots are read the same way as described previously except that each vertical line may represent a deviation of 3 or 5 dB from the reference level. The dB-per-division scale, applicable to each plot, is shown in the upper left-hand margin.

SECTION SIX
RESULTS

AMBIENT EMISSIONS MEASUREMENTS

Tables 6-1 and 6-2 summarize specific data points from the spectrum analyzer traces presented in Appendices C (outdoor ambient emissions data) and D (indoor ambient emissions data). While it is difficult to characterize all of the information provided in these plots within a single table, an attempt has been made to present the most pertinent data points from each plot such as the maximum emission amplitudes observed in each frequency band, the associate frequency and general signal structure, and the measured amplitude at the GPS center frequency. However, the data in these tables does not convey information such as the number of emissions observed in the band or the intermediate amplitude levels (e.g., those emission levels less than the maximum observed amplitude). This information must be obtained from the individual spectral plots presented in the appendices.

The following explanation of each of the columns in these tables is offered. The first column defines the frequency band that the subsequent data pertains to. Column two shows the maximum emission amplitude (power level) observed in the band. The values in column three compares the maximum observed emission amplitude to the GPS interference threshold assumed in the derivation of the UWB emission limit. Column four provides the frequency associated with the maximum amplitude emission observed. The fifth column describes the general emission characteristic in terms of narrow band or broadband emissions. The final column shows the measured emission amplitude at the center frequency of each of the GPS bands. There are no entries provided in this column for the data collected in the lower ARNS band, since GPS neither currently operates nor has a future plan to operate in this band.

RADIATED EMISSIONS MEASUREMENTS

Table 6-3 summarizes the specific data points from the spectrum analyzer traces from the measurements of radiated spurious emissions produced by common electronic devices into the GPS frequency bands. The complete data plots are presented in Appendix E. In this table, the column descriptions presented above apply.

TABLE 6-1. Summary of Outdoor Ambient Emissions Measurement Data.

MEASUREMENT BAND (MHz)	MAXIMUM EMISSION AMPLITUDE (dBm)	EMISSION AMPLITUDE RELATIVE TO THRESHOLD (dB)	EMISSION FREQUENCY (MHz)	EMISSION CHARACTERISITC	MEASURED AMPLITUDE at GPS CENTER FREQUENCY (dBm)
Measurement Location: Baltimore-Washington International Airport					
GPS L1	-117.5	0	1564	Narrow Band	-122.0
GPS L2	-120.0	-2.5	1215-1240	Broad Band	-122.0
GPS L5	-62.0	55.5	1185	Narrow Band	-118.0
960-1010	-112.0	5.5	984	Narrow Band	N/A
1010-1060	-83.0	34.5	1030	Narrow Band	N/A
1060-1110	-94.0	23.5	1090	Narrow Band	N/A
1110-1160	-87.0	30.5	1122	Narrow Band	N/A
Measurement Location: Ronald Reagan National Airport					
GPS L1	-122.0	-4.5	1563-1588	Broad Band	-122.0
GPS L2	-120.0	-2.5	1215-1240	Broad Band	-122.0
GPS L5	-118.0	-0.5	1165	Narrow Band	-122.0
960-1010	-82.0	35.5	1008	Narrow Band	N/A
1010-1060	-95.0	22.5	1030	Narrow Band	N/A
1060-1110	-76.0	41.5	1072	Narrow Band	N/A
1110-1160	-90.0	27.5	1149	Narrow Band	N/A
Measurement Location: Dulles International Airport					
GPS L1	-122.0	-4.5	1563-1588	Broad Band	-122.0
GPS L2	-121.0	-3.5	1215-1240	Broad Band	-122.0
GPS L5	-87.0	30.5	1169	Narrow Band	-122.0
960-1010	-119.0	-1.5	960-1010	Broad Band	N/A
1010-1060	-80.0	37.5	1028	Narrow Band	N/A
1060-1110	-79.0	38.5	1106	Narrow Band	N/A
1110-1160	-94.0	23.5	1122 & 1114	Narrow Band	N/A

TABLE 6-1 (continued). Summary of Outdoor Ambient Emissions Measurement Data.

MEASUREMENT BAND (MHz)	MAXIMUM EMISSION AMPLITUDE (dBm)	EMISSION AMPLITUDE RELATIVE TO THRESHOLD (dB)	EMISSION FREQUENCY (MHz)	EMISSION CHARACTERISITC	MEASURED AMPLITUDE at GPS CENTER FREQUENCY (dBm)
Measurement Location: Port of Baltimore					
GPS L1	-118.0	-0.5	1563-1588	Broad Band	-117.5
GPS L2	-117.0	0.5	1215-1240	Broad Band	-117.0
GPS L5	-85.0	32.5	1185	Narrow Band	-117.0
960-1010	-115.0	2.5	960-1010	Broad Band	N/A
1010-1060	-80.0	37.5	1030	Narrow Band	N/A
1060-1110	-82.0	35.5	1090 & 1102	Narrow Band	N/A
1110-1160	-95.0	22.5	1125	Narrow Band	N/A
Measurement Location: U.S. Coast Guard Yard					
GPS L1	-117.0	0.5	1563-1588	Broad Band	-117.0
GPS L2	-117.0	0.5	1215-1240	Broad Band	-117.0
GPS L5	-96.0	11.5	1185	Narrow Band	-117.0
960-1010	-111.0	6.5	975	Narrow Band	N/A
1010-1060	-85.0	32.5	1030	Narrow Band	N/A
1060-1110	-84.0	33.5	1071	Narrow Band	N/A
1110-1160	-83.0	34.5	1134	Narrow Band	N/A
Measurement Location: AMTRAK Maintenance Facility					
GPS L1	-117.0	0.5	1570	Narrow Band	-121.0
GPS L2	-116.0	1.5	1234	Narrow Band	-120.0
GPS L5	-113.0	4.5	1181	Narrow Band	-119.0
960-1010	-95.0	12.5	960	Narrow Band	N/A
1010-1060	-109.0	8.5	1030	Narrow Band	N/A
1060-1110	-95.0	12.5	1090	Narrow Band	N/A
1110-1160	-91.0	16.5	1116	Narrow Band	N/A
Measurement Location: Urban (Industrial) Area					
GPS L1	-118.0	-0.5	1575	Narrow Band	-118.0
GPS L2	-117.5	0.0	1226	Narrow Band	-117.5
GPS L5	-100.0	17.5	1164	Narrow Band	-117.5
960-1010	-77.0	40.5	960	Narrow Band	N/A
1010-1060	-86.0	31.5	1041	Narrow Band	N/A
1060-1110	-90.0	27.5	1090	Narrow Band	N/A
1110-1160	-95.0	22.5	1122	Narrow Band	N/A

TABLE 6-2. Summary of Indoor Ambient Emissions Measurement Data.

MEASUREMENT BAND (MHz)	MAXIMUM EMISSION AMPLITUDE (dBm)	EMISSION AMPLITUDE RELATIVE TO THRESHOLD (dB)	EMISSION FREQUENCY (MHz)	EMISSION CHARACTERISITC	MEASURED AMPLITUDE at GPS CENTER FREQUENCY (dBm)
Measurement Location: Office Location #1					
GPS L1	-108.0	9.5	1573	Narrow Band	-113.0
GPS L2	-104.0	13.5	1220	Narrow Band	-109.0
GPS L5	-94.0	23.5	1181	Narrow Band	-106.0
960-1010	-91.0	26.5	998	Narrow Band	N/A
1010-1060	-99.0	18.5	1040	Narrow Band	N/A
1060-1110	-93.0	24.5	1062	Narrow Band	N/A
1110-1160	-95.0	22.5	1119	Narrow Band	N/A
Measurement Location: Office Location #2					
GPS L1	-99.0	18.5	1575	Narrow Band	-101.0
GPS L2	-94.0	23.5	1222	Narrow Band	-108.0
GPS L5	-93.0	24.5	1169	Narrow Band	-98.0
960-1010	-84.0	33.5	1009	Narrow Band	N/A
1010-1060	-85.0	32.5	1036	Narrow Band	N/A
1060-1110	-83.0	34.5	1063	Narrow Band	N/A
1110-1160	-92.0	25.5	1125	Narrow Band	N/A
Measurement Location: Office Location #3					
GPS L1	-109.0	8.5	1572	Narrow Band	-113.0
GPS L2	-115.0	2.5	1215-1240	Broad Band	-115.0
GPS L5	-114.0	3.5	1175	Narrow Band	-116.0
960-1010	-105.0	12.5	989	Narrow Band	N/A
1010-1060	-110.0	7.5	1020 & 1050	Narrow Band	N/A
1060-1110	-106.0	11.5	1090	Narrow Band	N/A
1110-1160	-110.0	7.5	1125	Narrow Band	N/A
Measurement Location: Office Location #4					
GPS L1	-97.0	20.5	1566	Narrow Band	-110.0
GPS L2	-91.0	26.5	1233	Narrow Band	-108.0
GPS L5	-81.0	36.5	1166	Narrow Band	-107.0
960-1010	-84.0	33.5	966	Narrow Band	N/A
1010-1060	-84.0	33.5	1033	Narrow Band	N/A
1060-1110	-84.0	33.5	1100	Narrow Band	N/A
1110-1160	-90.0	27.5	1133	Narrow Band	N/A

TABLE 6-2 (continued). Summary of Indoor Ambient Emissions Measurement Data.

MEASUREMENT BAND (MHz)	MAXIMUM EMISSION AMPLITUDE (dBm)	EMISSION AMPLITUDE RELATIVE TO THRESHOLD (dB)	EMISSION FREQUENCY (MHz)	EMISSION CHARACTERISITC	MEASURED AMPLITUDE ON GPS CENTER FREQUENCY (dBm)
Measurement Location: Office Location #5					
GPS L1	-107.0	10.5	1571	Narrow Band	-115.0
GPS L2	-106.0	11.5	1236	Narrow Band	-114.0
GPS L5	-102.0	15.5	1164	Narrow Band	-114.0
960-1010	-102.0	15.5	1002	Narrow Band	N/A
1010-1060	-102.0	15.5	1040	Narrow Band	N/A
1060-1110	-101.0	16.5	1104	Narrow Band	N/A
1110-1160	-103.0	14.5	1136	Narrow Band	N/A
Measurement Location: Factory Location #1					
GPS L1	-105.0	12.5	1568	Narrow Band	-114.0
GPS L2	-106.0	11.5	1225	Narrow Band	-109.0
960-1010	-100.0	17.5	995-1000	Narrow Band	N/A
1010-1060	-101.0	16.5	1038	Narrow Band	N/A
1060-1110	-94.0	23.5	1088	Narrow Band	N/A
1110-1160	-105.0	12.5	1117	Narrow Band	N/A
Measurement Location: Factory Location #2					
GPS L1	-120.0	-2.5	1563-1588	Broad Band	-120.0
GPS L2	-115.0	2.5	1229	Narrow Band	-118.0
GPS L5	-117.5	0.0	1164-1189	Broad Band	-118.0
960-1010	-114.0	3.5	998	Narrow Band	N/A
1010-1060	-114.0	3.5	1049	Narrow Band	N/A
1060-1110	-113.0	4.5	1088	Narrow Band	N/A
1110-1160	-104.0	13.5	1147	Narrow Band	N/A
Measurement Location: Factory Location #3					
GPS L1	-94.0	23.5	1574	Narrow Band	-105.0
GPS L2	-80.0	37.5	1227	Narrow Band	-104.0
GPS L5	-97.0	20.5	1170	Narrow Band	-106.0
960-1010	-91.0	26.5	984	Narrow Band	N/A
1010-1060	-95.0	22.5	1023	Narrow Band	N/A
1060-1110	-93.0	24.5	1091	Narrow Band	N/A
1110-1160	-90.0	27.5	1134	Narrow Band	N/A

TABLE 6-3. Summary of Radiated Spurious Emissions Measurement Data.

MEASUREMENT BAND (MHz)	MAXIMUM EMISSION AMPLITUDE (dBm)	EMISSION AMPLITUDE RELATIVE TO THRESHOLD (dB)	EMISSION FREQUENCY (MHz)	EMISSION CHARACTERISITC	MEASURED AMPLITUDE ON GPS CENTER FREQUENCY (dBm)
DUT: Desktop Computer 1					
GPS L1	-103.0	14.5	1584	Narrow Band	-118.0
GPS L2	-115.0	2.5	1224	Narrow Band	-116.0
GPS L5	-110.0	7.5	1165	Narrow Band	-116.0
DUT: Desktop Computer 2					
GPS L1	-119.0	-1.5	1573	Narrow Band (Ambient)	-120.0
GPS L2	-116.0	1.5	1222	Narrow Band	-119.0
GPS L5	-114.0	3.5	1167	Narrow Band	-118.0
DUT: Desktop Computer 3					
GPS L1	-113.0	4.5	1563	Narrow Band	-118.0
GPS L2	-109.0	8.5	1216	Narrow Band	-114.0
GPS L5	-111.0	6.5	1166	Narrow Band	-115.0
DUT: Laptop Computer 1					
GPS L1	-113.0	4.5	1563	Narrow Band	-118.0
GPS L2	-111.0	6.5	1227	Narrow Band	-116.0
GPS L5	-114.0	3.5	1164	Narrow Band	-118.0
DUT: Laptop Computer 2					
GPS L1	-112.0	5.5	1564	Narrow Band	-118.0
GPS L2	-103.0	14.5	1238	Narrow Band	-118.0
GPS L5	-109.0	8.5	1173	Narrow Band	-118.0
DUT: Laptop Computer 3					
GPS L1	-116.0	1.5	1584	Narrow Band	-117.5
GPS L2	-109.0	8.5	1235	Narrow Band	-116.0
GPS L5	-104.0	13.5	1170	Narrow Band	-115.0
DUT: Laptop Computer 4					
GPS L1	-114.0	3.5	1563	Narrow Band	-119.0
GPS L2	-112.0	5.5	1238	Narrow Band	-119.0
GPS L5	-106.0	11.5	1173	Narrow Band	-118.0

TABLE 6-3 (continued). Summary of Radiated Spurious Emissions Measurement Data.

MEASUREMENT BAND (MHz)	MAXIMUM EMISSION AMPLITUDE (dBm)	EMISSION AMPLITUDE RELATIVE TO THRESHOLD (dB)	EMISSION FREQUENCY (MHz)	EMISSION CHARACTERISITC	MEASURED AMPLITUDE ON GPS CENTER FREQUENCY (dBm)
DUT: PDA					
GPS L1	-118.0	-0.5	1563-1588	Broad Band	-118.0
GPS L2	-109.0	8.5	1216	Narrow Band	-114.0
GPS L5	-111.0	6.5	1166	Narrow Band	-115.0
DUT: Pendant Transmitter					
GPS L1	-90.0	27.5	1575	Narrow Band	-95.0
DUT: Electric Drill #1					
GPS L1	-100.0	17.5	1574	Impulsive-Broad Band	-110.0
GPS L2	-87.0	30.5	1239	Impulsive-Broad Band	-105.0
GPS L5	-84.0	34.5	1188	Impulsive-Broad Band	-90.0
DUT: Electric Drill #2					
GPS L1				Impulsive	
GPS L2	-110.0	7.5	1233	Impulsive	-117.5
GPS L5	-113.0	4.5	1167	Impulsive	-117.5
DUT: Electric Hair Dryer #1					
GPS L1	-100.0	17.5	1589	Impulsive-Broad Band	-111.0
GPS L2	-99.0	18.5	1217	Impulsive-Broad Band	-116.0
GPS L5	-95.0	22.5	1182	Impulsive-Broad Band	-111.0
DUT: Electric Hair Dryer #2					
GPS L1	-106.0	11.5	1577	Impulsive	-119.0
GPS L2	-110.0	7.5	1235	Impulsive	-117.5
GPS L5	-111.0	6.5	1165	Impulsive	-117.0
DUT: Electric Vacuum Cleaner					
GPS L1	-103.0	14.5	1578	Impulsive-Broad Band	-106.0
GPS L2	-102.0	15.5	1238	Impulsive-Broad Band	-103.0
GPS L5	-100.0	17.5	1169	Impulsive-Broad Band	-102.0

SECTION SEVEN
OBSERVATIONS, CONCLUSIONS AND RECOMMENDATIONS

OBSERVATIONS

Ambient Emissions Measurements - Outdoor Sites

The ambient emissions measurements performed in the GPS L1 and L2 frequency bands reveal these two bands to be relatively quiet with respect to existing RF activity. At most of the outdoor locations, no emissions exceeding the sensitivity of the measurement system were detected. At those few locations where emissions were observed, the associated power levels were determined to be very low, and in all cases, less than the interference threshold assumed for GPS receivers in the derivation of the UWB limits applicable in these frequency bands.

Ambient emissions measurements performed in the GPS L5 frequency band disclose a greater level of RF activity than in the GPS L1 and L2 frequency bands. Existing ambient emissions were observed in this band at many of the measurement locations; however, they appear to be associated with frequency assignments to what are assumed to be authorized systems operating in the band. In all locations, the emissions detected in this band were removed in frequency from the GPS L5 center frequency. The waveforms associated with these emissions were observed to decrease to amplitude levels less than the assumed GPS interference threshold within the likely pass band of a GPS L5 receiver.

The ambient emissions measurements performed in the lower ARNS band (960-1160 MHz) show a high level of RF activity within this region of the spectrum. At all measurement sites significant emissions were observed in the band with associated power levels well in excess of the assumed interference threshold. Existing ambient emissions were observed in the band, at levels up to 35 dB (more than 3000 times) greater than the interference threshold assumed in deriving the UWB emission limits applicable to the band. For some of these observed emissions the source(s) were readily identifiable (e.g., the Air Traffic Control Radio Beacon System interrogator and reply); however, for many others the source was not readily known.

Ambient Emissions Measurements - Indoor Sites

When the measurement system was moved indoors to detect the presence and amplitude of existing ambient emissions at those locations consistent with the operational scenario assumed in the derivation of the UWB emission limits (e.g., inside office buildings, factories, etc), a different trend emerged. In the outdoor measurements, no distinct emissions were observed in either the GPS L1 or L2 frequency bands. However, at many of the indoor measurement locations, narrow-band emissions were observed at amplitudes exceeding the assumed GPS interference threshold by as much as 37.5 dB (i.e., by more than 5600 times). It was beyond the scope of this effort to identify the source of these emissions; however, it was presumed that they emanate from existing electronic devices (e.g., computers and peripherals, copiers, etc) and other man-made noise generated by a variety of other office equipment including electric motors. The magnitude of these emissions was observed to be related to the density and distribution of the electronic systems present within the immediate measurement environment.

It is recognized that a comparison, in terms of interference potential, between a narrow-band ambient emission and a UWB emission is specious unless the narrow band signal is coincident with the pass band of a GPS receiver. However, at several of the indoor measurement sites the maximum-amplitude narrow-band emission was indeed detected at frequencies coincident with the pass band of a GPS receiver (e.g., Office Location #2, and Factory Location #3). In other cases, although the maximum-amplitude emission did not fall within the pass band, one of the intermediate-amplitude emissions did.

Finally, a comparison between the values presented in the last columns of Tables 6-1 and 6-2 reveal that the measurement system experienced some level of desensitization at all but one of the indoor measurement sites. For the outdoor measurement locations, the minimum detectable ambient signal was typically limited only by the sensitivity of the measurement system. However, for all but one of the indoor measurement locations the minimum detectable signal was limited not by the measurement system sensitivity, but by the existing ambient noise environment. This measurement system desensitization ranged between 2 and 24 dB, depending on the measurement band and location. Since the measurement system was configured to simulate the RF front-end of a GPS receiver, it is reasonable to expect that a GPS receiver would likely experience a similar desensitization.

Similar results were observed in both the GPS L5 and the lower ARNS band. At least some of the ambient emissions detected in the ARNS band were attributed to known systems (e.g., ATCRBS) but at reduced amplitudes (relative to the outdoor measurement data) as a result of signal attenuation through the building walls.

Radiated Emissions Measurements

Narrow-band spurious emissions, radiating from those consumer-grade electronic devices tested as a part of this effort, were observed in each of the GPS frequency bands. The power density levels associated with these emissions were typically low relative to the applicable emissions limit (e.g., Part 15.109[22]), but were nonetheless in excess of the UWB emission limits by as much as 27.5 dB (more than 500 times greater). Stated another way, each of the devices measured complies with the applicable emission limits in the frequency bands under examination; however, if they were subjected to the emission limits for UWB, most of the devices examined would fail a compliance test.

[22] 47 C.F.R. Chapter 15, Part 15, Subpart B, § 15.109.

All of the radiated spurious emissions observed from the consumer-grade electronic devices were narrow band in structure. As stated previously, a comparison, in terms of interference potential, between a narrow-band ambient emission and a UWB emission is specious unless the narrow band signal is coincident with the pass band of a GPS receiver. Such was the case for two of the devices examined (Laptop Computer #2 and the Pendant Transmitter). Based on these observations, it is reasonable to suspect that other unlicensed electronic devices exist, although not examined within this effort, whose circuitry also generates spurious emissions into these bands, and perhaps also within the GPS receiver pass band.

Emissions were also observed from the consumer-grade electrical devices in all of the measurement bands at various amplitude levels, most of which exceeded the GPS receiver interference threshold assumed in the derivation of the UWB limit. The emissions observed from these measurements are all attributed to electromagnetic energy resulting from the armature-stator interaction common to all electric motors. These types of emission sources are deemed incidental radiators since their function does not require the generation of radio frequency signals. The power density associated with these types of emissions attenuates rapidly with separation distance, and thus they are not usually considered in interference analyses to electronic systems. Because of the low potential for interference from these types of devices to electronic-communication systems, the FCC does not regulate them. The following statement from the Code of Federal Regulations is the only applicable regulation with regard to these devices: "Manufacturers of these devices shall employ good engineering practices to minimize the risk of harmful interference."[23] However, under extremely conservative assumptions, such as the two-meter interaction distance assumed in deriving the UWB emission limits, these types of devices can also be considered as potential interferers.

The data collected from this part of the effort shows that when measured at a distance of two meters, the radiated emission amplitudes from the consumer-grade electrical devices were as much as 34.5 dB (more than 2800 times) greater than the assumed interference threshold within the GPS registered frequency bands. The data further shows that these emission amplitudes were as much as 27.5 dB (more than 560 times) greater than the theoretical GPS interference threshold within the pass band of a GPS receiver.

CONCLUSIONS

The following statement was included in the NTIA letter and was incorporated into the UWB R&O. "…, the minimum level of the GPS signal that can be used for an E-911 position determination will be determined by the receiver system noise density."[24] The ambient measurement results show that the GPS L1 and L2 frequency bands are quiet with respect to existing ambient emissions at those outdoor locations where tests were conducted. However, the data also reveals that in at least some locations, particularly indoor locations similar to those assumed in the derivation of the UWB

[23] 47 C.F.R. Chapter 15, Part 15, Subpart B, § 15.13.
[24] NTIA Letter at p. 9, and UWB R&O at par. 101.

emission limits, the ambient noise environment, rather than the GPS receiver thermal noise density, may actually be the limitation to the reception of the low-amplitude GPS signals.

The radiated emissions measurement results show that although many of the devices tested radiate emissions into the GPS frequency bands, the associated amplitudes were at much lower levels than permitted by the applicable limits. However, it was also determined that the amplitudes (power density) associated with these emissions were frequently in excess of the limits established for UWB emissions.

As part of this measurement effort, the ambient noise environment in the lower ARNS (960-1160 MHZ) frequency band was also examined. This band is not used to support GPS operations nor is it identified for use in the GPS modernization plan. Rather this frequency band is used to support terrestrial-based navigational aids such as the Distance Measuring Equipment (DME) and the Air Traffic Control Radio Beacon (ATCRBS). NTIA stated that "the operational limits required for the protection of the GPS will also be adequate to protect DME operations." The measurement results show that the ambient emissions in this band are generally above the adopted UWB emission limits. Thus it appears that the limiting factor in this band will also be the ambient noise environment rather than the limit based on the GPS receiver thermal noise density. In addition, Table 6 in the NTIA letter shows that a maximum EIRP of -64 dBm/MHz is required to protect the DME system under the most conservative assumptions, which is well above both the adopted UWB limit and the ambient noise environment for this band."

APPENDIX A
MEASURMENT SYSTEM CALIBRATION DATA

In this appendix, the spectrum analyzer plots produced from the calibration of the RF front-end (between the antenna input and the spectrum analyzer input) of the two measurement systems used to collect the data in this effort are presented. This calibration was performed by inserting a known-amplitude continuous wave (CW) signal into the antenna input of the measurement system. The signal was swept across each of the frequency bands under examination in this measurement effort. The spectrum analyzer was used to record the resultant power as a function of frequency. A calibrated signal generator was used to provide the CW signal. The input amplitude was set at –80 dBm for the calibration of System A and at – 65 dBm for the calibration of System B. The resultant spectrum analyzer trace depicts the signal gain (or loss) in the RF chain over the frequency range under examination and is reported in Tables A-1 and A-2 as the measurement system external gain. This external gain is the sum of the gain provided by the cascaded low noise amplifiers less the attenuation in the coaxial cables, connectors, isolation pad, and the insertion loss of the band pass filter.

Table A-1 summarizes the data obtained from the calibration curves for Measurement System A, given in figures A-1 through A-7. Table A-2 summarizes the data obtained from the calibration of Measurement System B, with the complete data provided in Figures A-8 through A-14.

TABLE A-1. Measurement System External Gain (System A).

CENTER FREQUENCY (MHz)	MEASUREMENT SYSTEM EXTERNAL GAIN (dB)
1575.4	64.8
1227.6	66.7
1176.0	66.4
985.0	68.0
1035.0	67.7
1085.0	67.3
1135.0	67.0

TABLE 4-3. Measurement System External Gain (System B).

CENTER FREQUENCY (MHz)	MEASUREMENT SYSTEM EXTERNAL GAIN (dB)
1575.4	63.5
1227.6	64.7
1176.0	64.9
985.0	67.4
1035.0	66.7
1085.0	66.6
1135.0	66.2

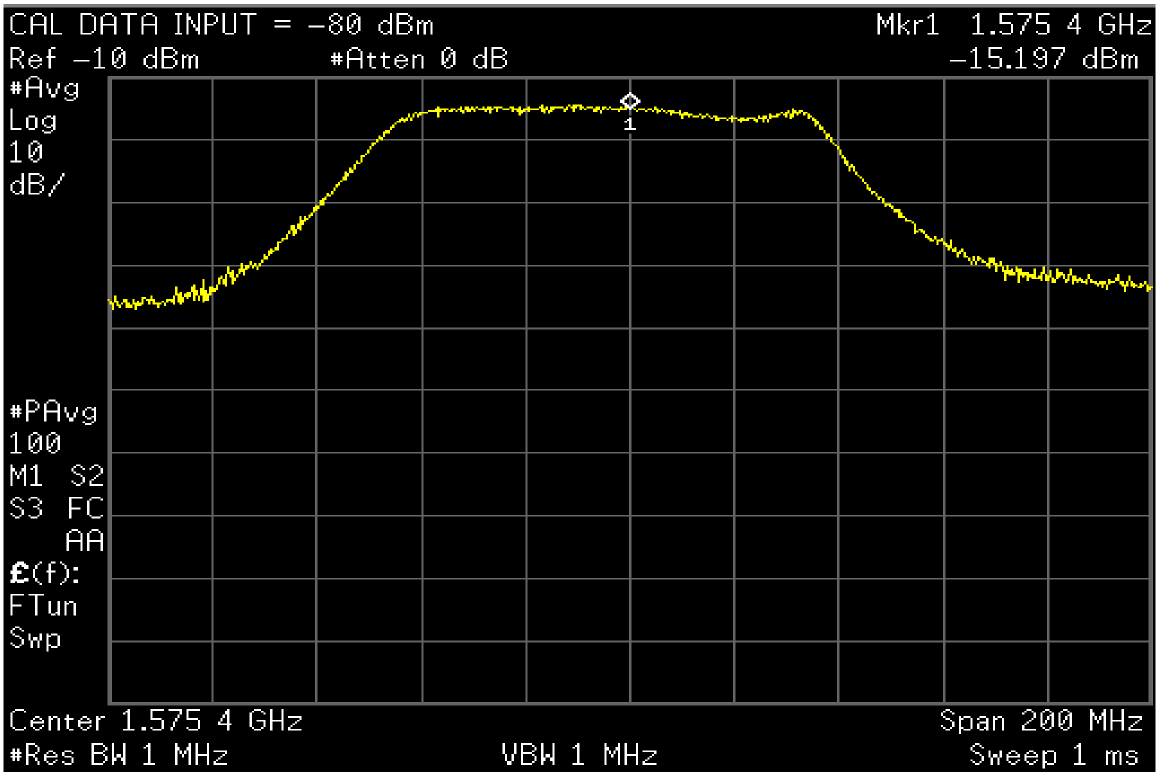


Figure A-1. Measurement System A Calibration Over GPS L1 Frequency Band.

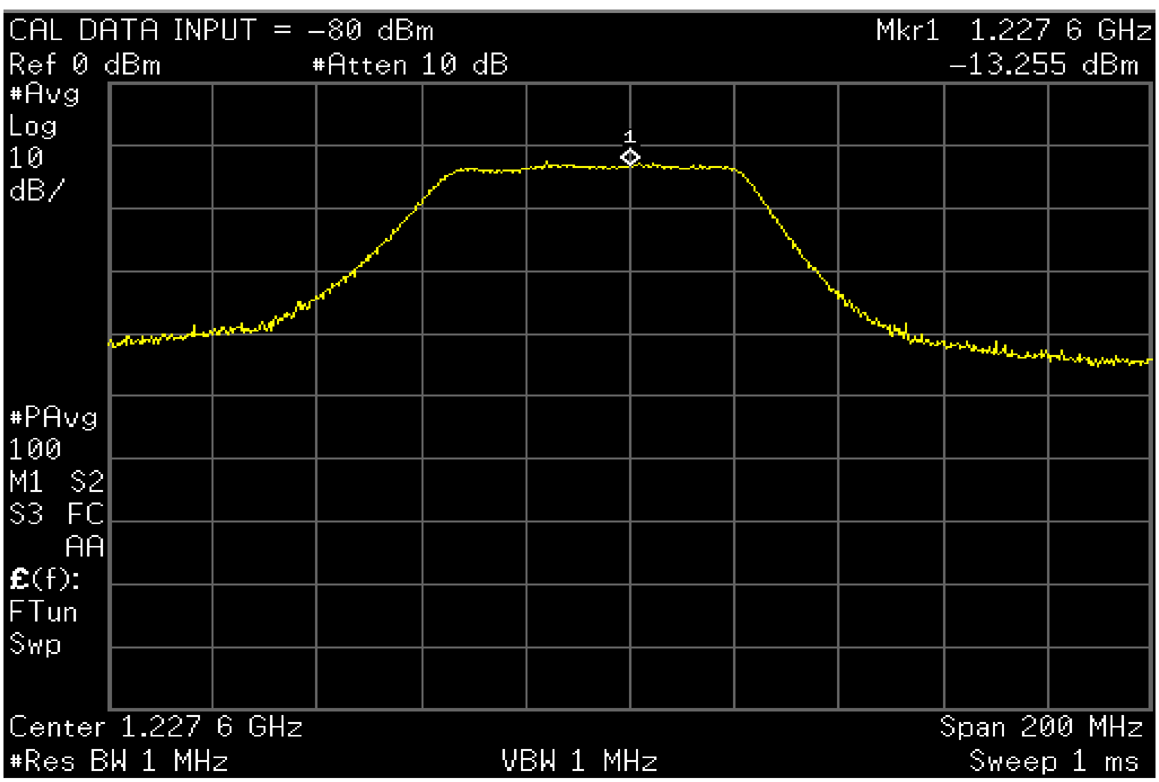


Figure A-2. Measurement System A Calibration Over GPS L2 Frequency Band.

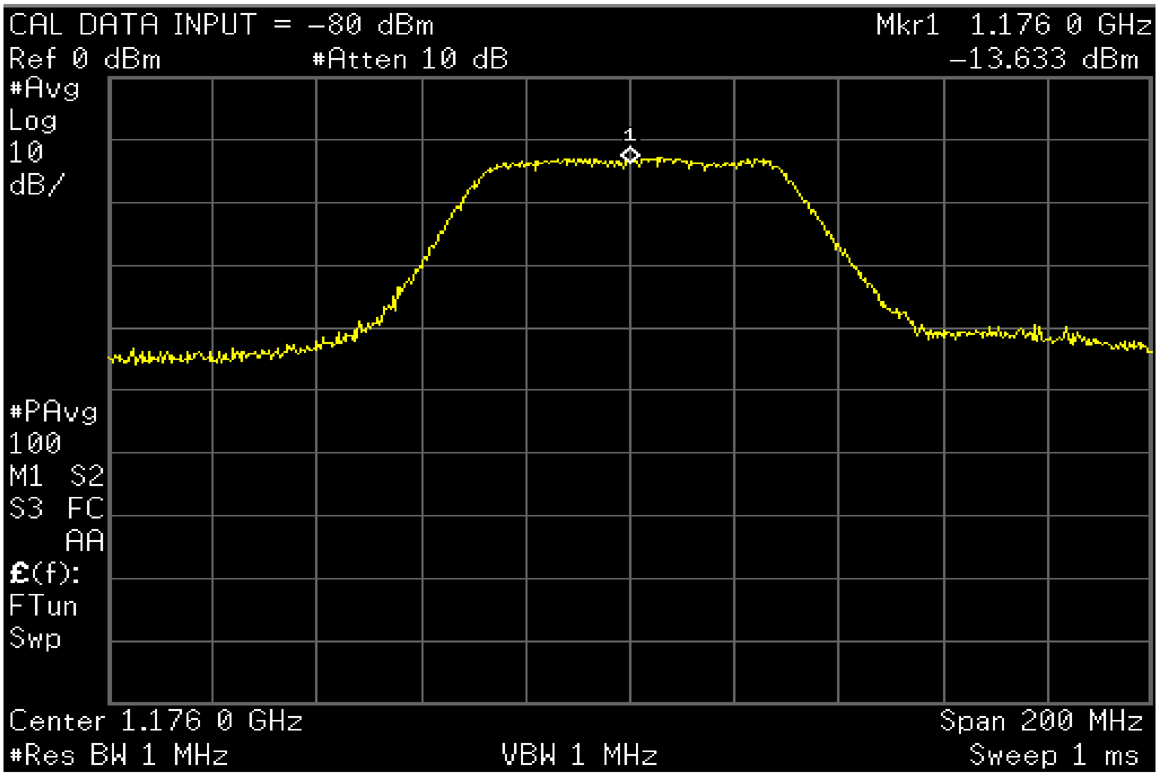


Figure A-3. Measurement System A Calibration Over GPS L5 Frequency Band.

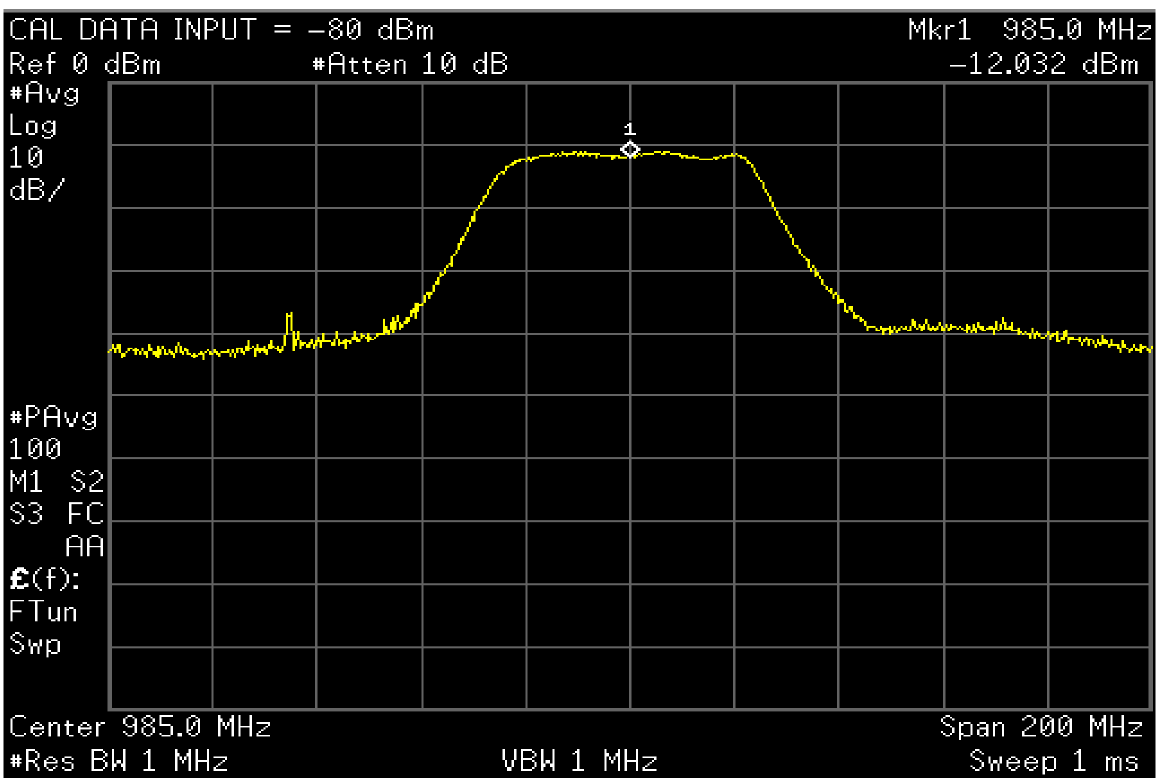


Figure A-4. Measurement System A Calibration Over 960-1010 MHz Frequency Band.

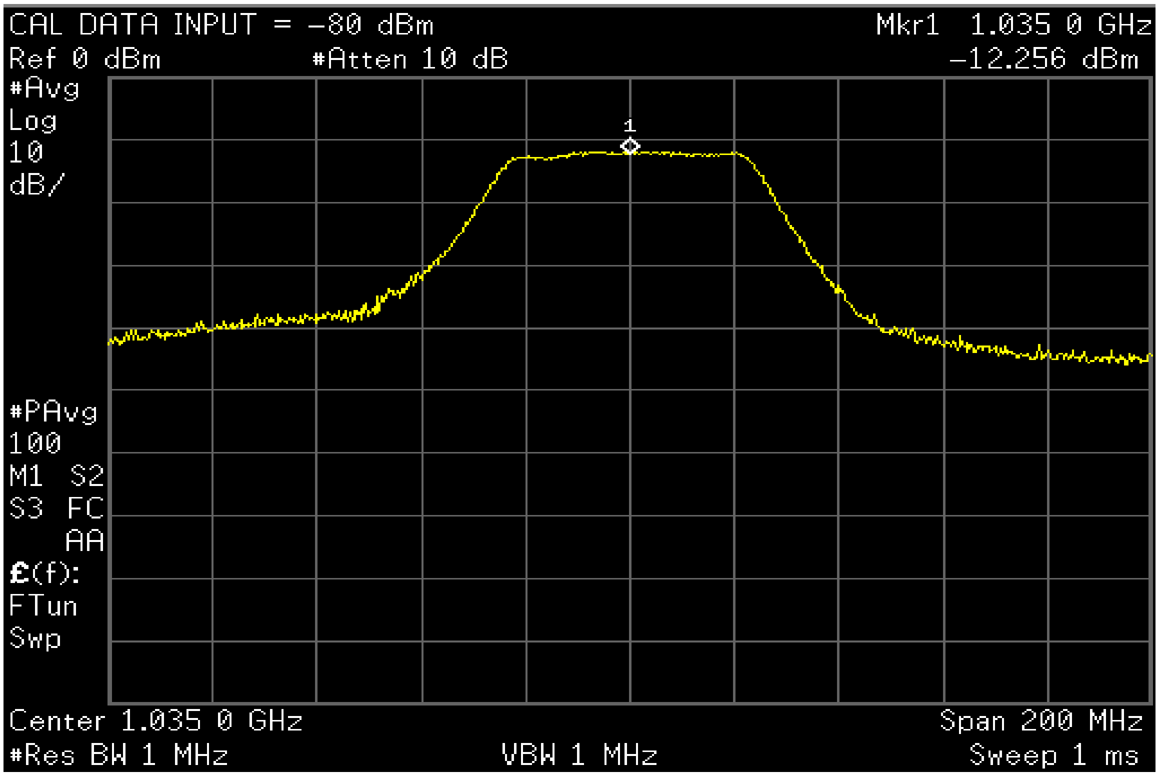


Figure A-5. Measurement System A Calibration Over 1010-1060 MHz Frequency Band.

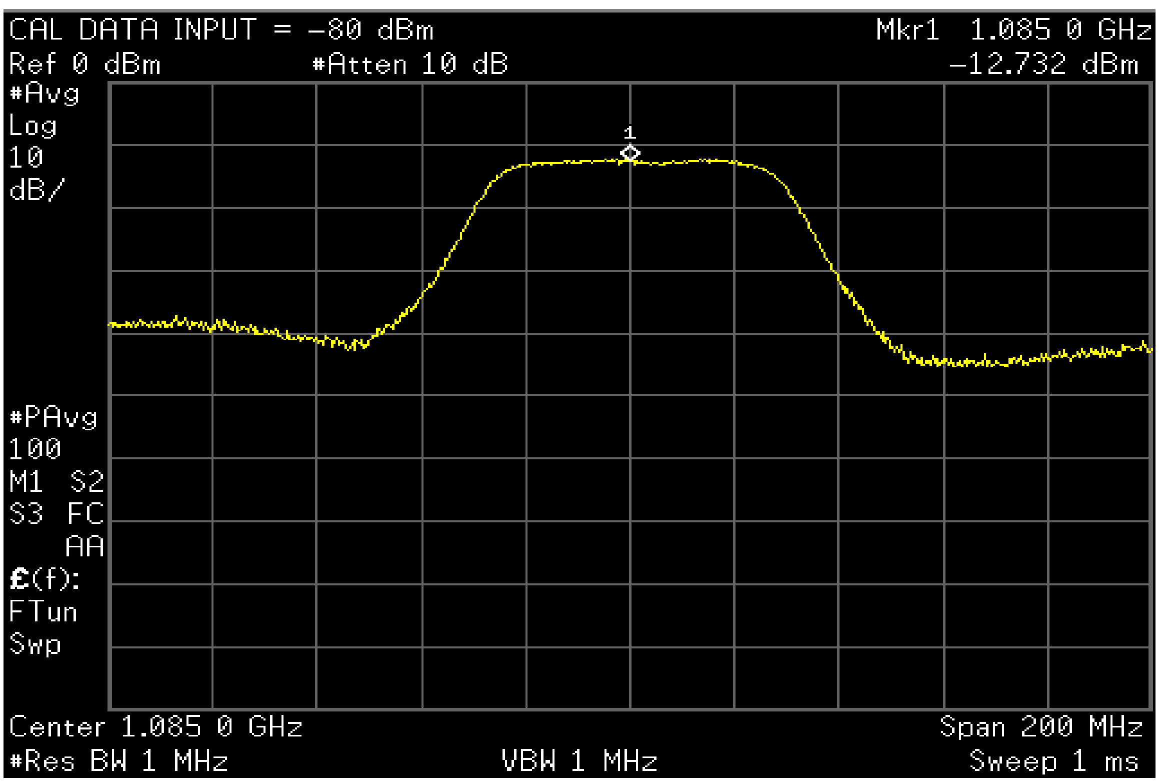


Figure A-6. Measurement System A Calibration Over 1060-1110 MHz Frequency Band.

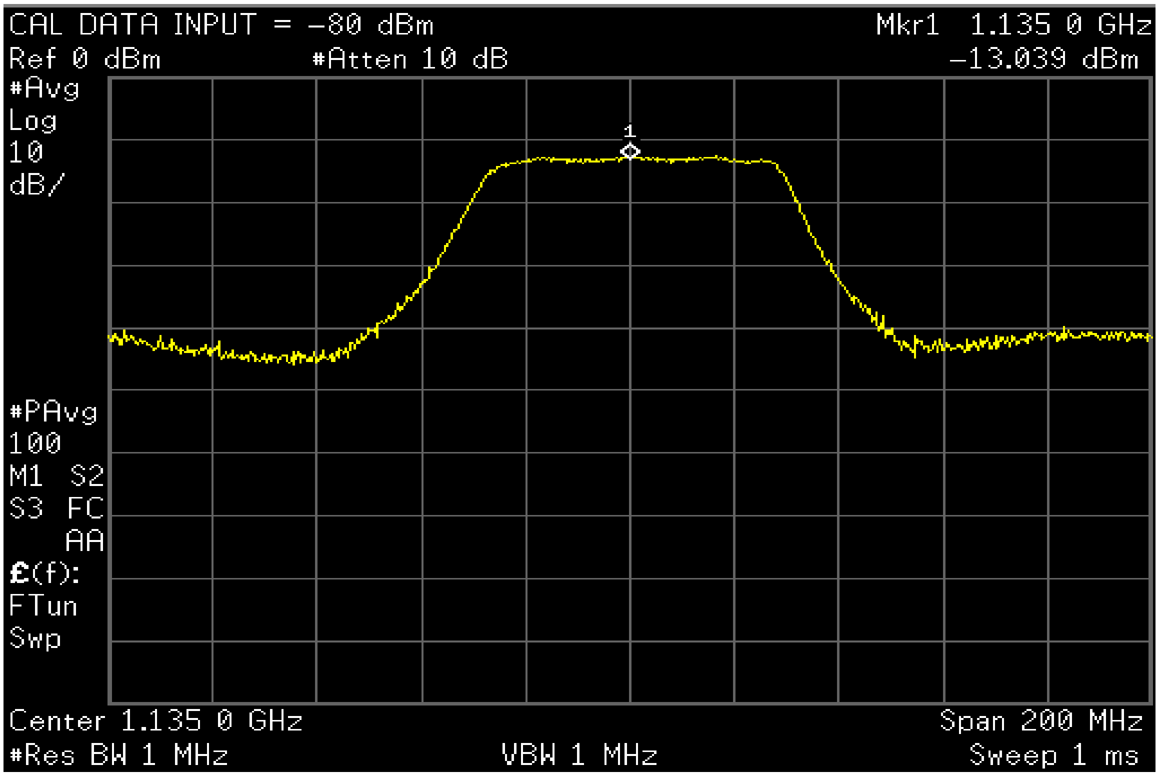


Figure A-7. Measurement System A Calibration Over 1110-1160 MHz Frequency Band.

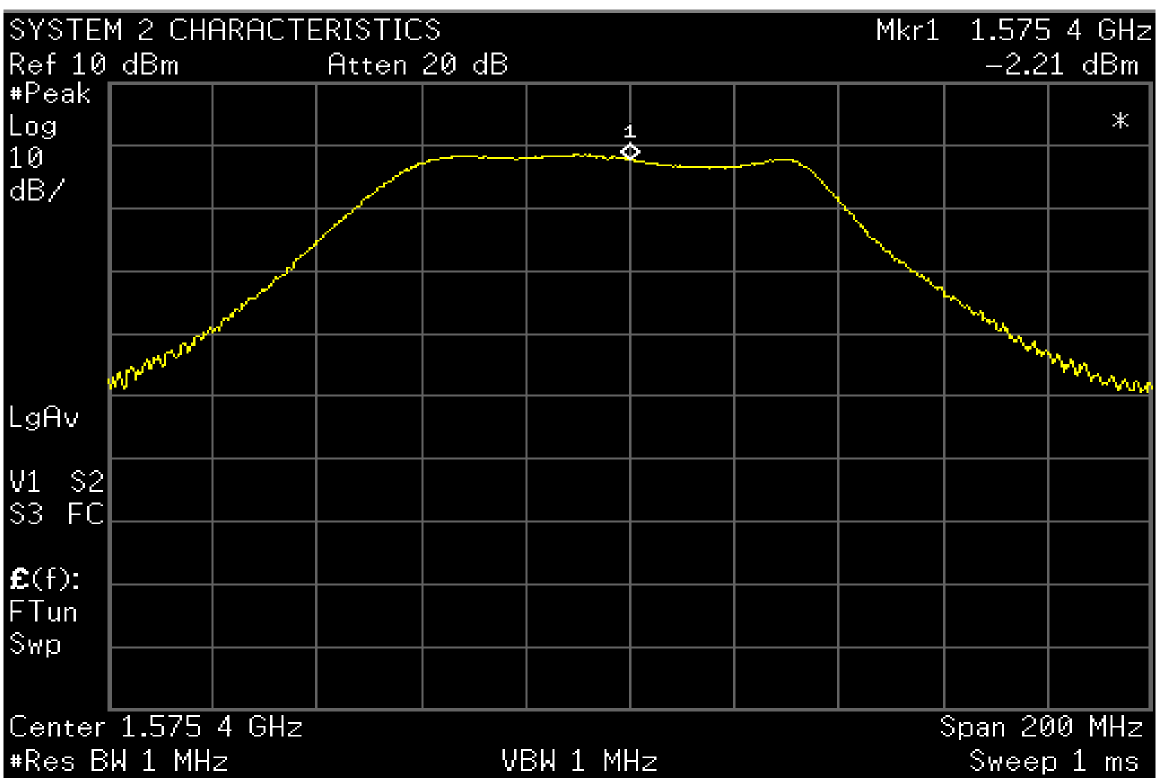


Figure A-8. Measurement System B Calibration Over GPS L1 Frequency Band.

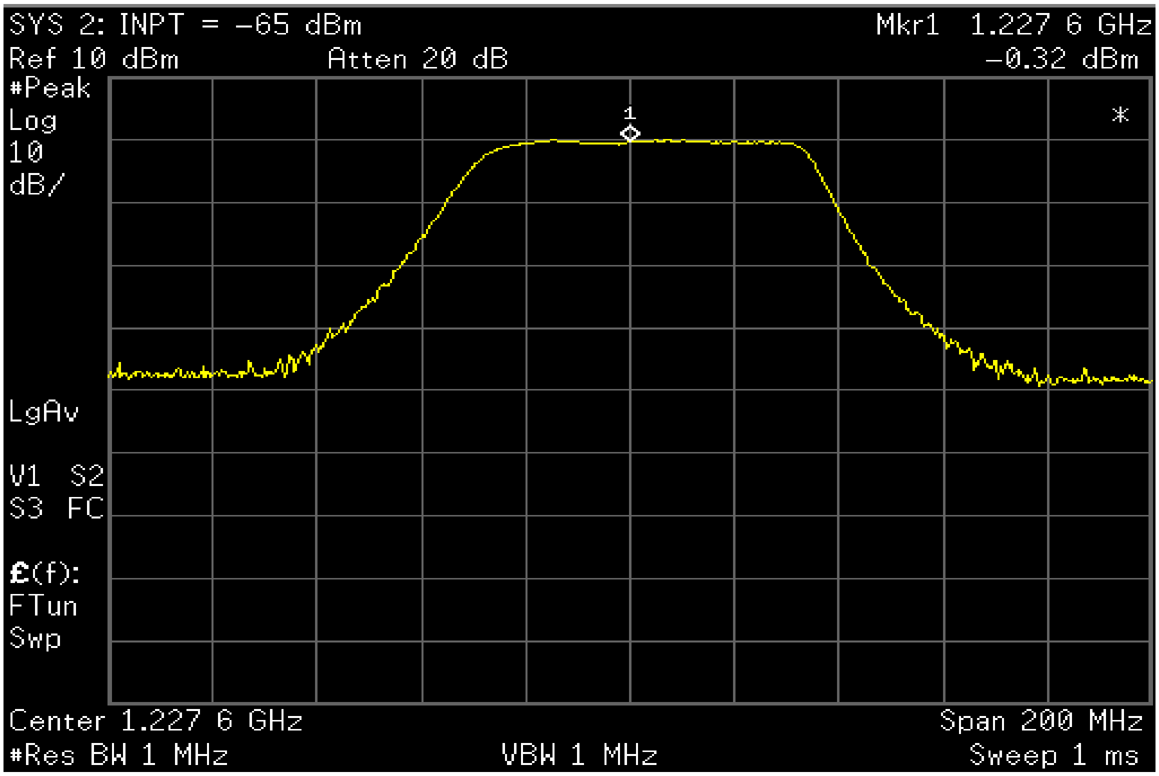


Figure A-9. Measurement System B Calibration Over GPS L2 Frequency Band.

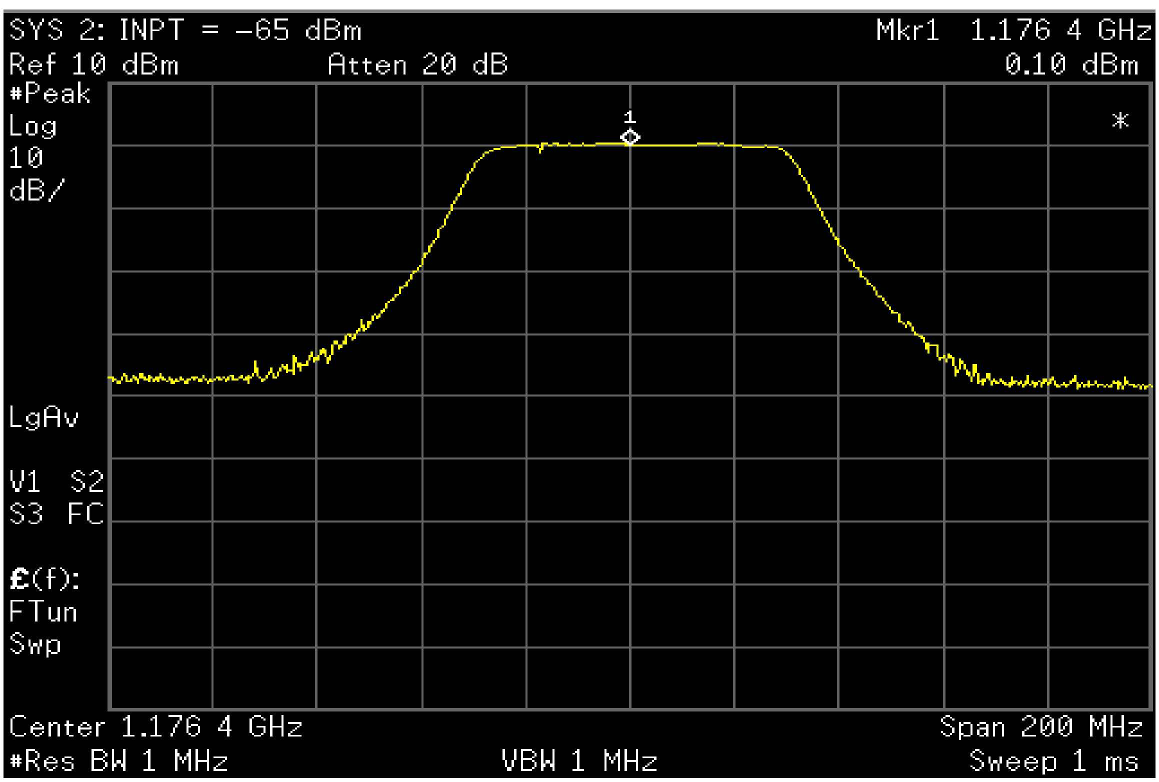


Figure A-10. Measurement System B Calibration Over GPS L5 Frequency Band.

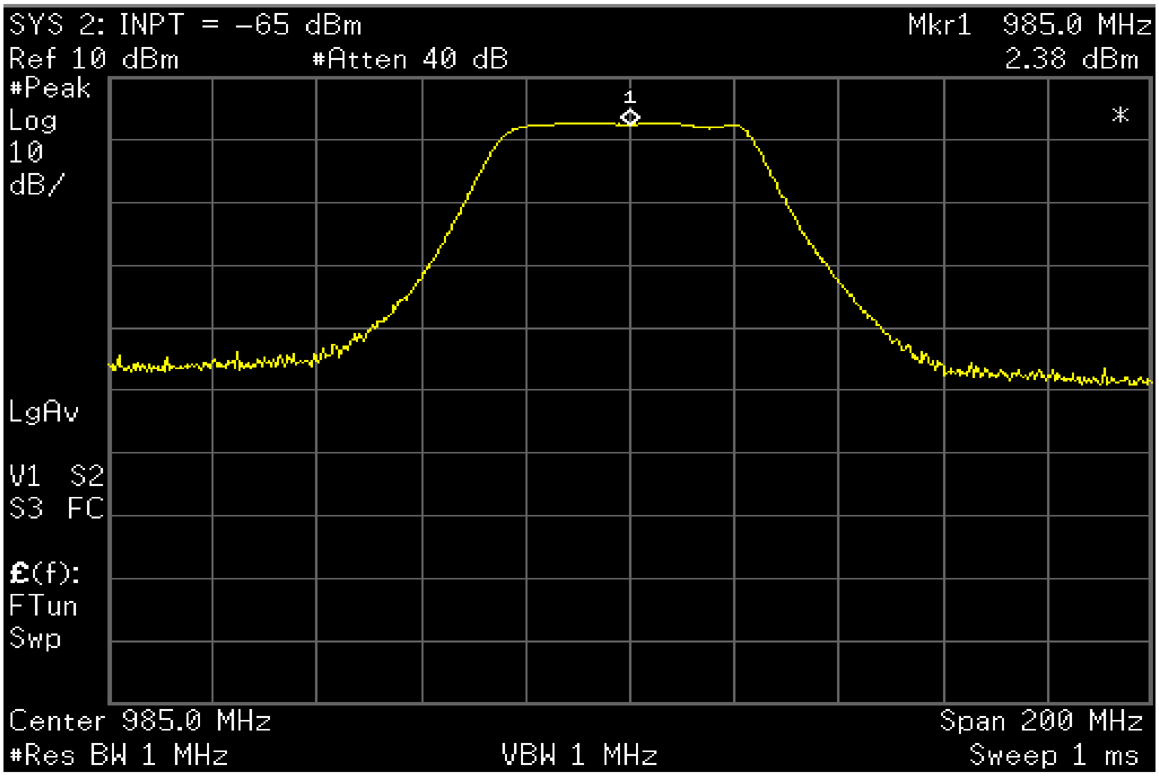


Figure A-11. Measurement System B Calibration Over 960-1010 MHz Frequency Band.

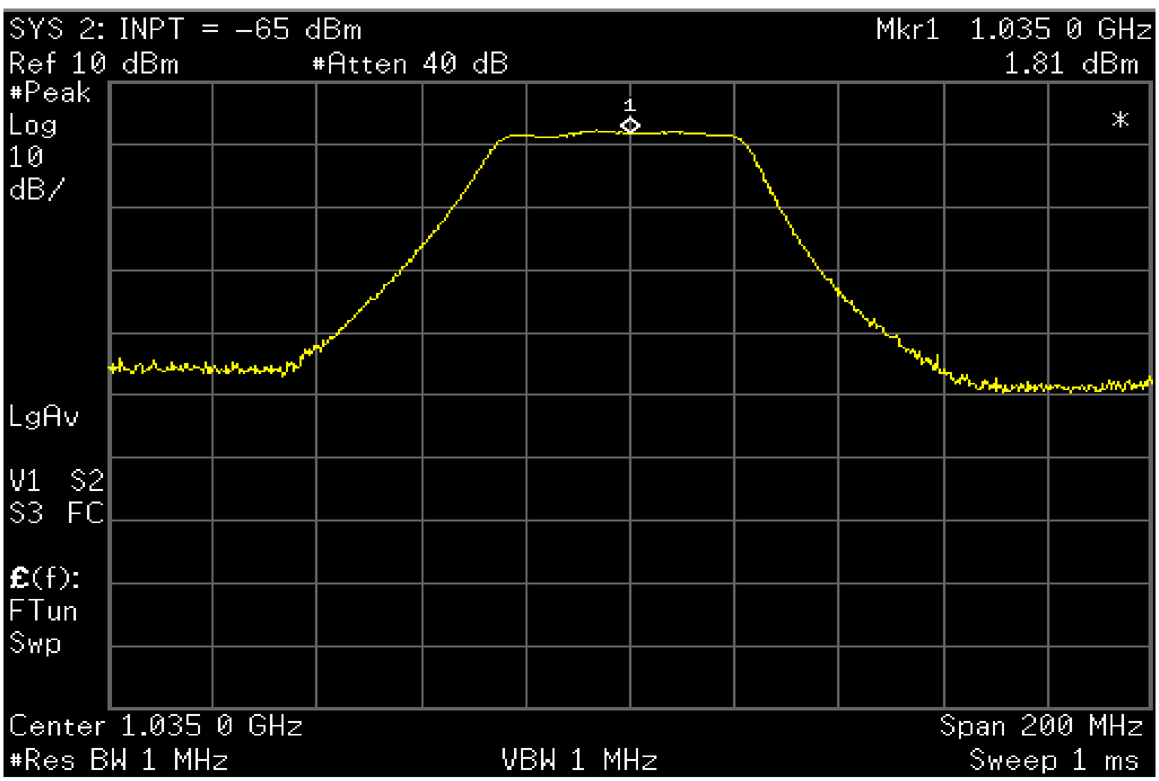


Figure A-12. Measurement System B Calibration Over 1010-1060 MHz Frequency Band.

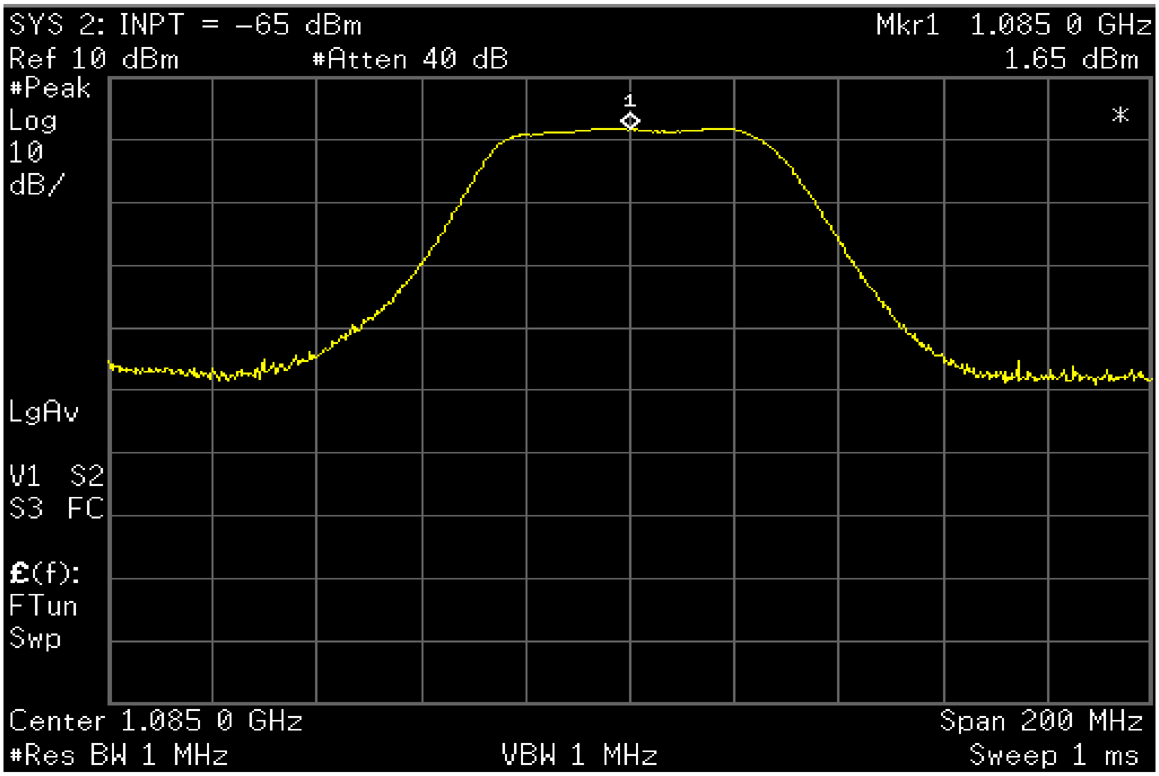


Figure A-13. Measurement System B Calibration Over 1060-1110 MHz Frequency Band.

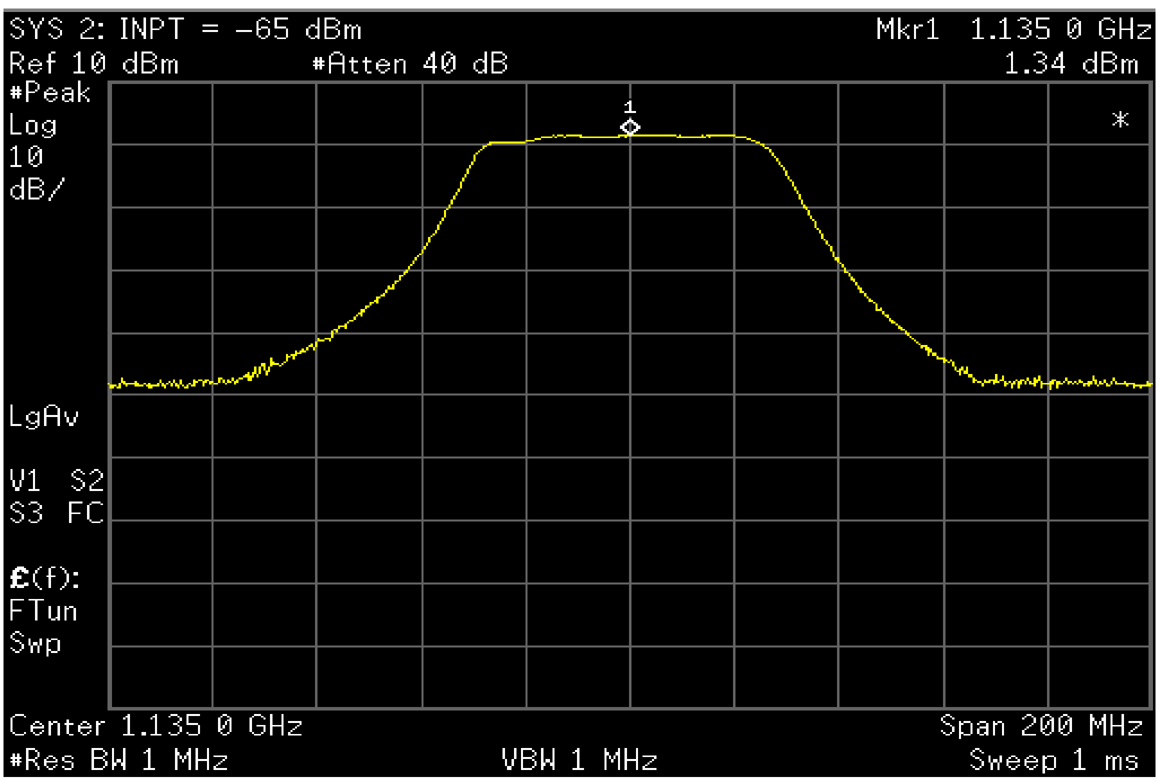


Figure A-14. Measurement System B Calibration Over 1110-1160 MHz Frequency Band.

APPENDIX B
MEASUREMENT PROCEDURES

This appendix presents the procedures used for collection of the data utilized in this report.

AMBIENT EMISSIONS MEASUREMENT PROCEDURES

The following procedures were applied in performing the measurements at each ambient emissions measurement location:

1. Set-up the measurement system as shown in Figure 2-1.

2. Set measurement antenna to a nominal height of four feet above ground level (roughly equivalent to typical height of a hand-held GPS receiver or E-911 enabled cell phone)

3. Orient the measurement antenna in vertical polarization and rotate through 360° observing peak signals and probable direction.

4. Repeat with antenna oriented in horizontal polarization.

5. Review the collected data to determine antenna polarization and the bearing that maximizes the received emission levels.

6. Using the data obtained from the previous steps, set up the spectrum analyzer display (e.g., reference level, amplitude scale, attenuation levels, etc.) to accommodate all subsequent measurements. Set the analyzer display line to –117.5 dBm.

7. Sequentially measure over each of the frequency bands under consideration (i.e., GPS L1, L2, and L5, and ARNS band segment) collecting peak emission traces and RMS average emission traces, by utilizing two of the three available analyzer traces.

8. When relatively high emission levels are observed, perform a system saturation test by inputting an additional 10-dB attenuator at the spectrum analyzer input and verifying that the received signal is attenuated by 10 dB.

9. Store the composite analyzer displays and associated trace data onto computer disk.

10. Record the relevant measurement site information, i.e., GPS coordinates, street address, site description, date, time, and antenna bearing.

RADIATED EMISSIONS MEASUREMENT PROCEDURES

The following procedures were implemented in the measurement of radiated emissions from common consumer electronic and electrical devices into the GPS frequency bands:

1. Assemble measurement system as shown in Figure 2-1.

2. Place the device under test (DUT) in the center of a non-conductive turntable and turn power on.

3. Place the measurement antenna at a distance of two meters from the DUT.

4. Use turntable to rotate the DUT through 360° with the measurement antenna oriented in vertical polarization.

5. Re-orient the measurement antenna to horizontal polarization and again rotate the DUT through 360°.

6. Review the data and observe the antenna polarization and the azimuth with respect to the DUT that produces the maximum emission levels. Use this polarization and DUT orientation for the remainder of the test.

7. With DUT radiating, move the measurement antenna up and down (between approximately 1 and 3 meters) to determine the antenna height at which the emissions are maximized. Set the antenna to the height determined from this procedure.

8. Using the data acquired in the previous steps, set up the spectrum analyzer display (e.g., reference level, amplitude scale, attenuation levels, etc.) to accommodate all subsequent measurements. Set the analyzer display line to –117.5 dBm.

9. Turn the DUT off and use the spectrum analyzers' trace 1 feature to record the ambient RF background.

10. Turn the DUT on and tune the spectrum analyzer to one of the frequency bands under consideration. Use analyzer trace 2 to record the RMS average emission from the DUT and use trace 3 to record the Log average measured emissions.

11. Store the composite analyzer trace and associated trace data to computer disk.

12. Repeat steps 9-11 for each of the frequency bands under consideration.

APPENDIX C
OUTDOOR AMBIENT EMISSIONS MEASUREMENT DATA

The data plots recorded from the measurement of existing ambient emissions at outdoor sites such as airports, shipyards, train yards, and urban/industrial locations are presented in this appendix. The following paragraphs provide guidance on reading and interpreting these plots.

In each of the figures presented in this appendix, the upper (yellow) trace depicts the ambient emissions measured in the subject frequency band using a peak detector and the maximum hold function (i.e., no averaging employed) over a fifteen-minute period. This trace was generated mainly as a tool for orienting the measurement antenna and for determining the maximum likely emission amplitudes to facilitate decisions pertaining to the necessity of adding additional attenuation in the measurement system so as to prevent overdriving of components. This data was not used for any analytical purposes. The lower (blue) trace represents the measured RMS average emission level over one hundred one-millisecond analyzer sweeps across the measurement band. This is the data used to compare to the assumed interference threshold for enhanced GPS receivers. The constant display line (green) at -117.5 dBm is used as the basis for comparing the measured data to the theoretical enhanced GPS interference threshold.

All external measurement system parameters (e.g., amplifier gains, cable loss, and antenna gain) are accounted for in the spectrum analyzer display and are provided on each plot under the tag Ext PG located at the top of the display. At some measurement locations, it was necessary to add additional attenuation in the measurement system due to the presence of relatively high-amplitude signals. In those cases where additional external attenuation was required, the Ext PG value was adjusted accordingly. Thus, the levels shown on the amplitude axis of the spectrum analyzer plots represent the actual RMS average power as measured in a 1 MHz bandwidth at the measurement system antenna.

In each of these plots, the horizontal axis represents frequency and the vertical axis represents amplitude. For measurements in the GPS frequency bands, a span of 25 MHz was used to encompass the 24 MHz registered frequency band. For a 25 MHz span, each vertical graticule line represents a 2.5 MHz deviation in frequency (25 MHz/10 graticule lines). For the measurements performed in the 960-1160 MHz (ARNS) band, a span of 50 MHz was used, the maximum that could be achieved within the pass band of the pre-select filter. In these plots, each vertical graticule line represents a frequency deviation of 5 MHz (50 MHz/10 graticule lines).

On the amplitude axis, each horizontal graticule line represents a 10 dB decrement from the reference level amplitude shown in the upper left-hand corner of the plot.

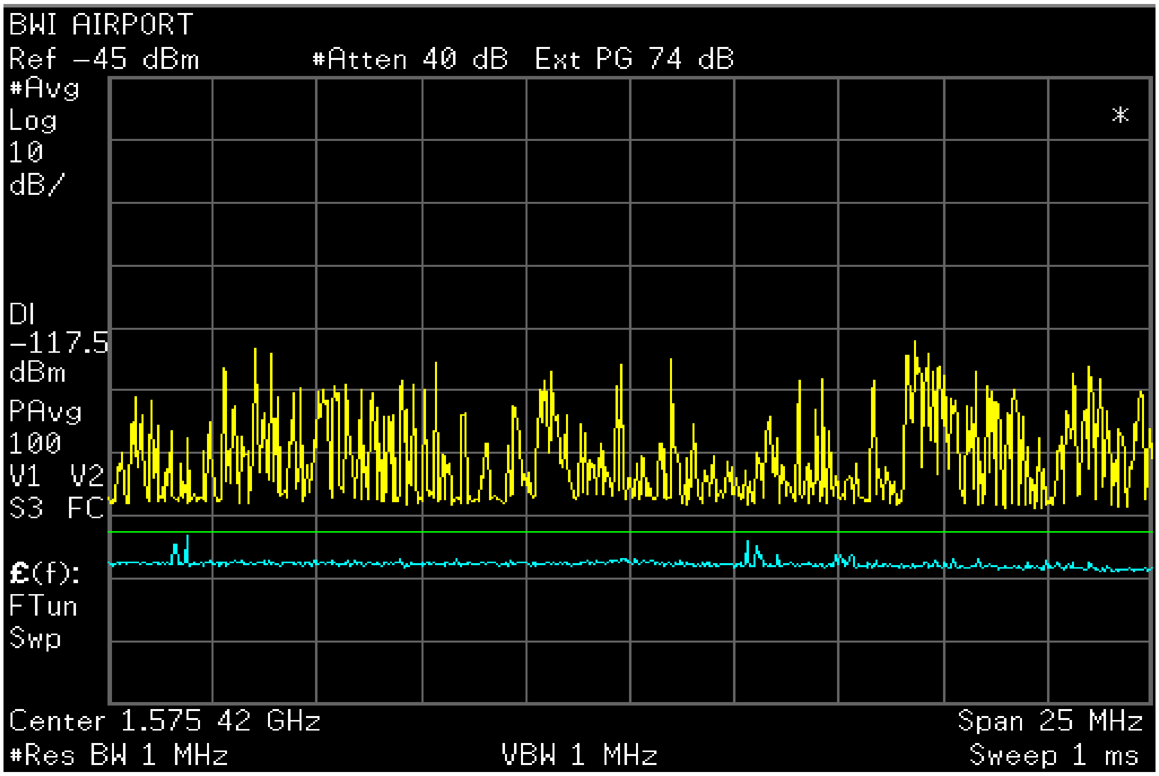


Figure C-15. Ambient Emissions in the GPS L1 Frequency Band at BWI Airport.

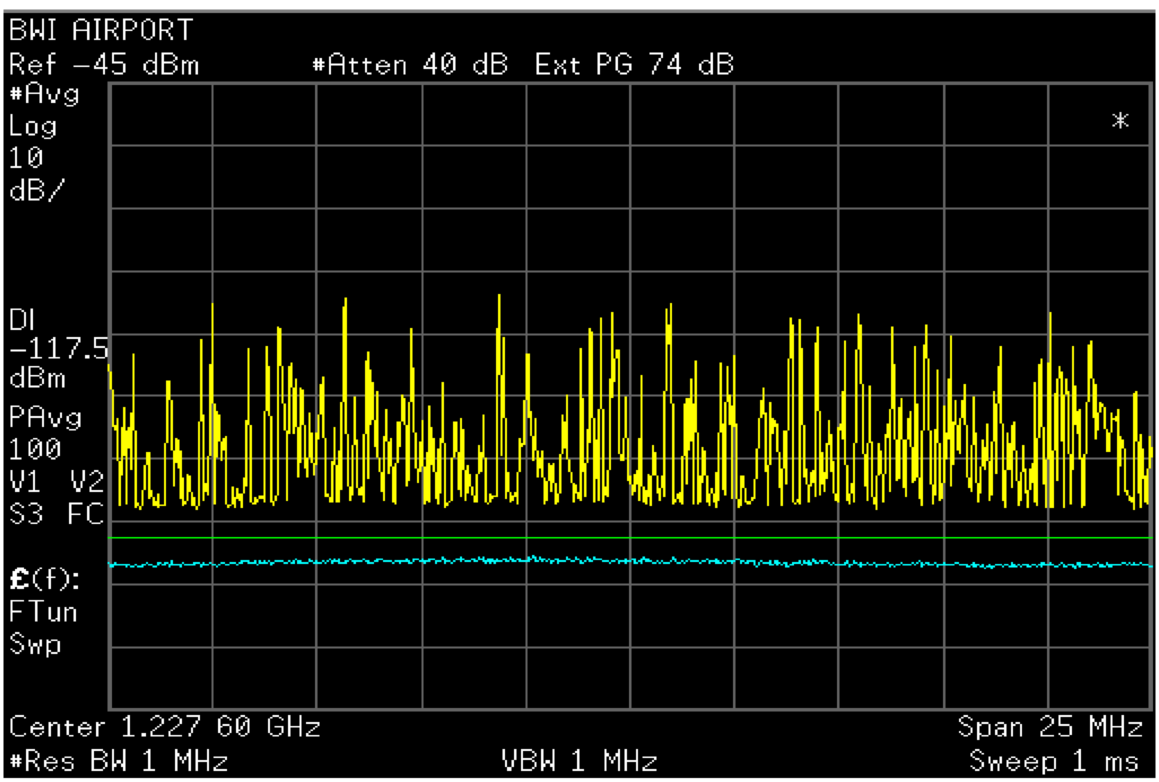


Figure C-16. Ambient Emissions in the GPS L2 Frequency Band at BWI Airport.

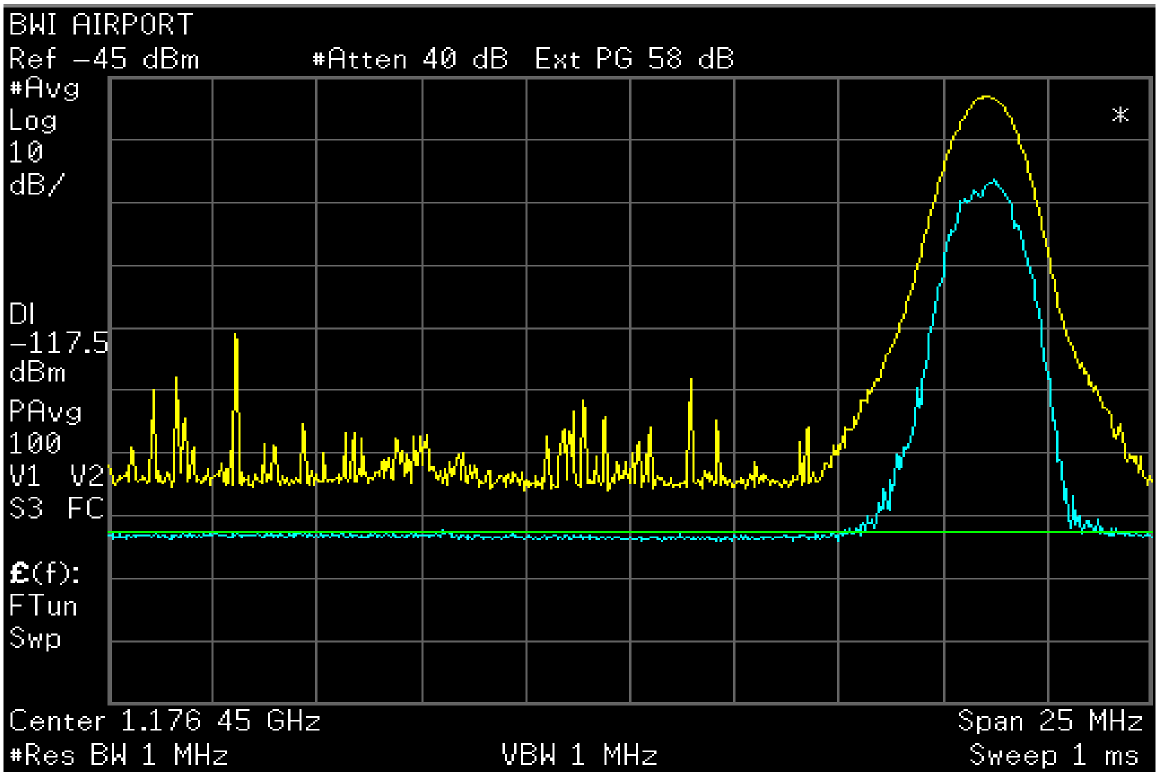


Figure C-17. Ambient Emissions in the GPS L5 Frequency Band at BWI Airport.

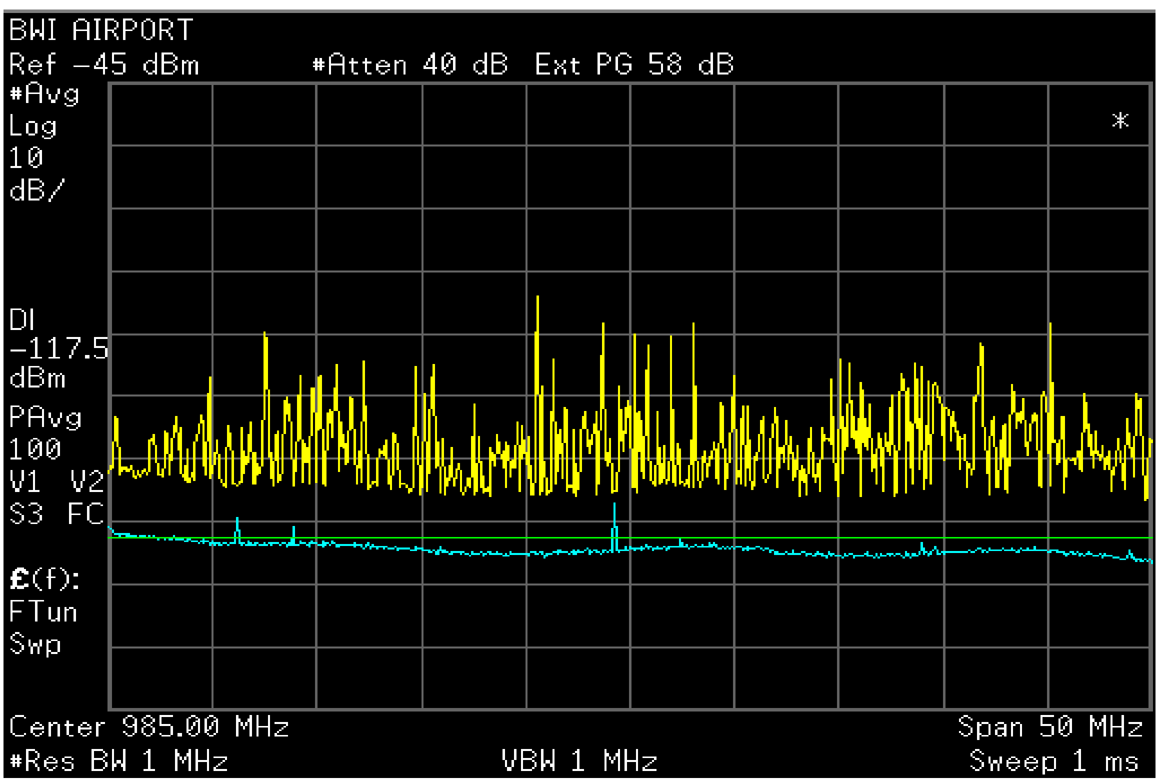


Figure C-18. Ambient Emissions in the 960-1010 MHz Frequency Band at BWI Airport.

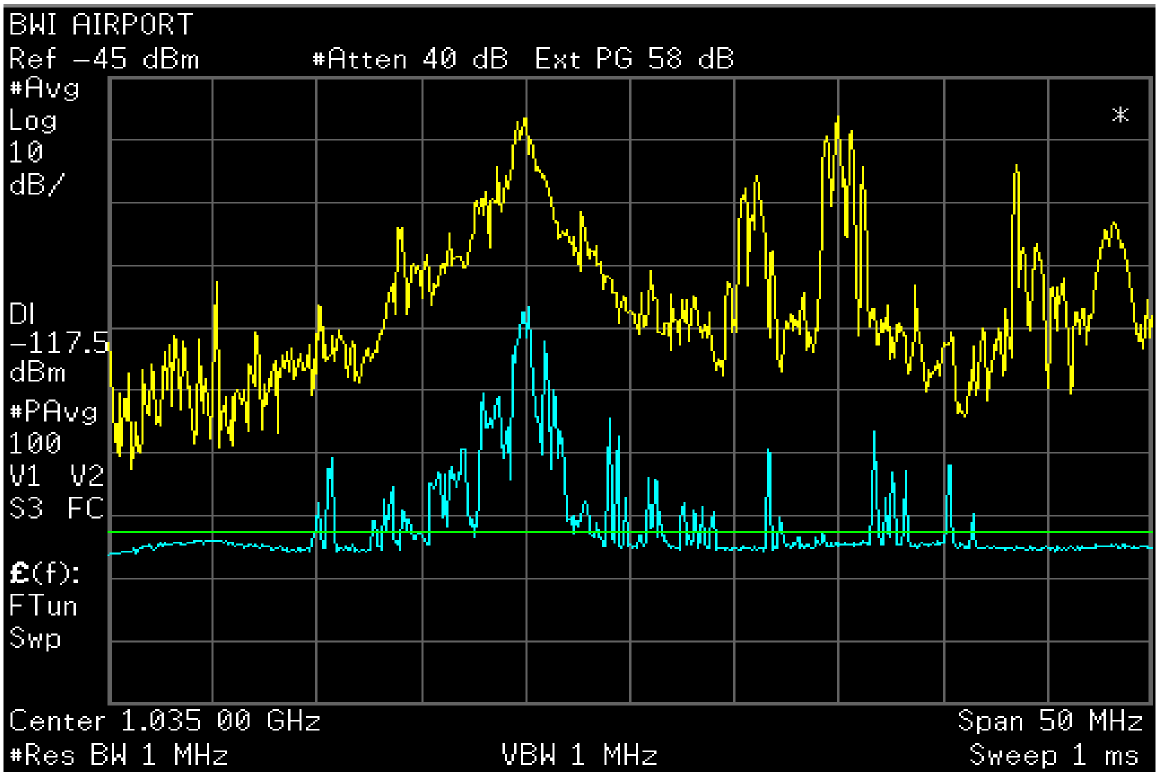


Figure C-19. Ambient Emissions in the 1010-1060 MHz Frequency Band at BWI Airport.

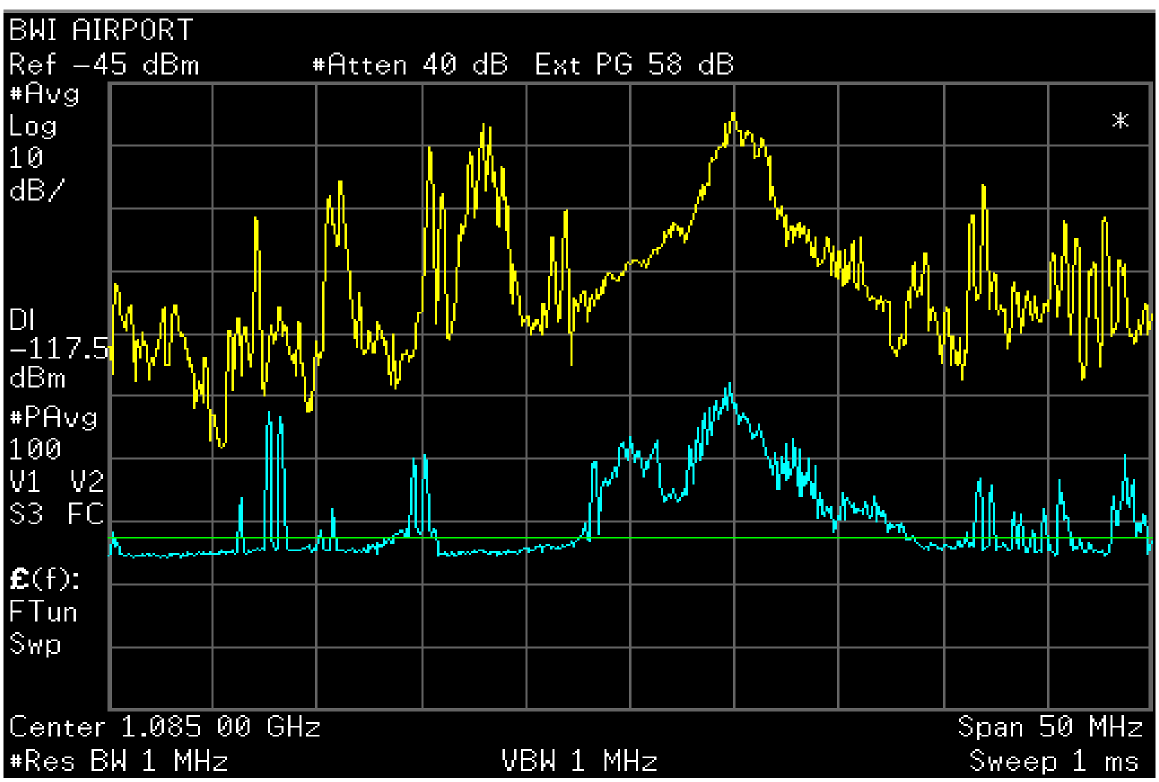


Figure C-20. Ambient Emissions in the 1060-1110 MHz Frequency Band at BWI Airport.

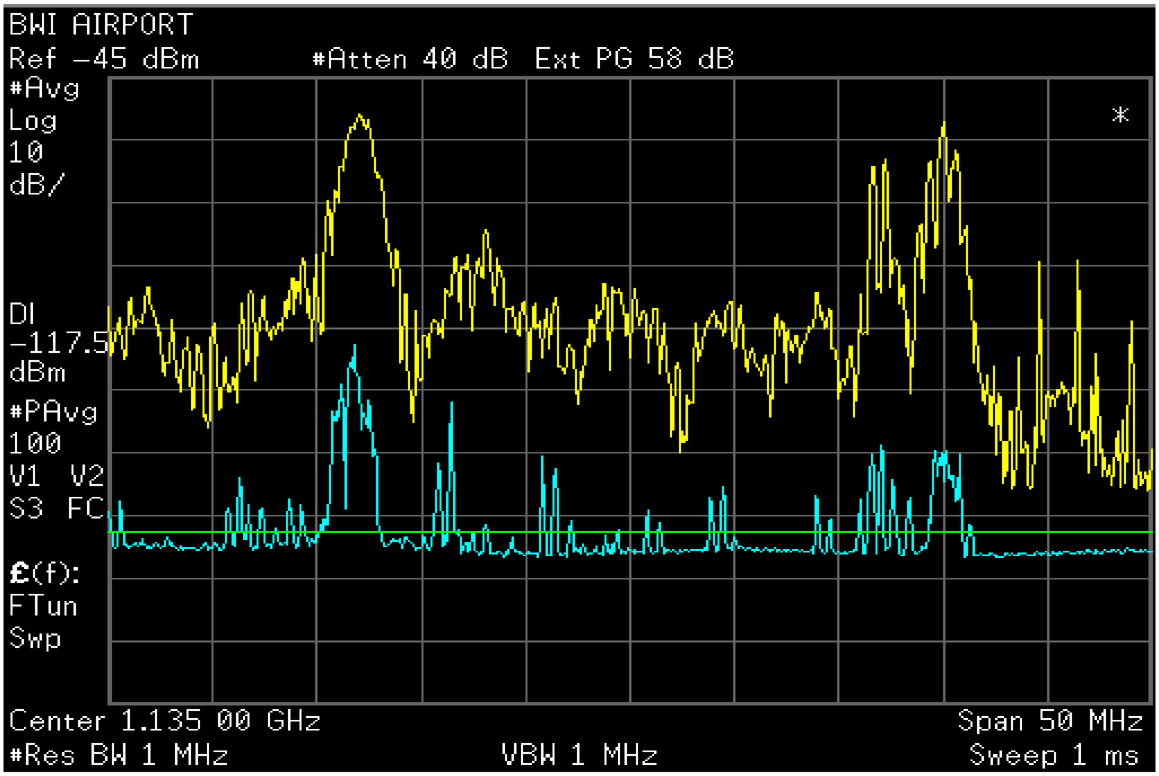


Figure C-21. Ambient Emissions in the 1110-1160 MHz Frequency Band at BWI Airport.

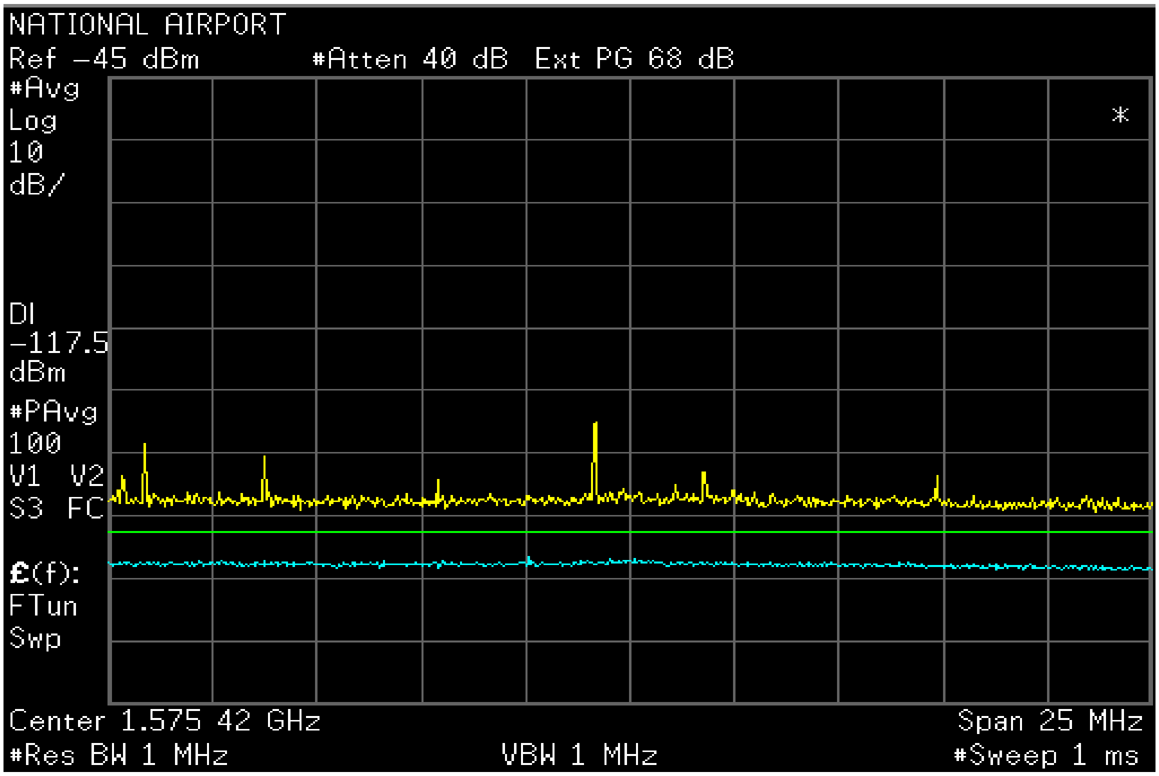


Figure C-22. Ambient Emissions in the GPS L1 Frequency Band at Reagan National Airport.

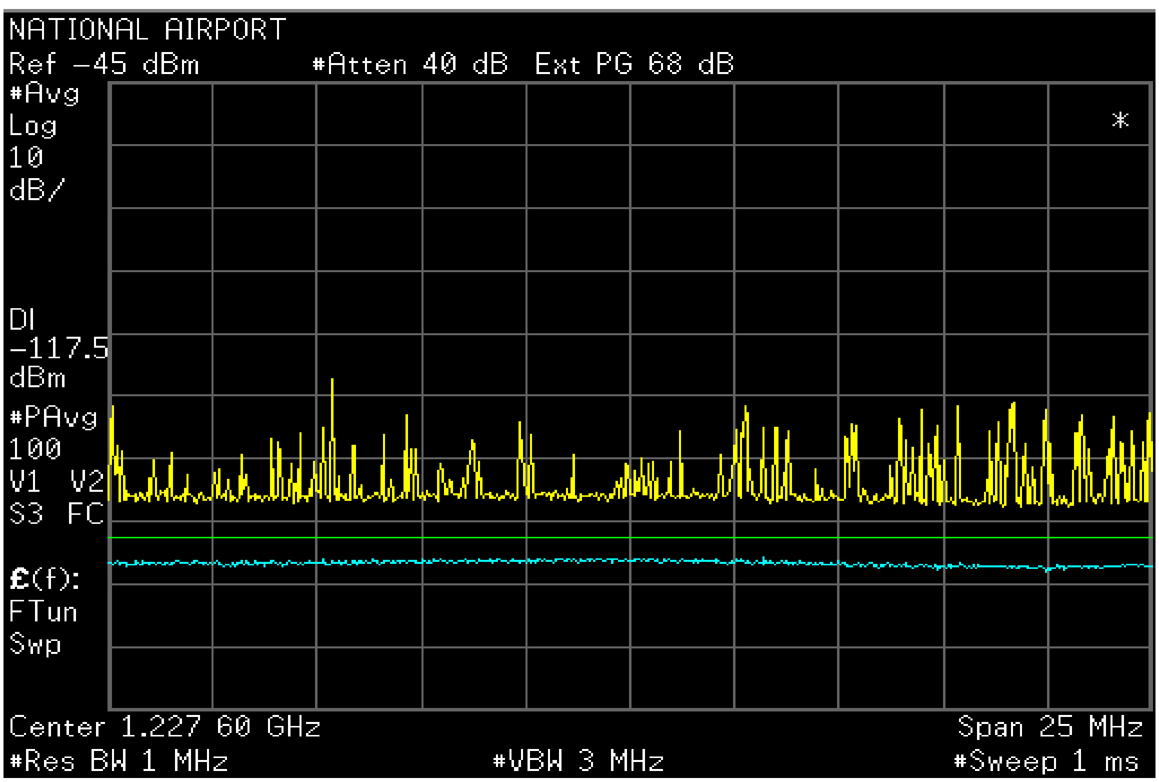


Figure C-23. Ambient Emissions in the GPS L2 Frequency Band at Reagan National Airport.

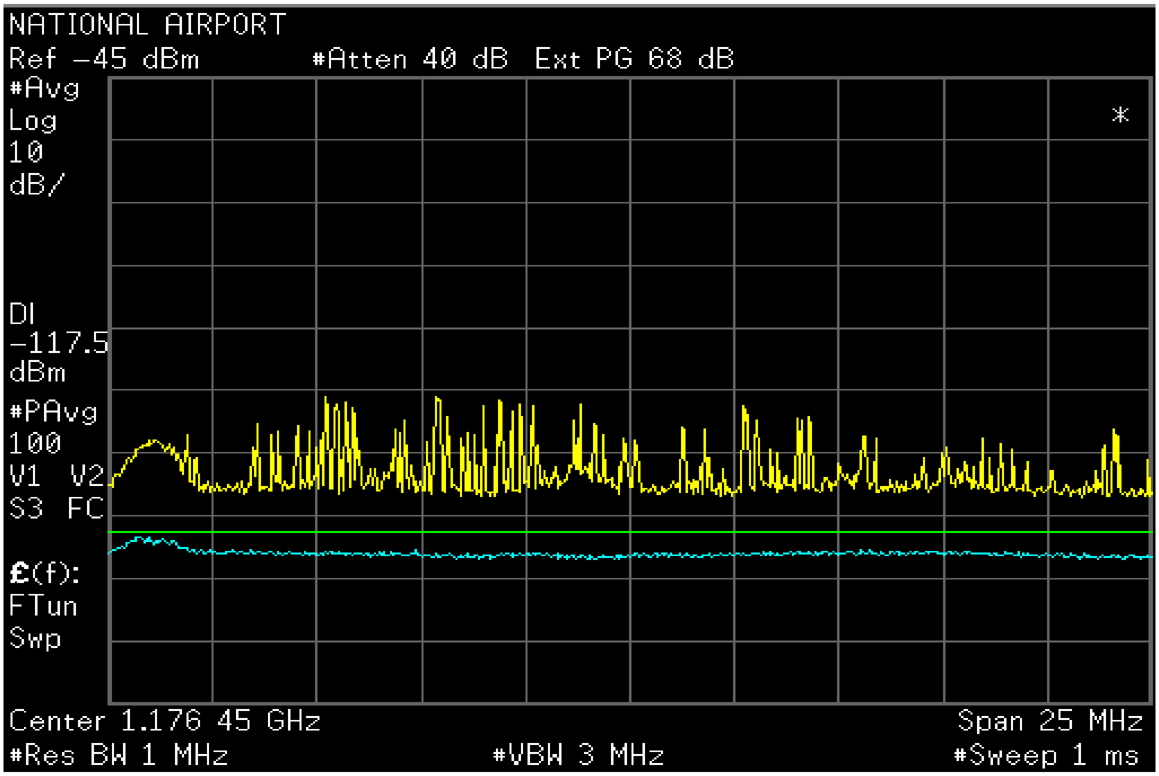


Figure C-24. Ambient Emissions in the GPS L5 Frequency Band at Reagan National Airport.

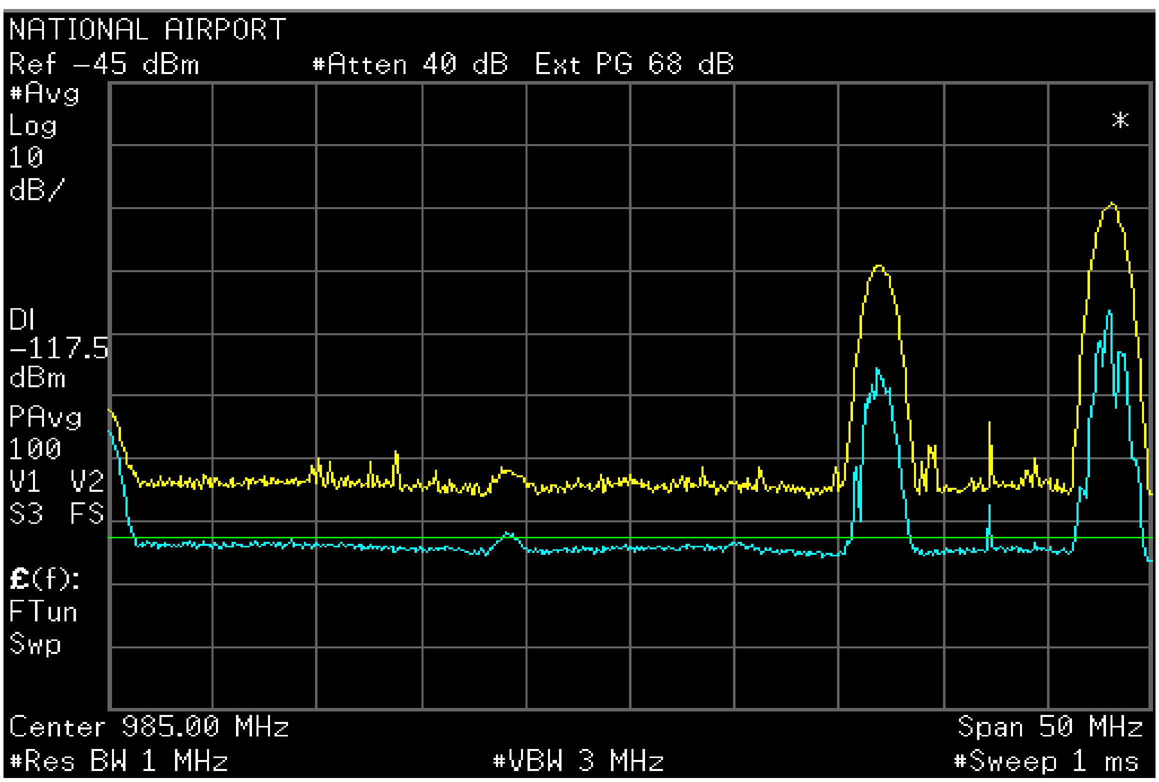


Figure C-25. Ambient Emissions in the 960-1010 MHz Frequency Band at Reagan National Airport.

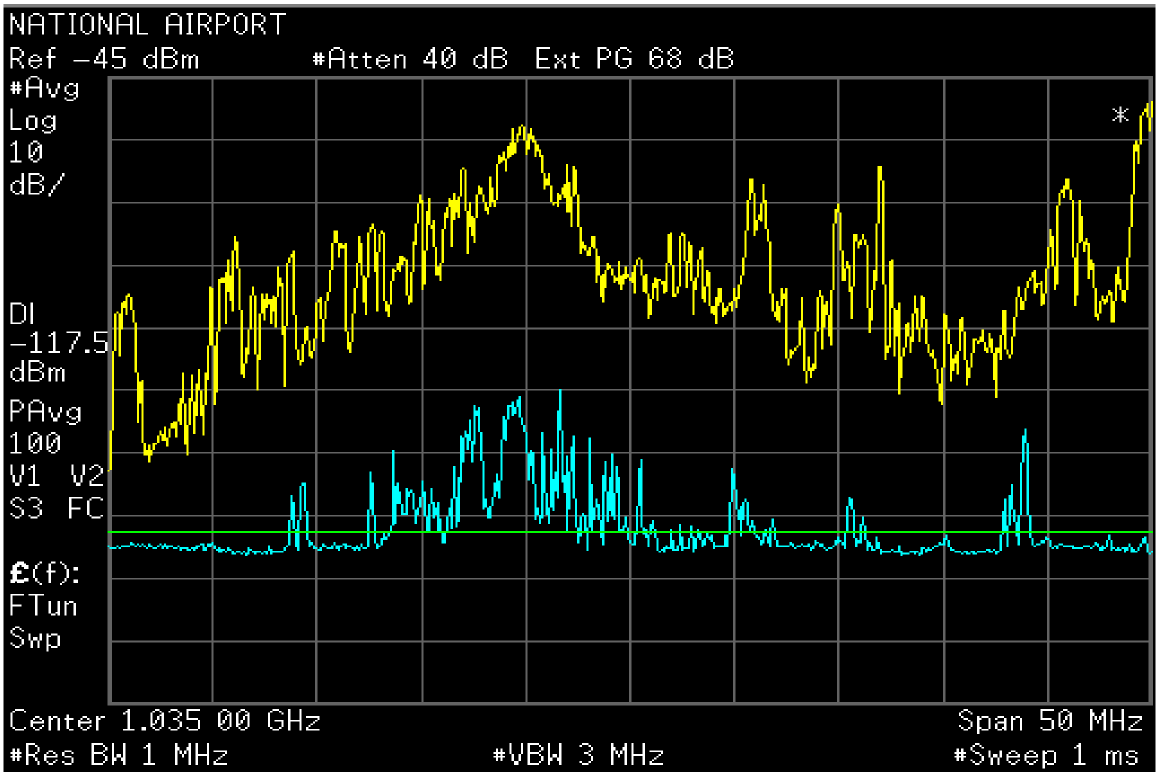


Figure C-26. Ambient Emissions in the 1010-1060 MHz Frequency Band at National Airport.

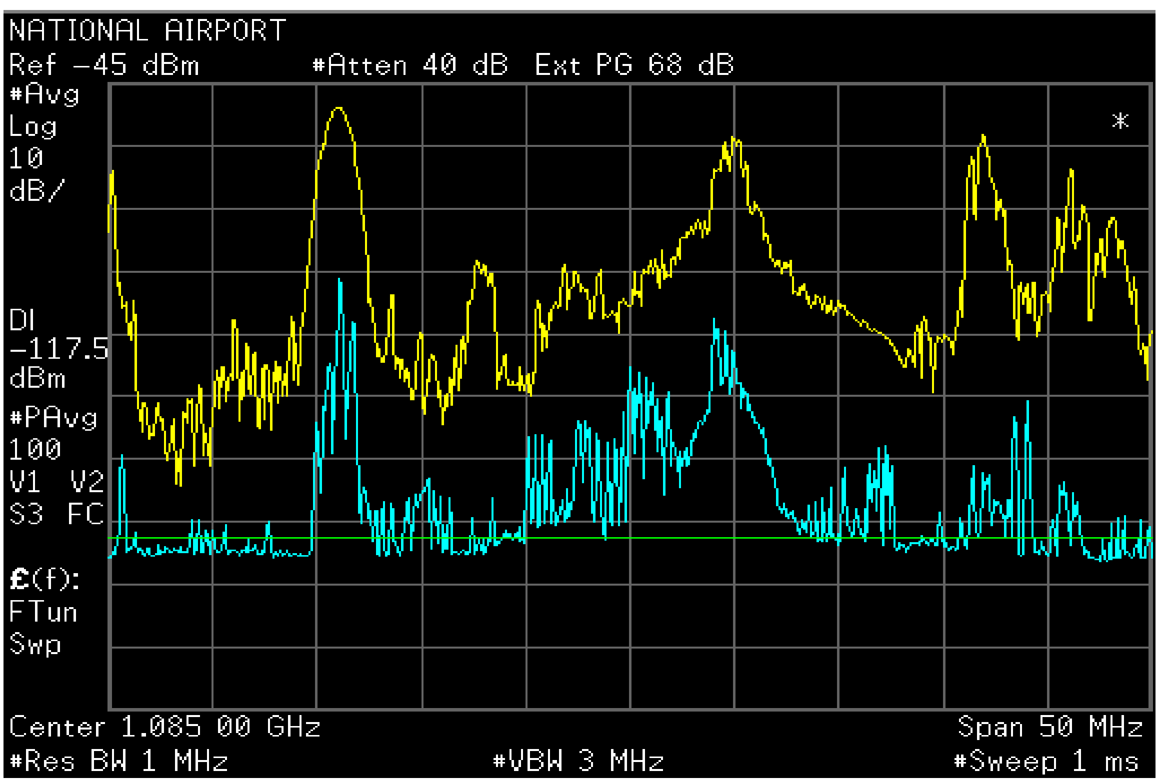


Figure C-27. Ambient Emissions in the 1060-1110 MHz Frequency Band at National Airport.

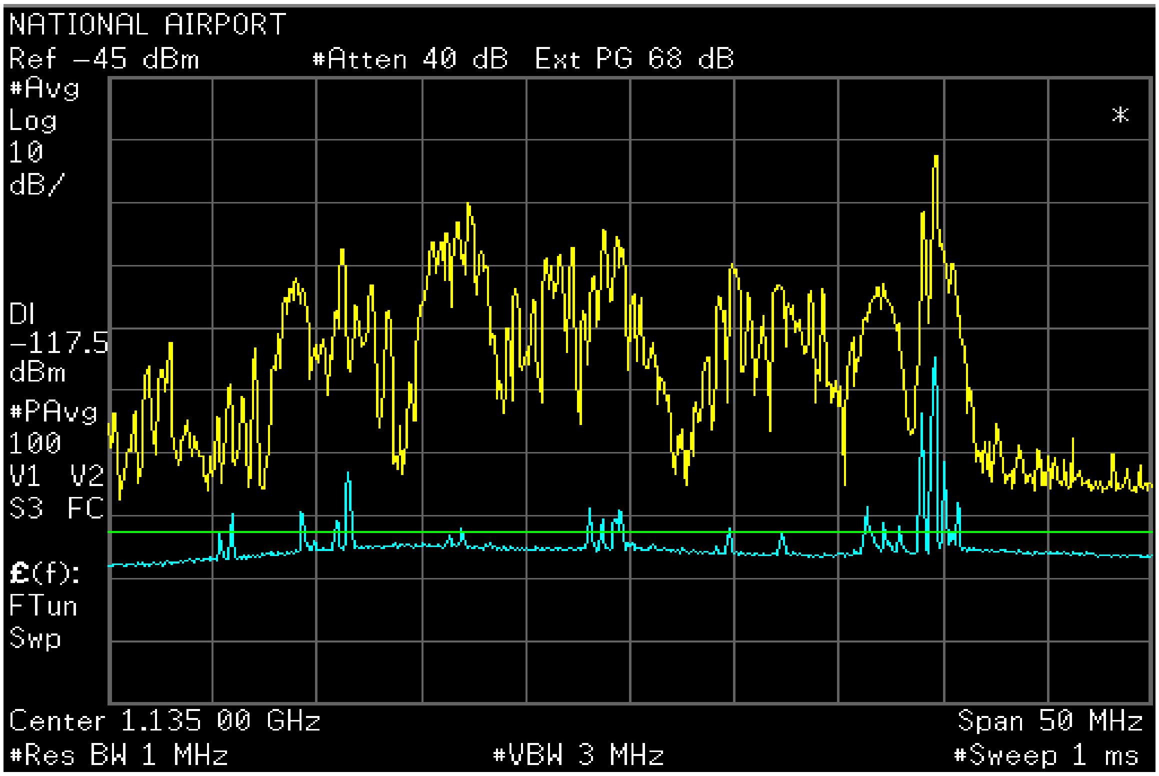


Figure C-28. Ambient Emissions in the 1110-1160 MHz Frequency Band at National Airport.

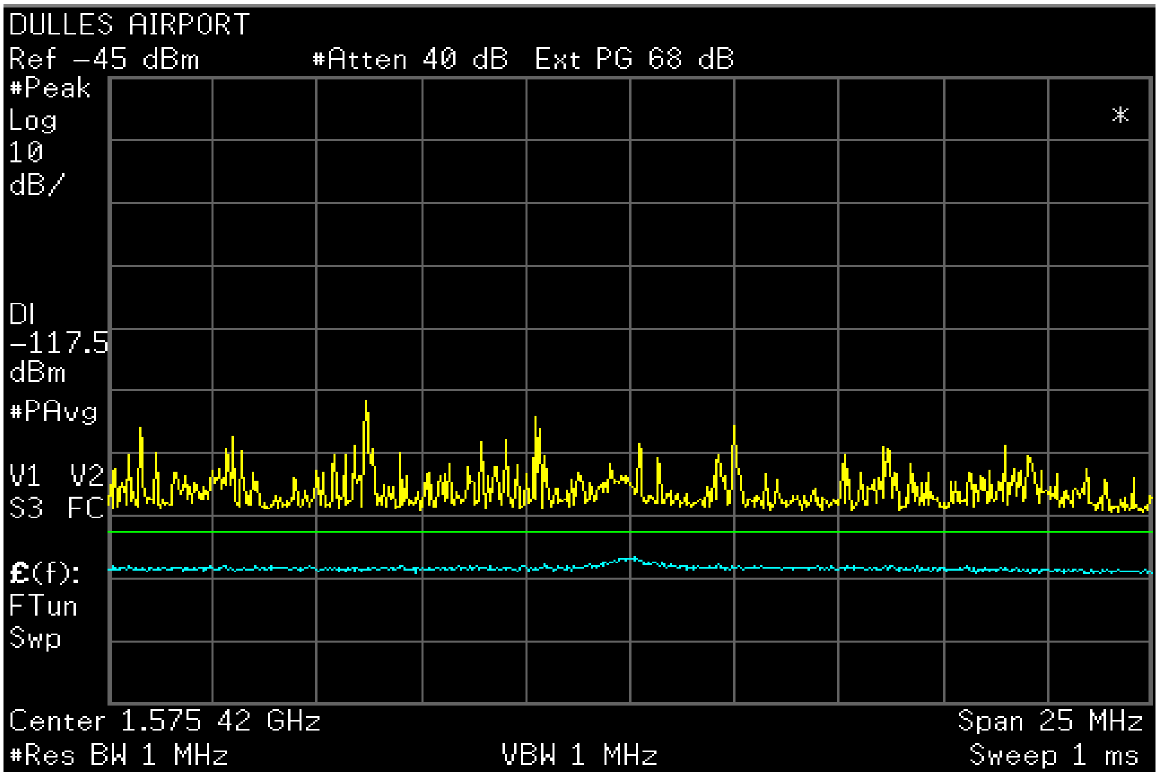


Figure C-29. Ambient Emissions in the GPS L1 Frequency Band at Dulles International Airport.

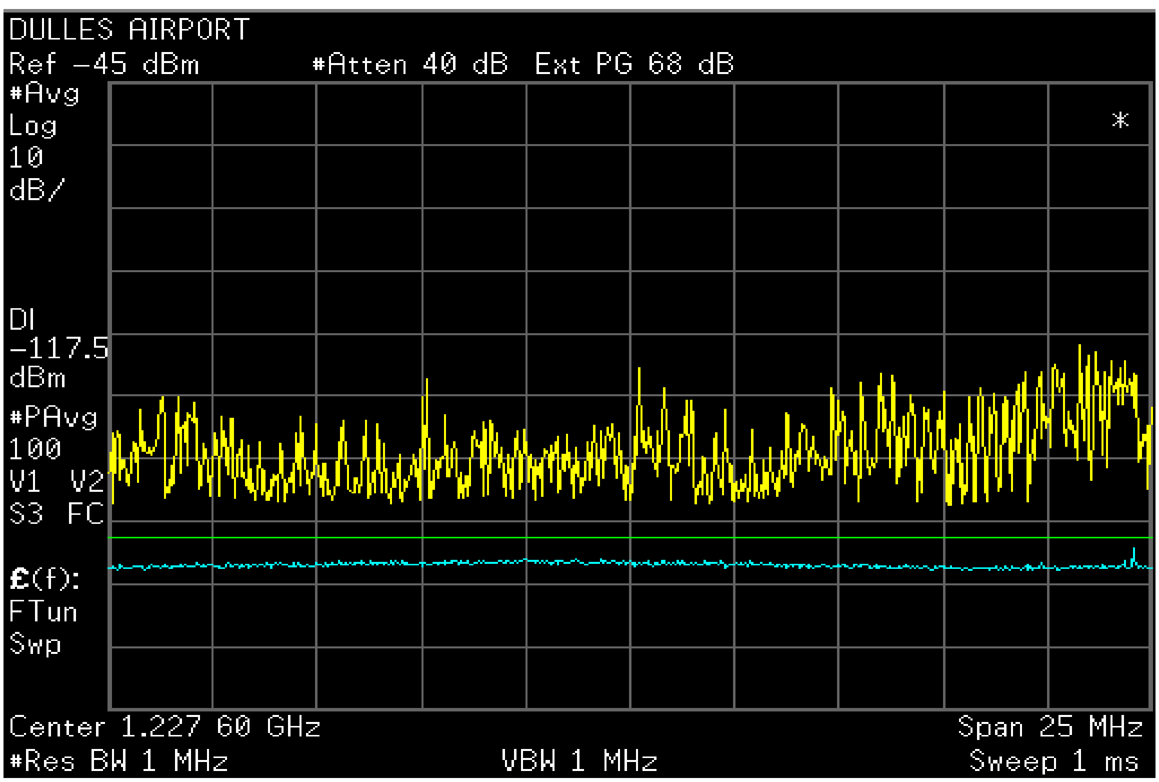


Figure C-30. Ambient Emissions in the GPS L2 Frequency Band at Dulles International Airport.

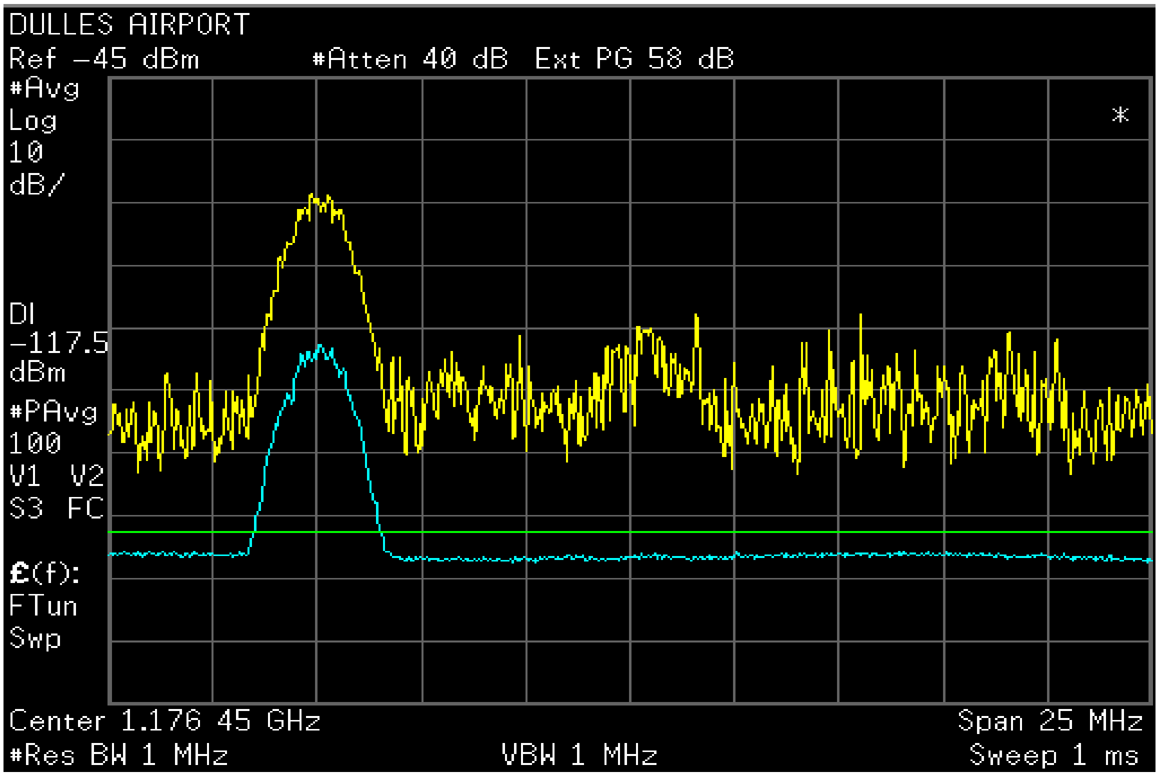


Figure C-31. Ambient Emissions in the GPS L5 Frequency Band at Dulles International Airport.

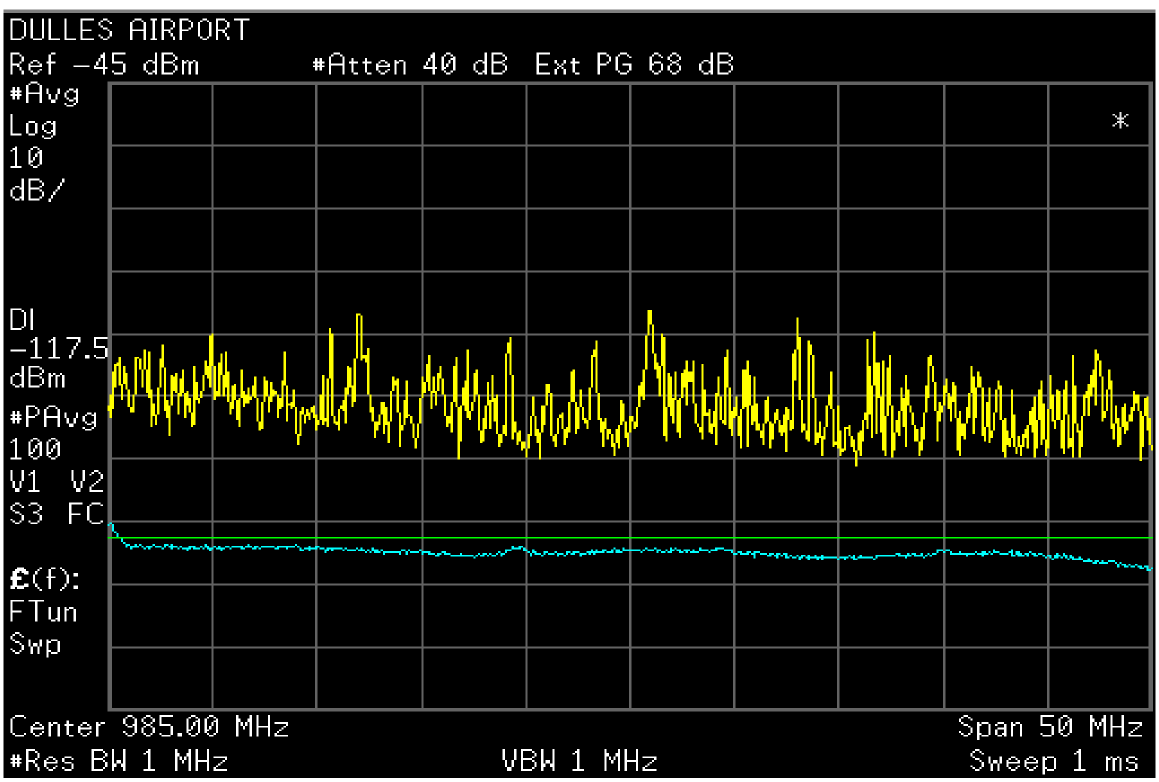


Figure C-32. Ambient Emissions in the 960-1010 MHz Frequency Band at Dulles Airport.

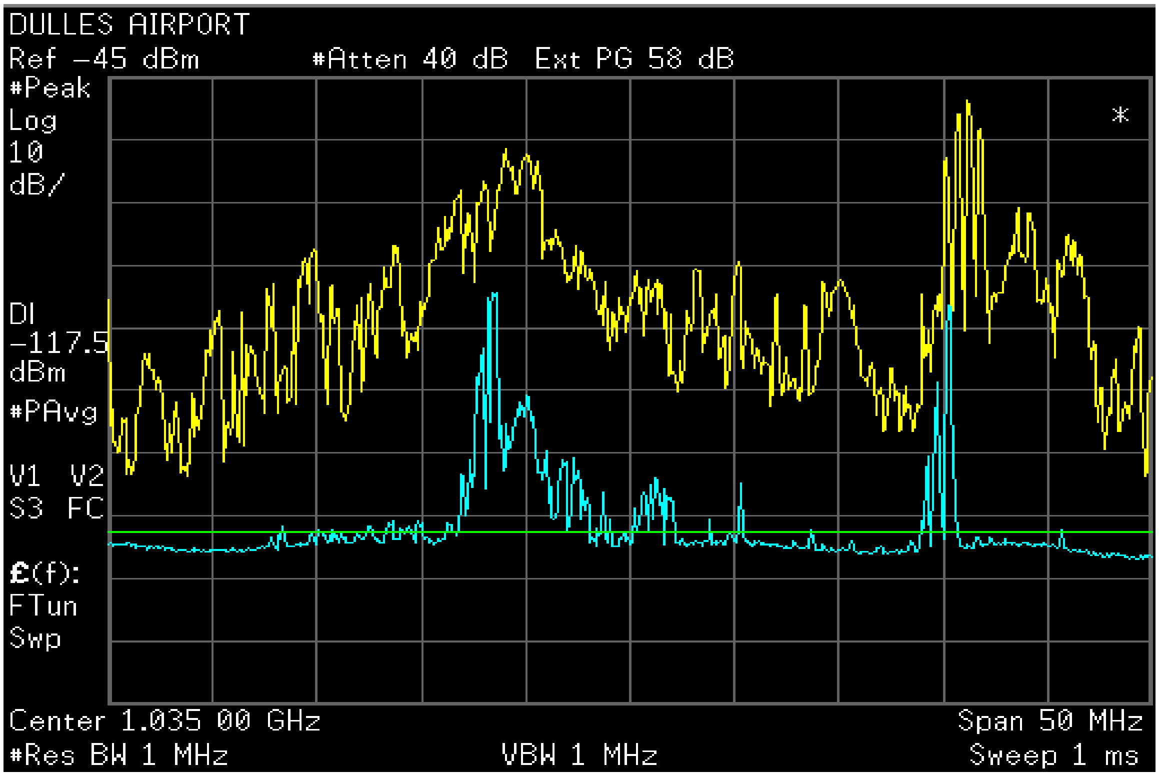


Figure C-33. Ambient Emissions in the 1010-1060 MHz Frequency Band at Dulles Airport.

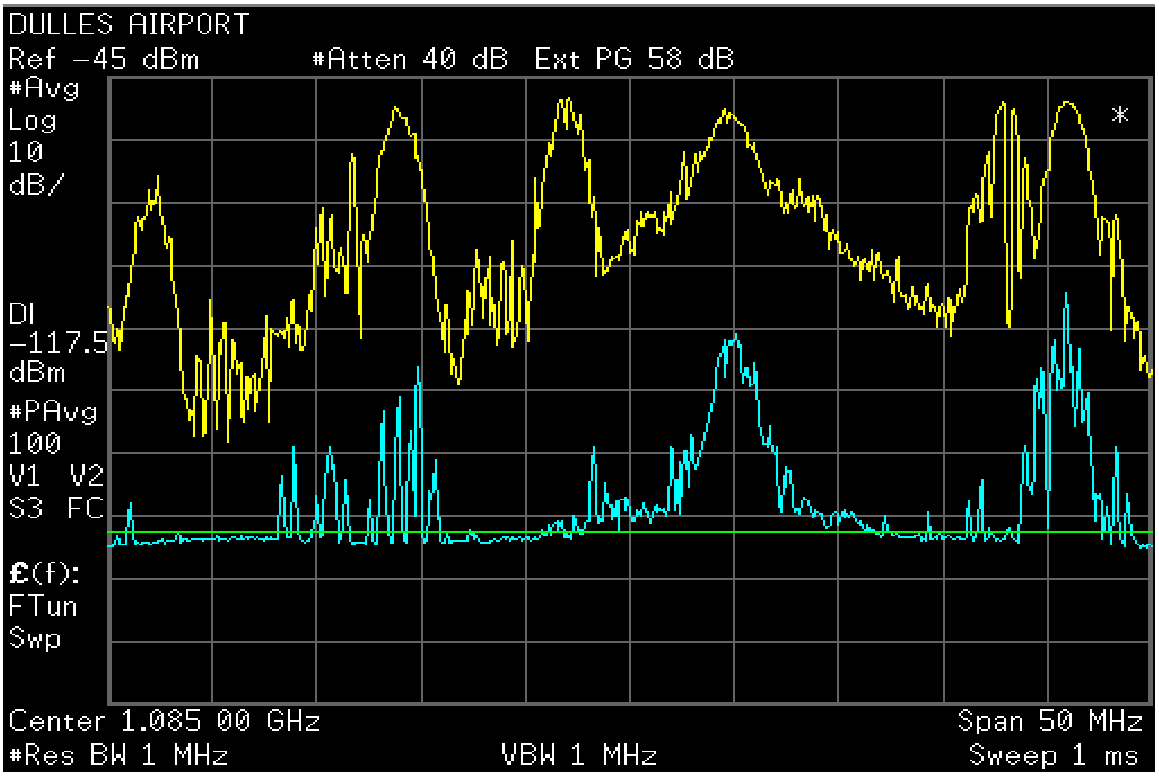


Figure C-34. Ambient Emissions in the 1060-1110 MHz Frequency Band at Dulles Airport.

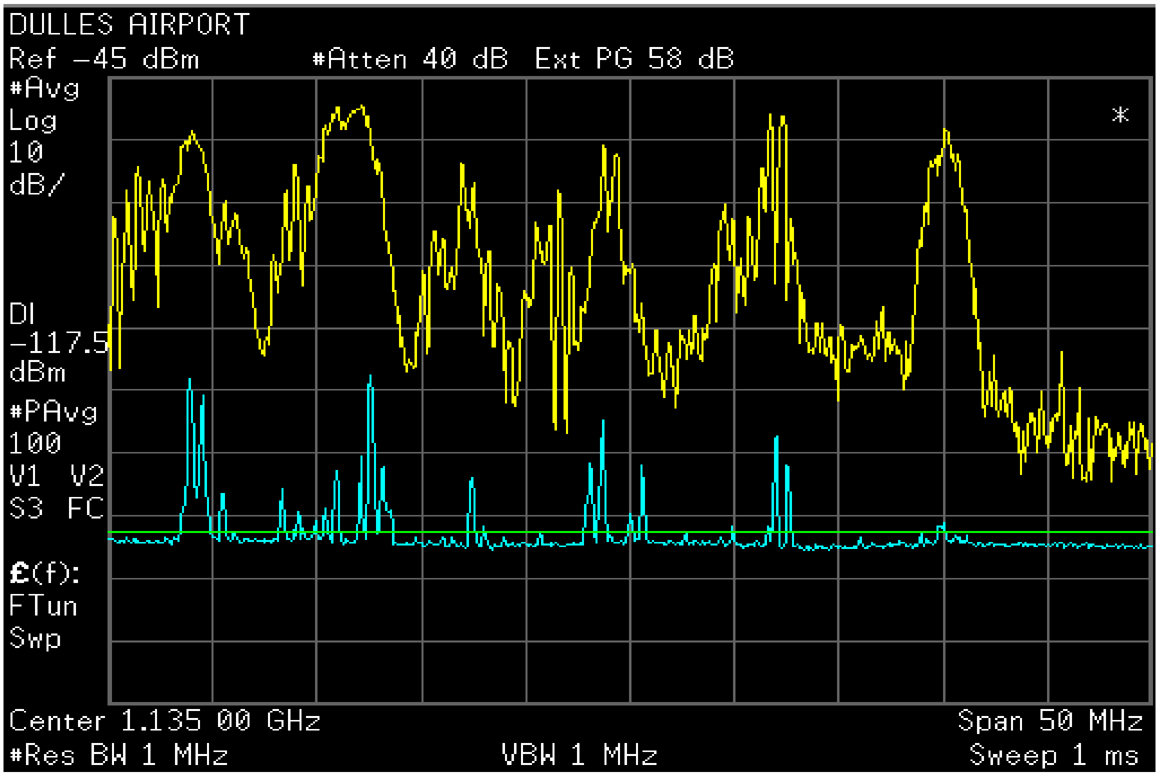


Figure C-35. Ambient Emissions in the 1110-1160 MHz Frequency Band at Dulles Airport.

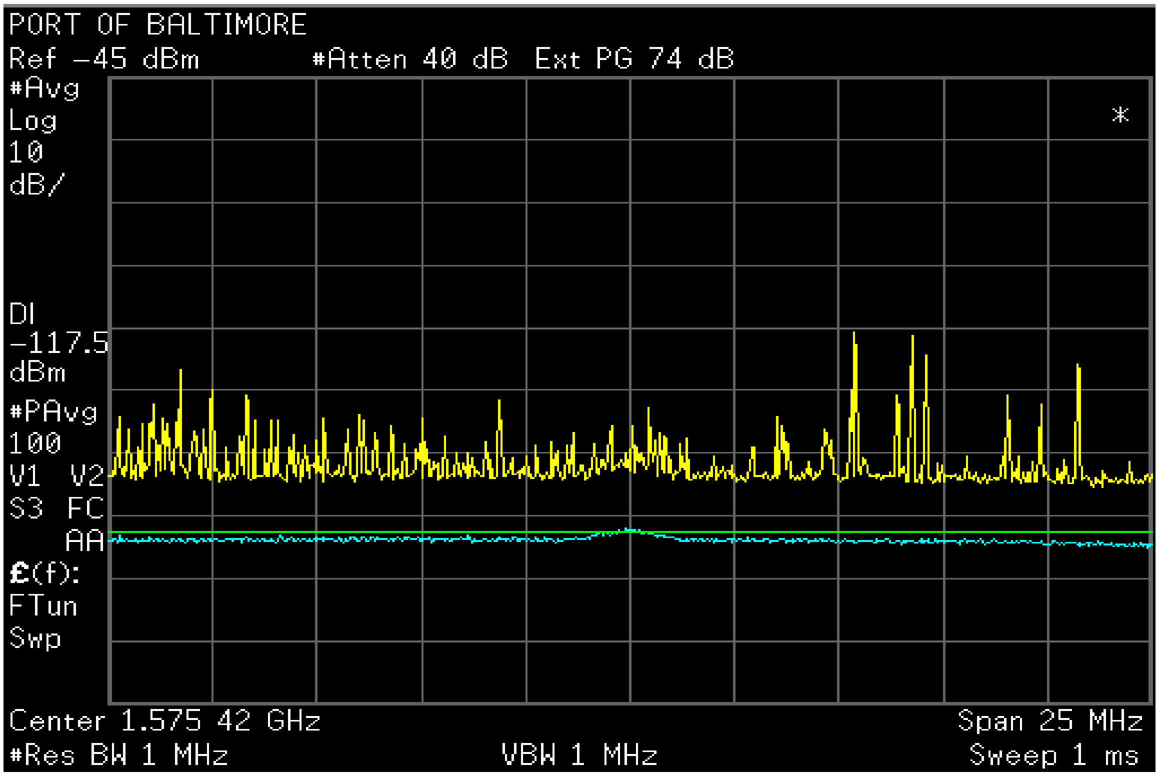


Figure C-36. Ambient Emissions in the GPS L1 Frequency Band at the Port of Baltimore.

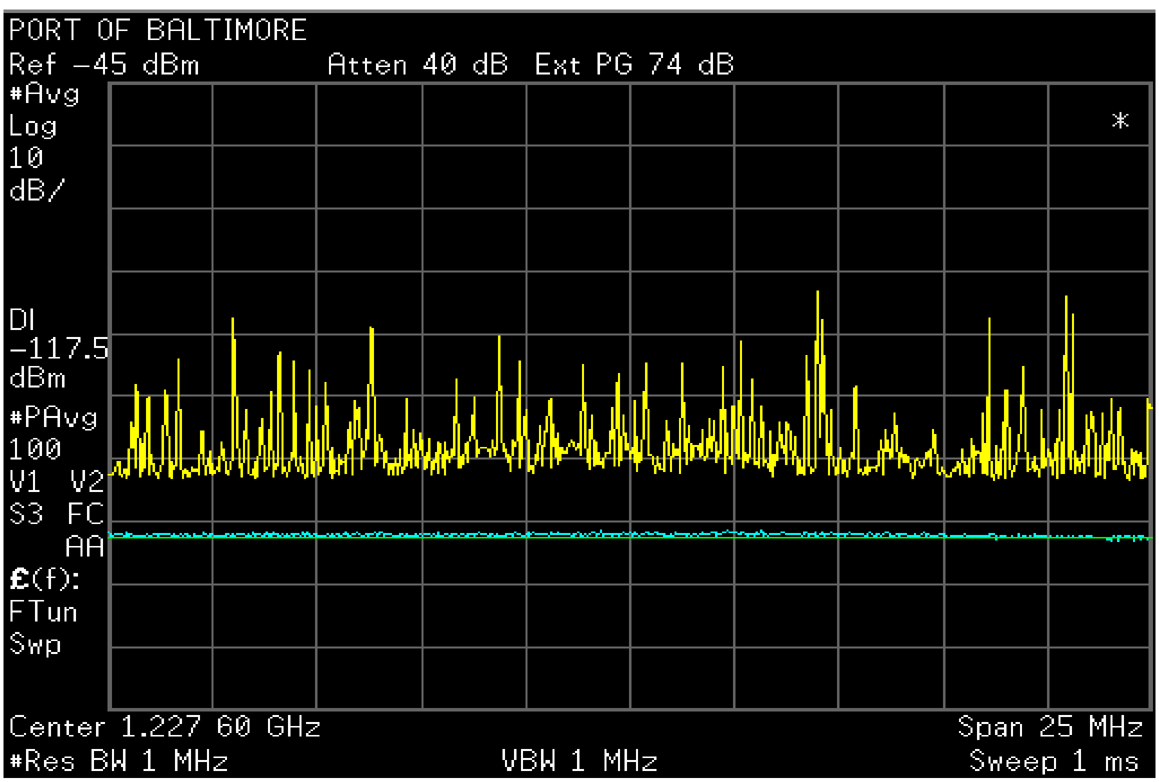


Figure C-37. Ambient Emissions in the GPS L2 Frequency Band at the Port of Baltimore.

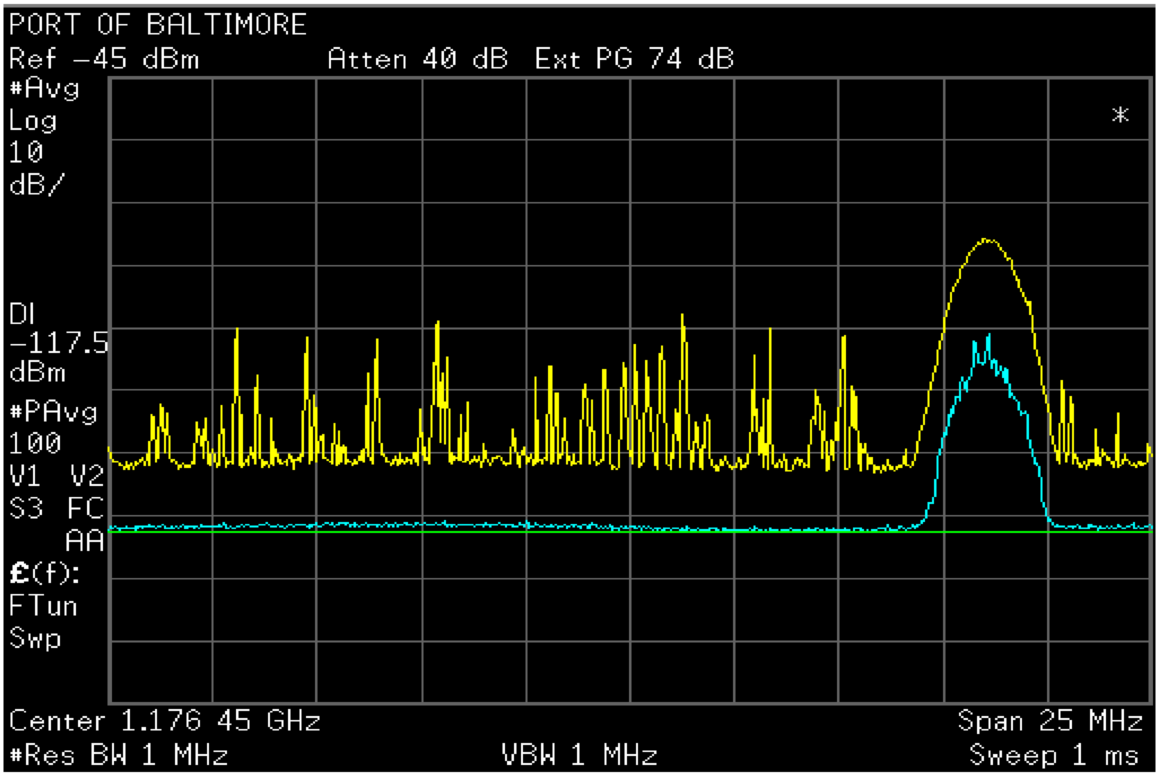


Figure C-38. Ambient Emissions in the GPS L5 Frequency Band at the Port of Baltimore.

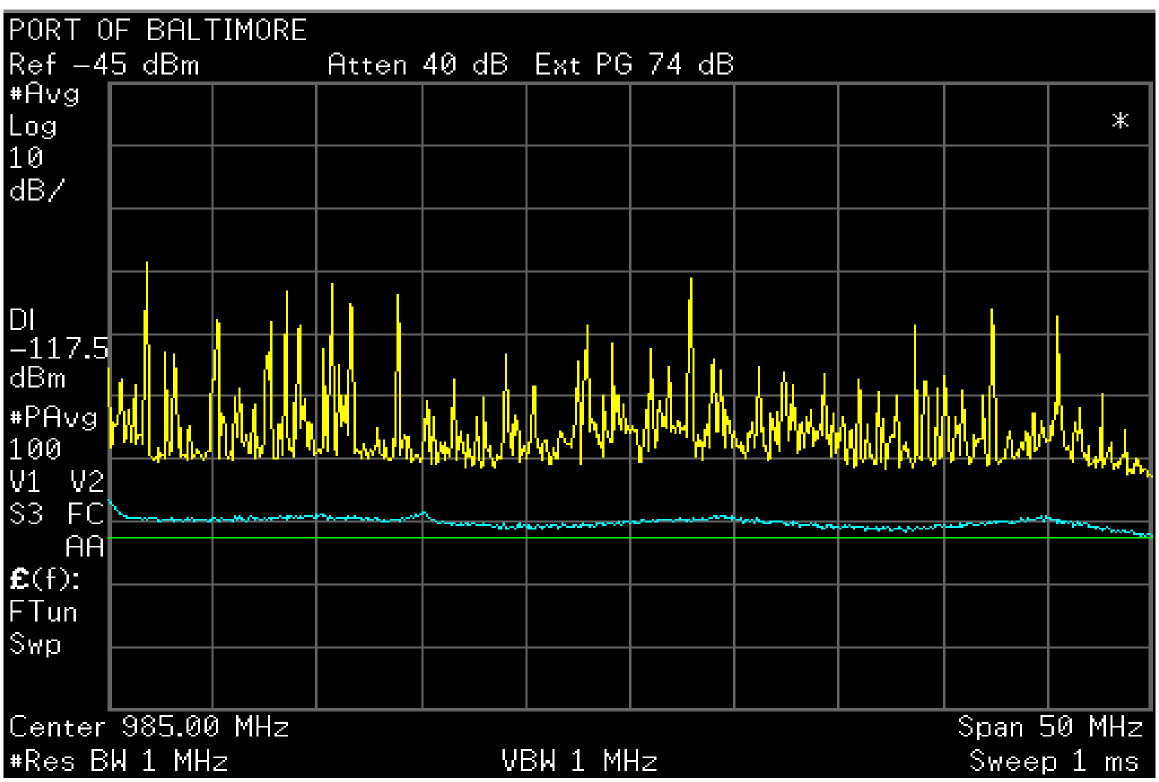


Figure C-39. Ambient Emissions in the 960-1010 MHz Frequency Band at the Port of Baltimore.

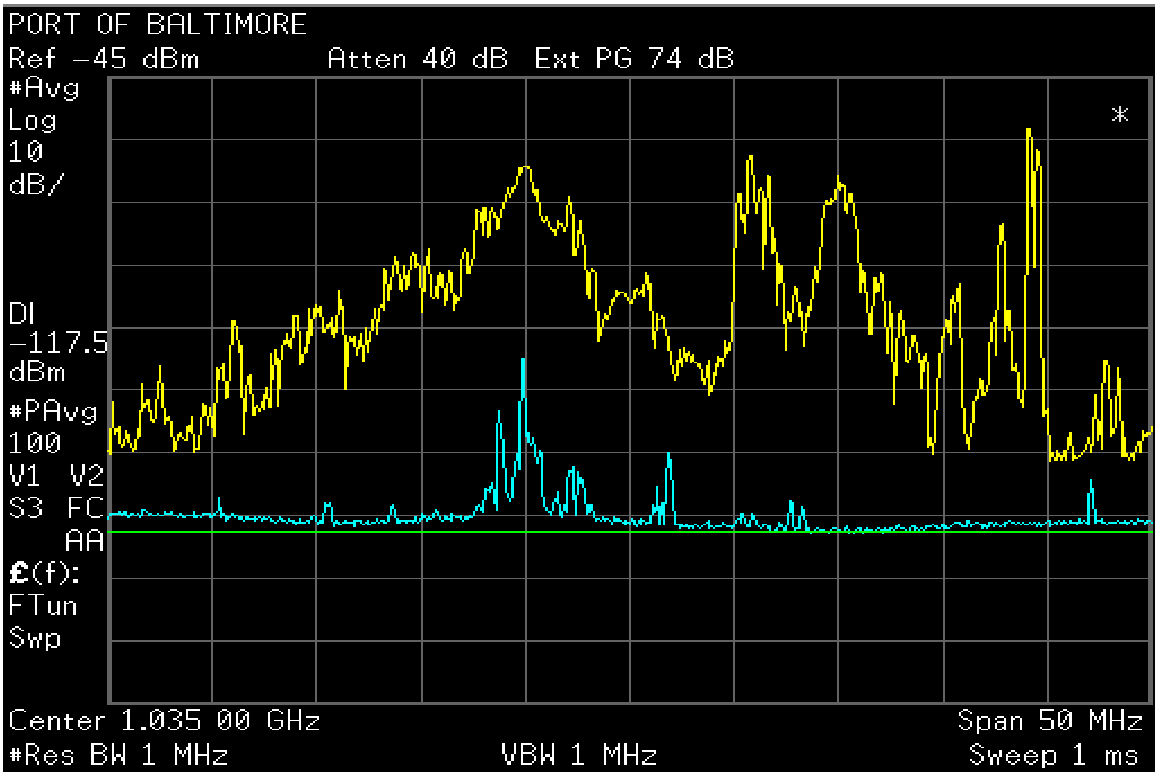


Figure C-40. Ambient Emissions in the 1010-1060 MHz Frequency Band at the Port of Baltimore.

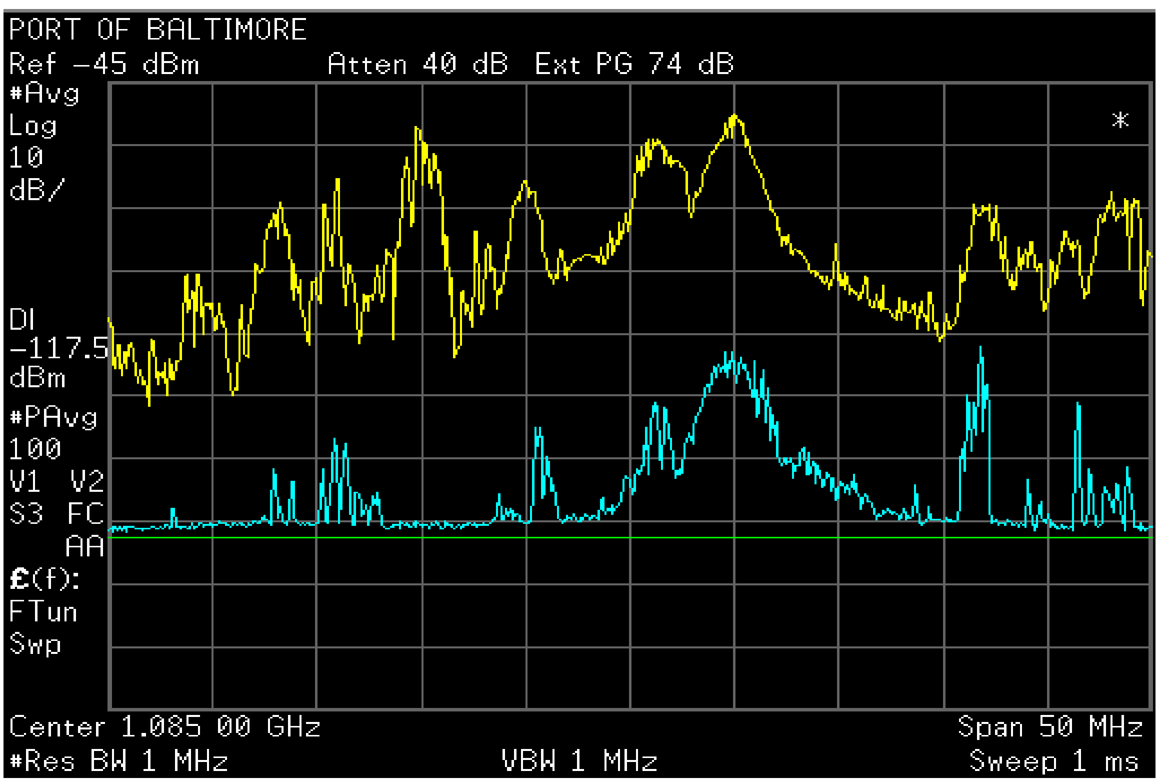


Figure C-41. Ambient Emissions in the 1060-1110 MHz Frequency Band at the Port of Baltimore.

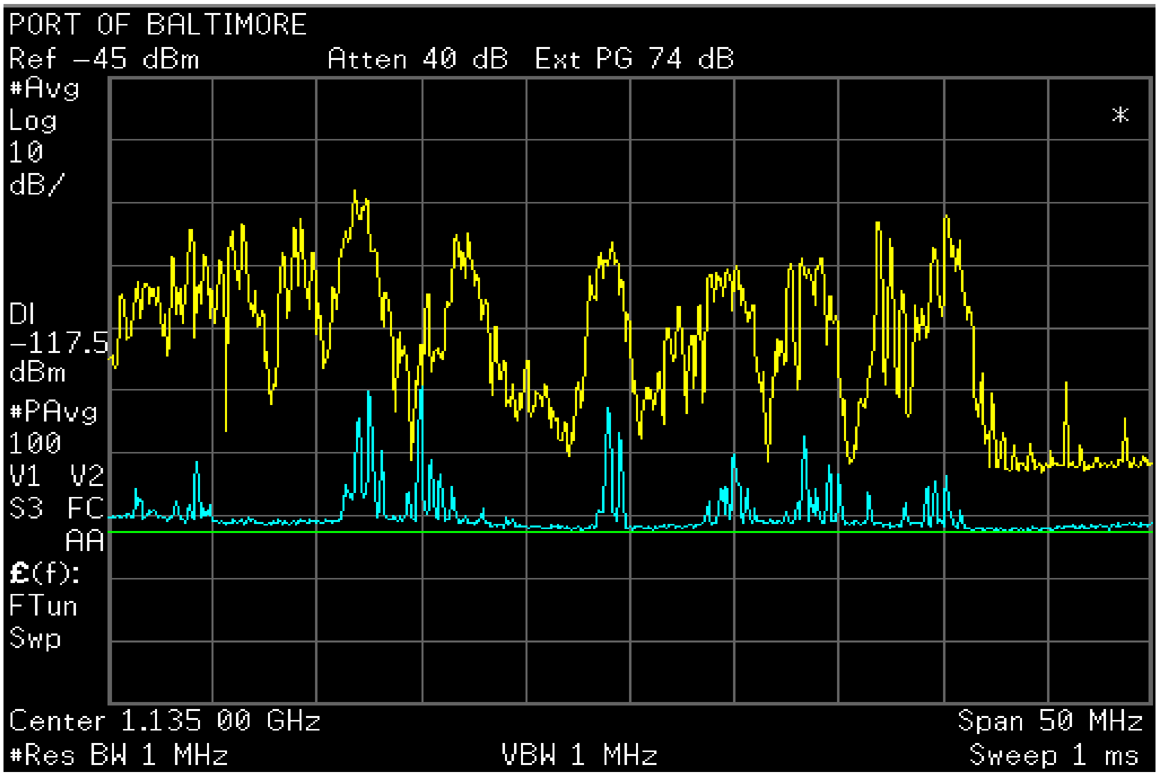


Figure C-42. Ambient Emissions in the 1110-1160 MHz Frequency Band at the Port of Baltimore.

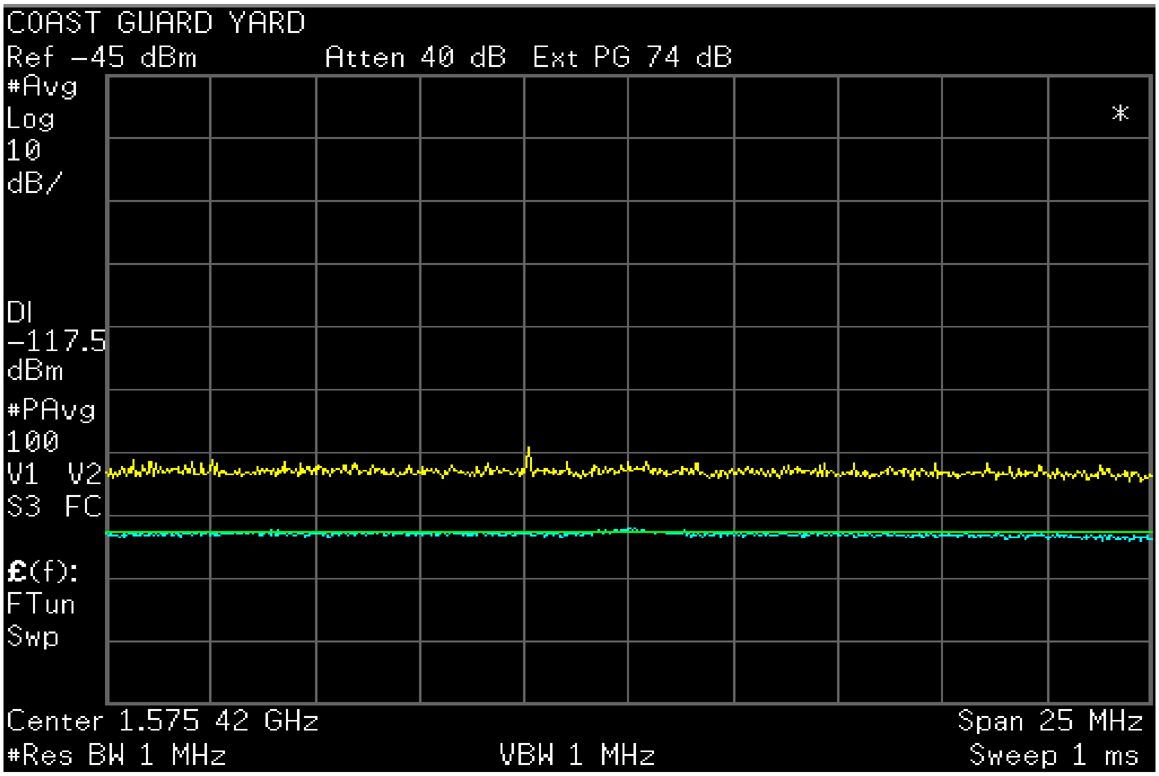


Figure C-43. Ambient Emissions in the GPS L1 Frequency Band at the U.S. Coast Guard Yard.

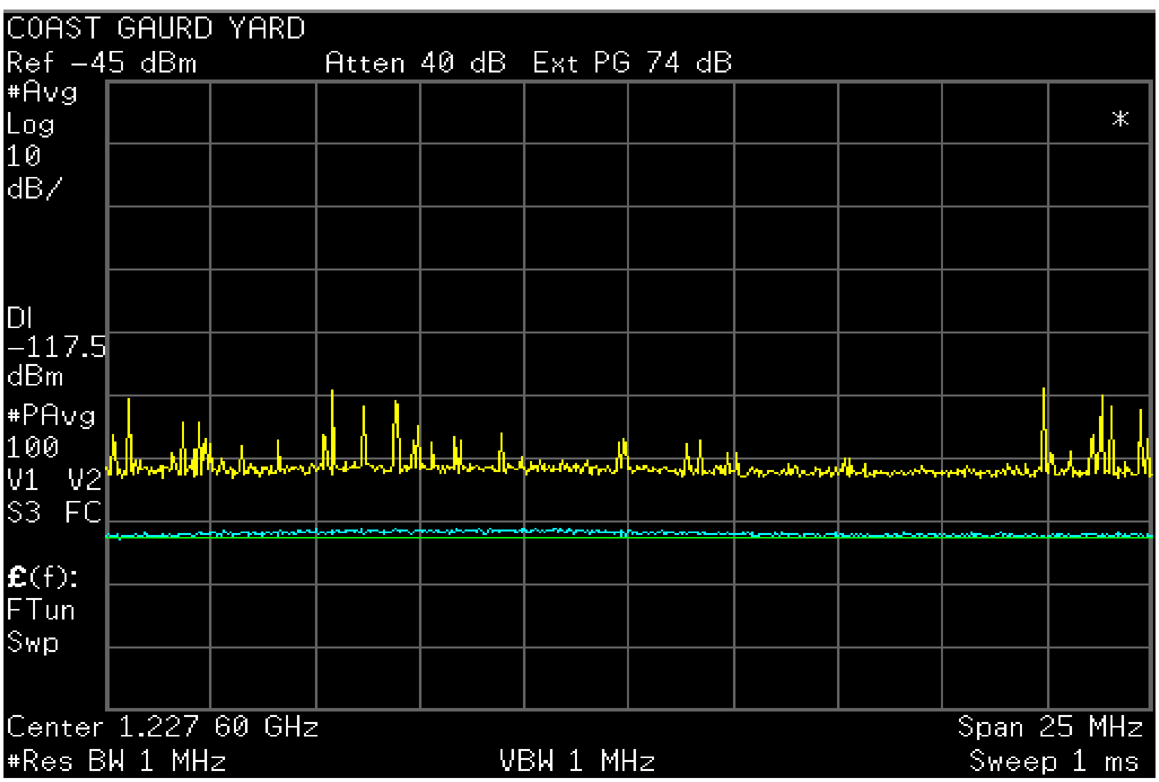


Figure C-44. Ambient Emissions in the GPS L2 Frequency Band at the U.S. Coast Guard Yard.

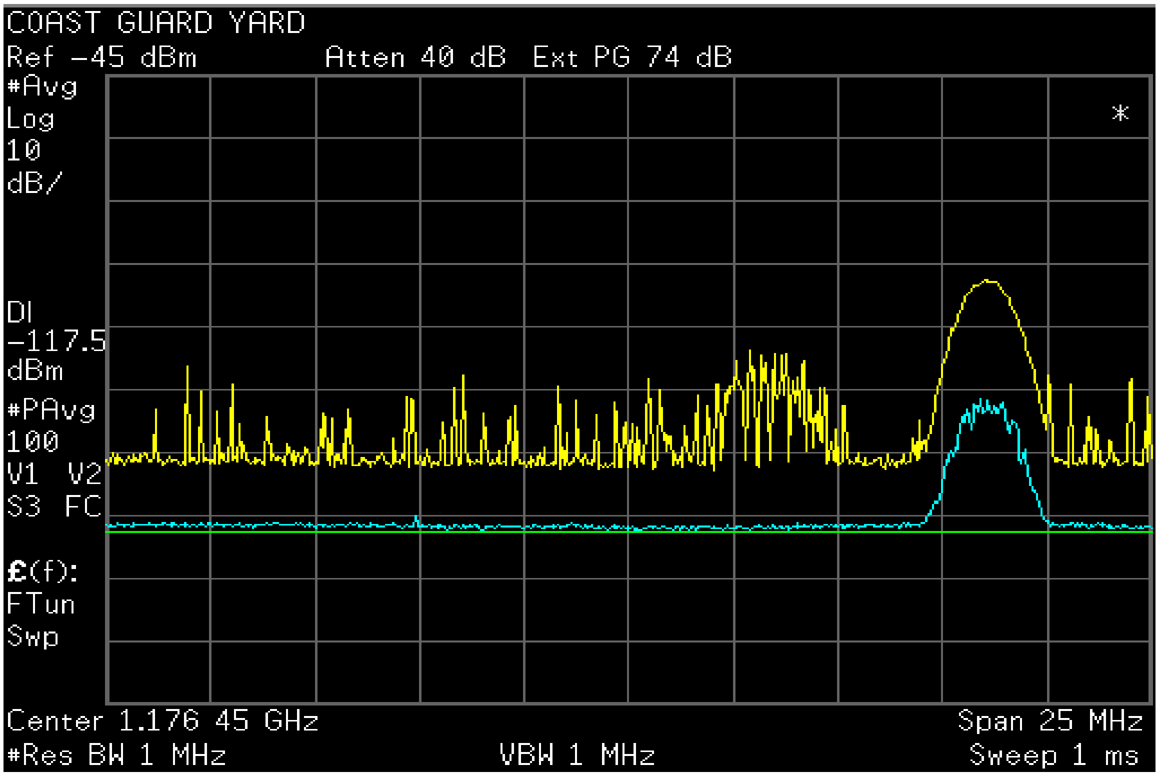


Figure C-45. Ambient Emissions in the GPS L5 Frequency Band at the U.S. Coast Guard Yard.

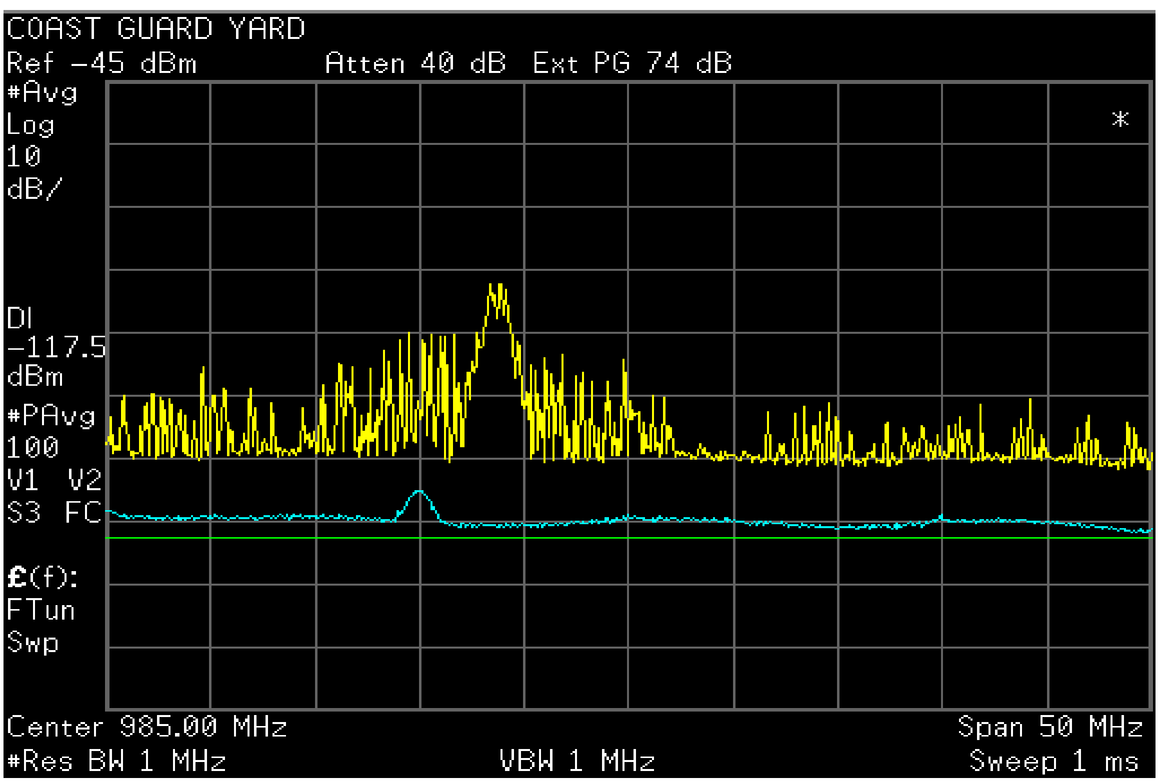


Figure C-46. Ambient Emissions in the 960-1010 MHz Frequency Band at the Coast Guard Yard.

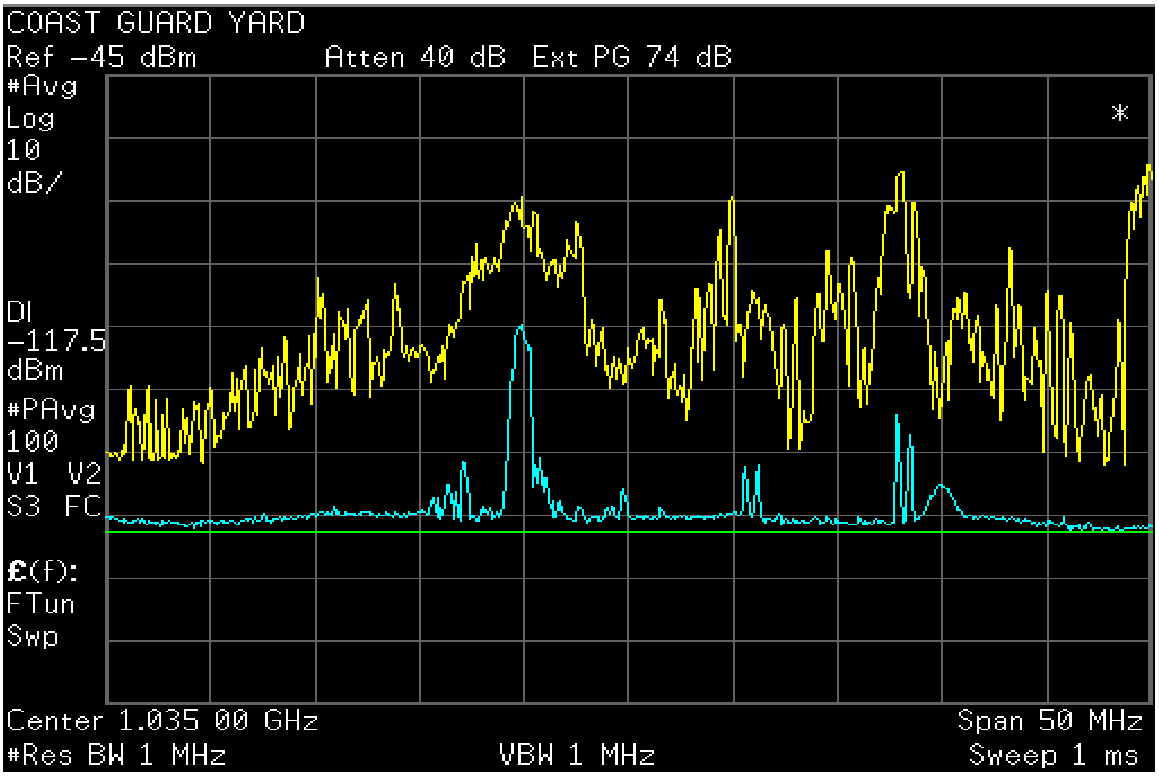


Figure C-47. Ambient Emissions in the 1010-1060 MHz Frequency Band at the Coast Guard Yard.

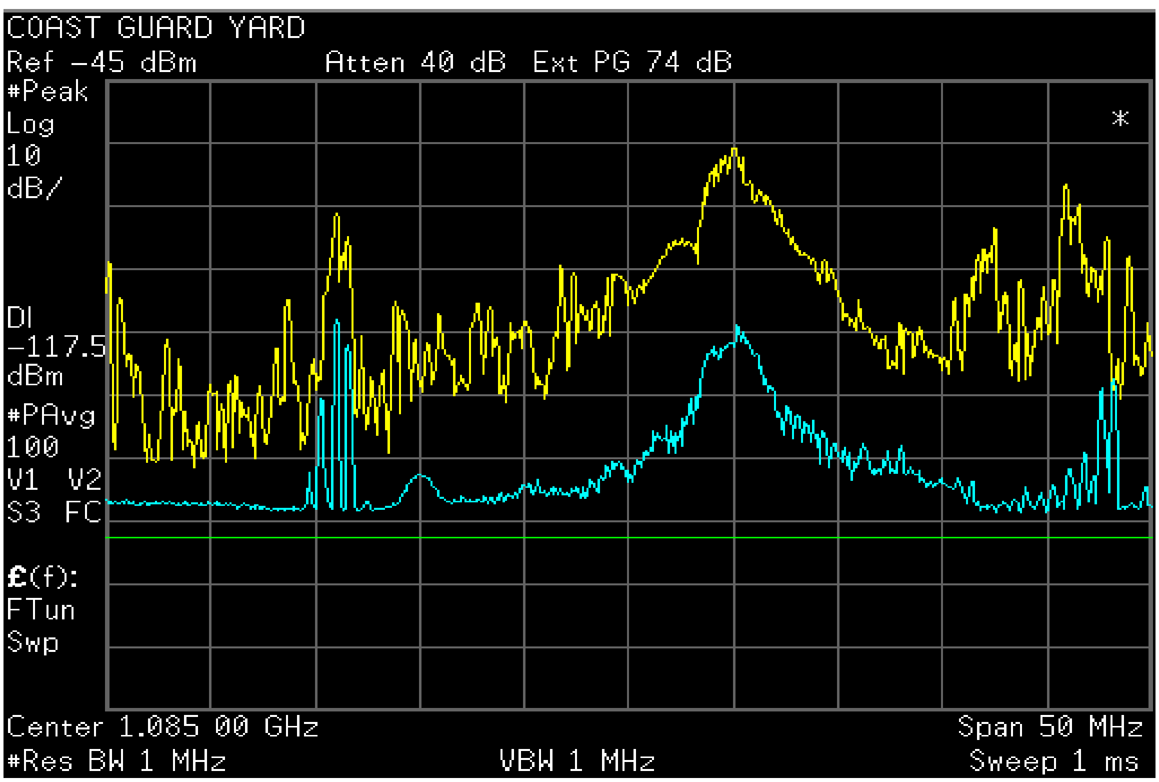


Figure C-48. Ambient Emissions in the 1060-1110 MHz Frequency Band at the Coast Guard Yard.

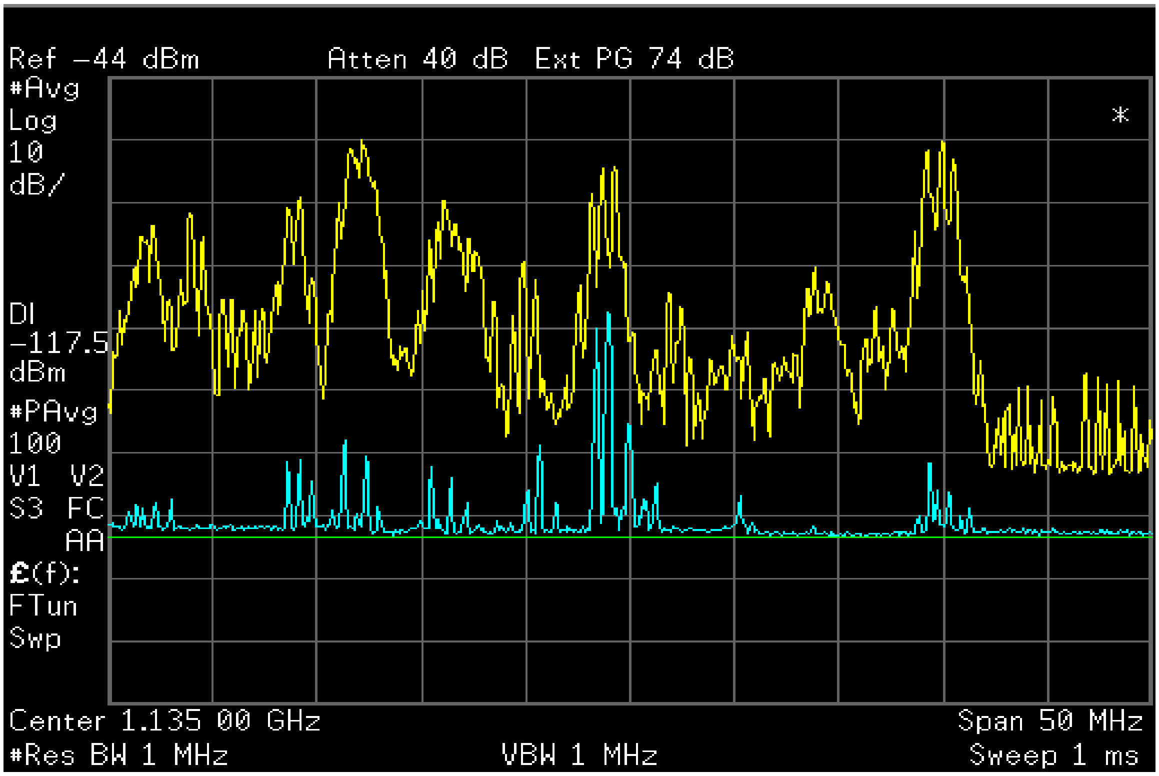


Figure C-49. Ambient Emissions in the 1110-1160 MHz Frequency Band at the Coast Guard Yard.

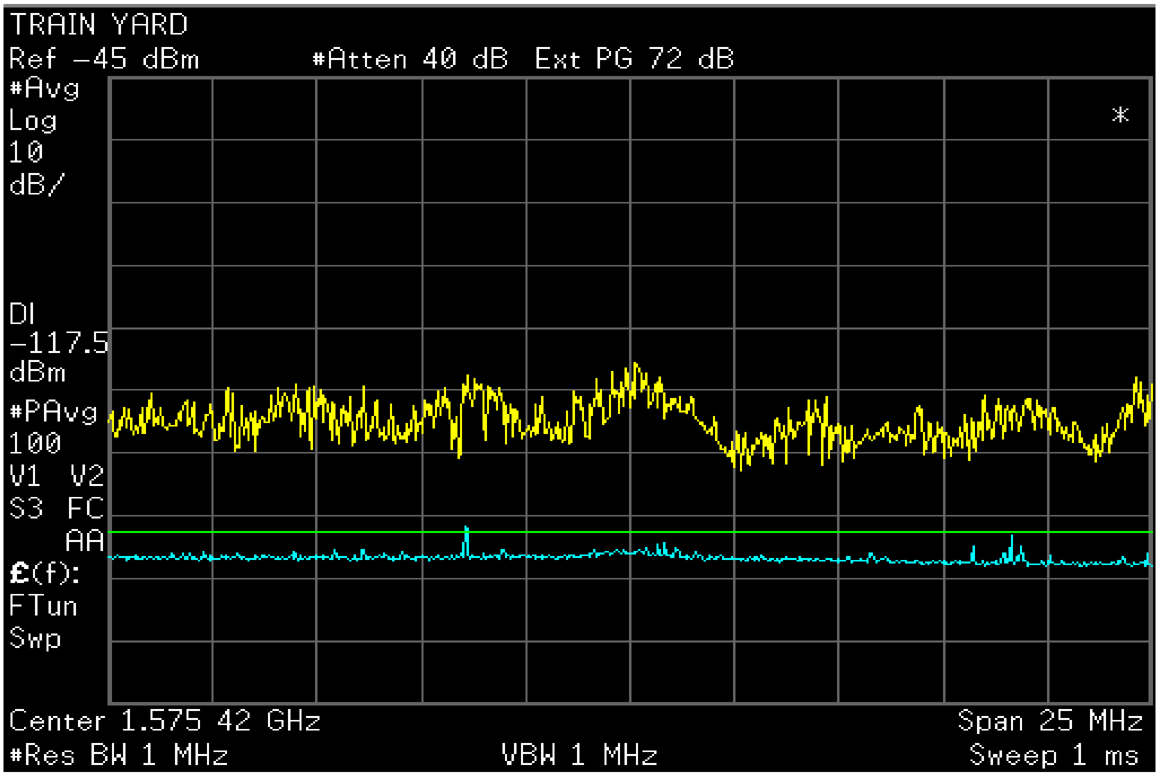


Figure C-50. Ambient Emissions in the GPS L1 Frequency Band at the AMTRAK Train Yard.

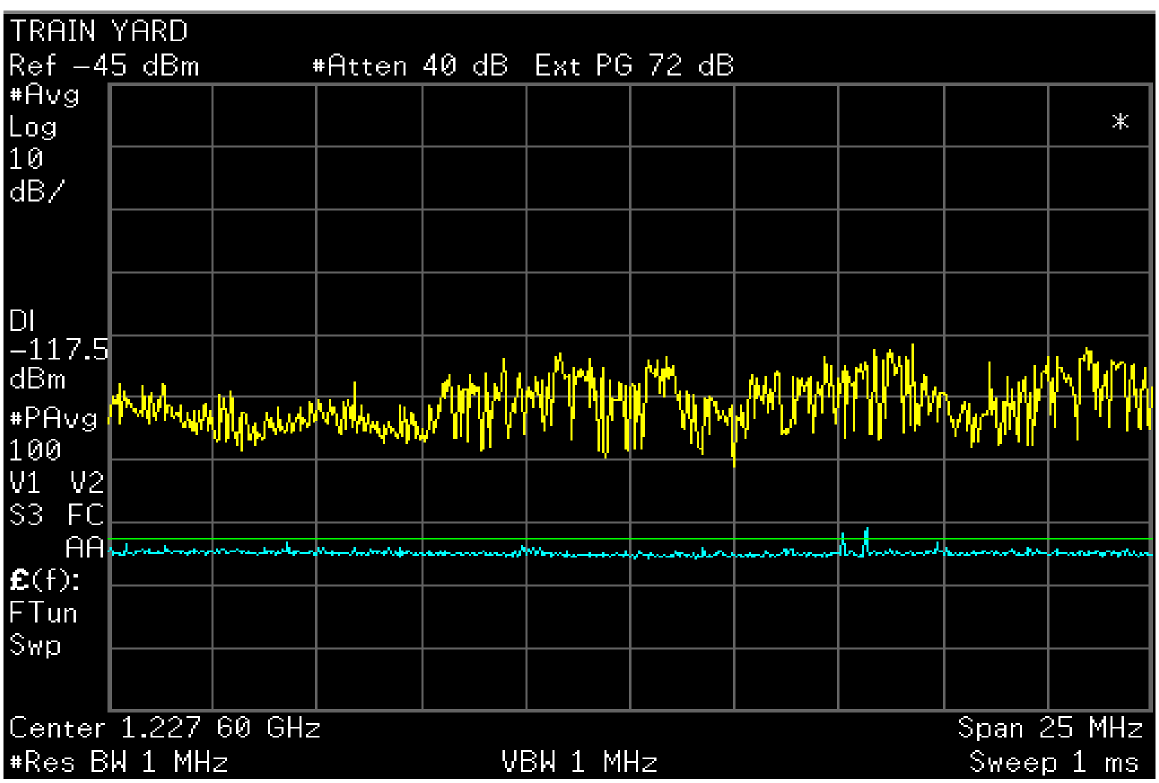


Figure C-51. Ambient Emissions in the GPS L2 Frequency Band at the AMTRAK Train Yard.

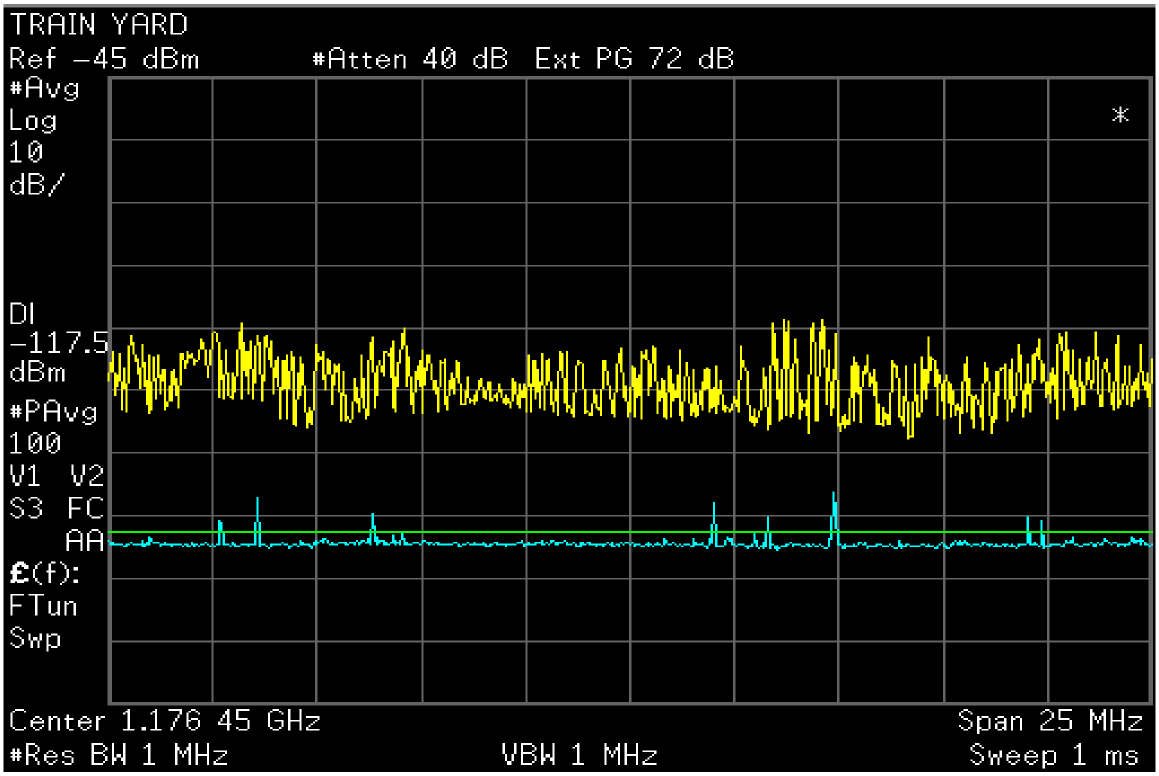


Figure C-52. Ambient Emissions in the GPS L5 Frequency Band at the AMTRAK Train Yard.

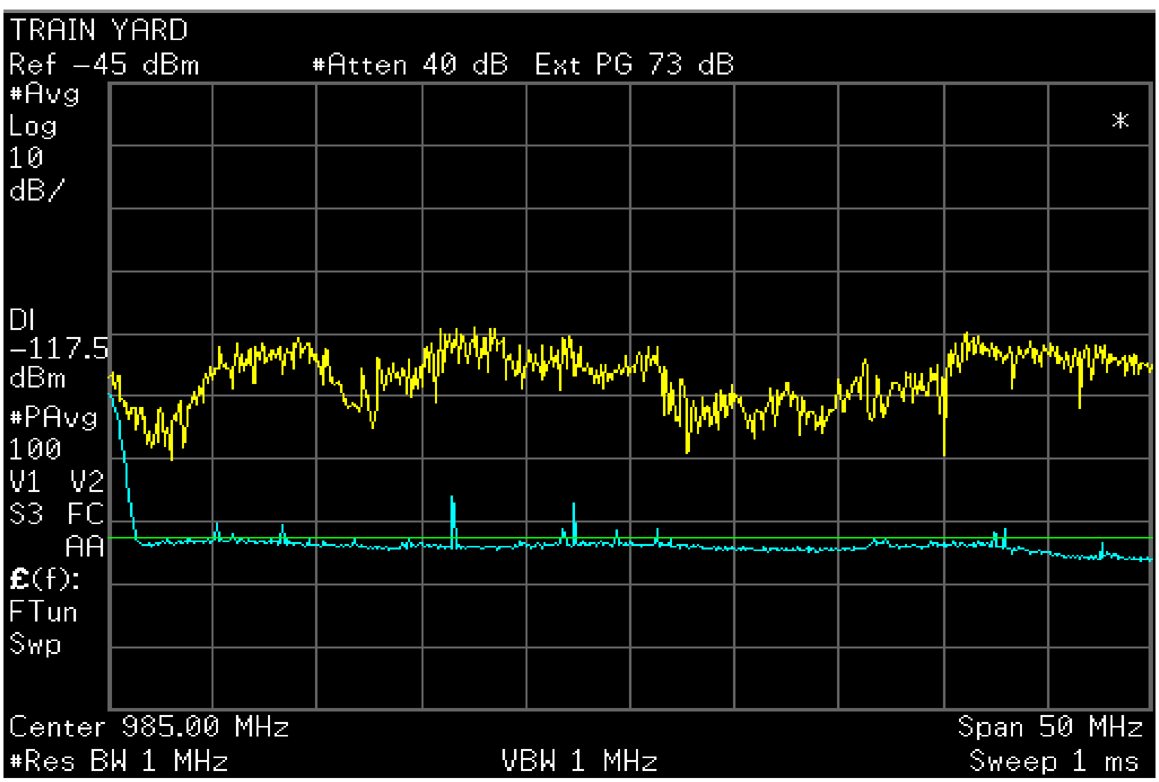


Figure C-53. Ambient Emissions in the 960-1010 MHz Frequency Band at the Train Yard.

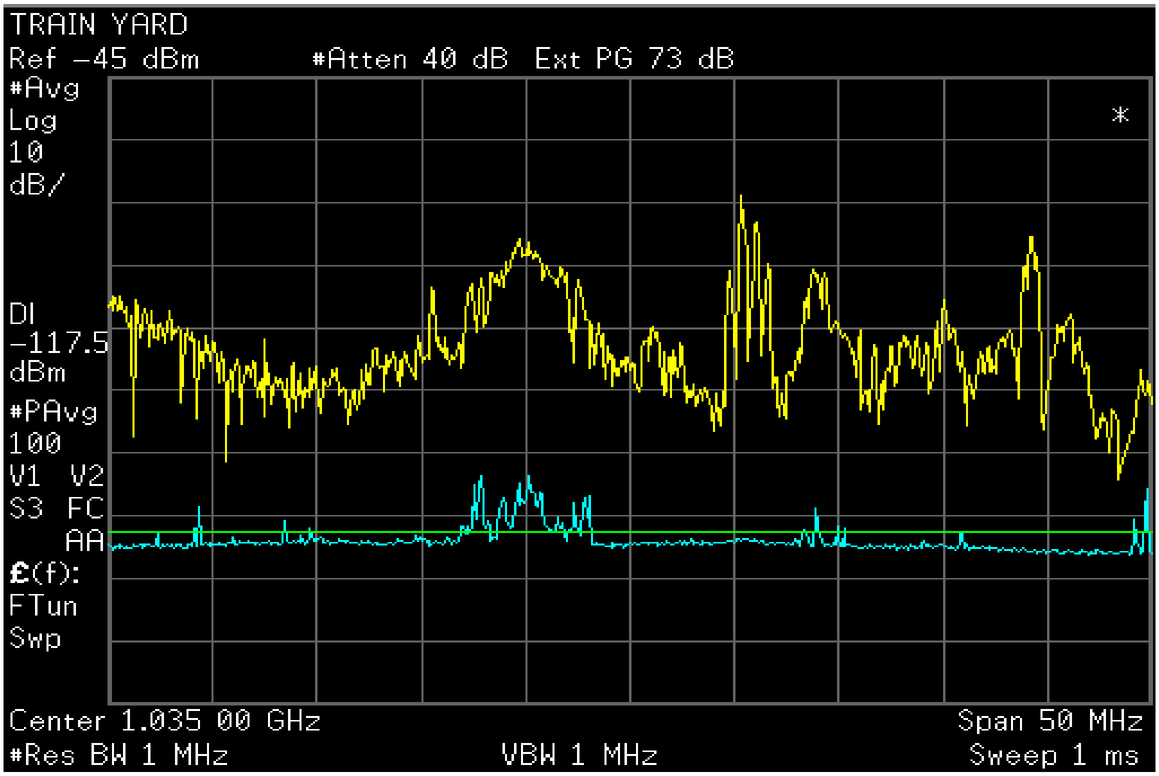


Figure C-54. Ambient Emissions in the 1010-1060 MHz Frequency Band at the Train Yard.

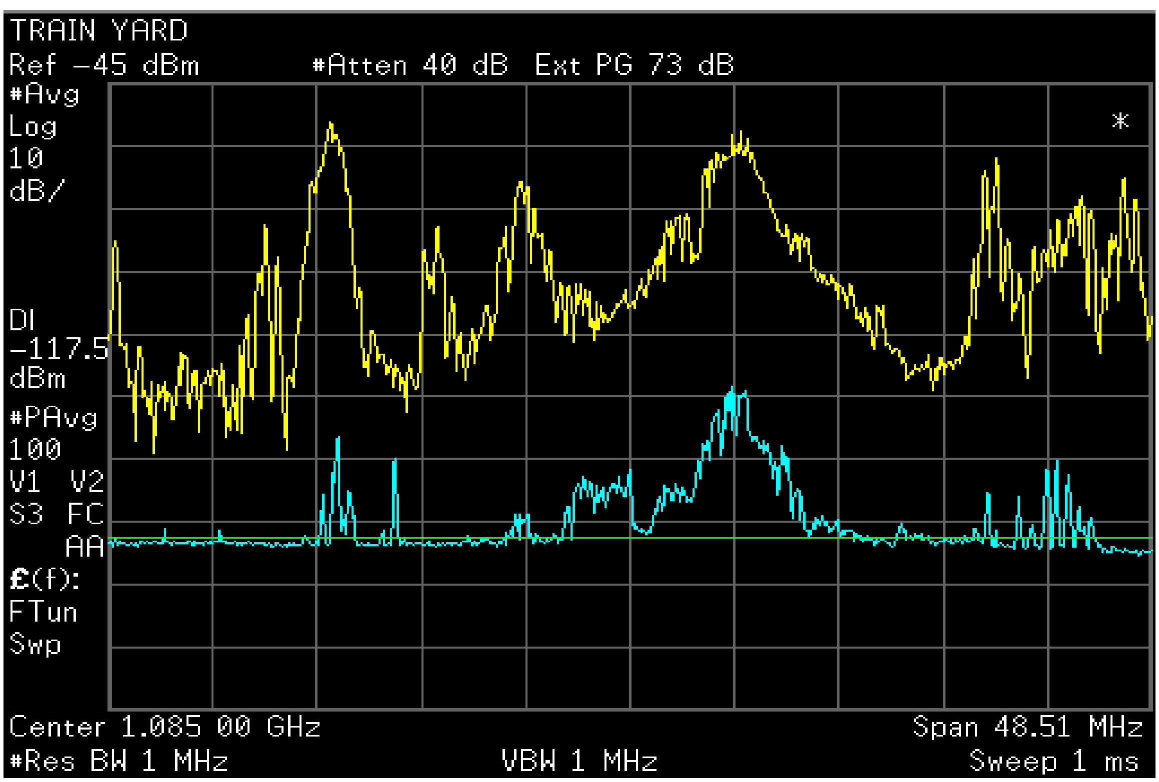


Figure C-55. Ambient Emissions in the 1060-1110 MHz Frequency Band at the Train Yard.

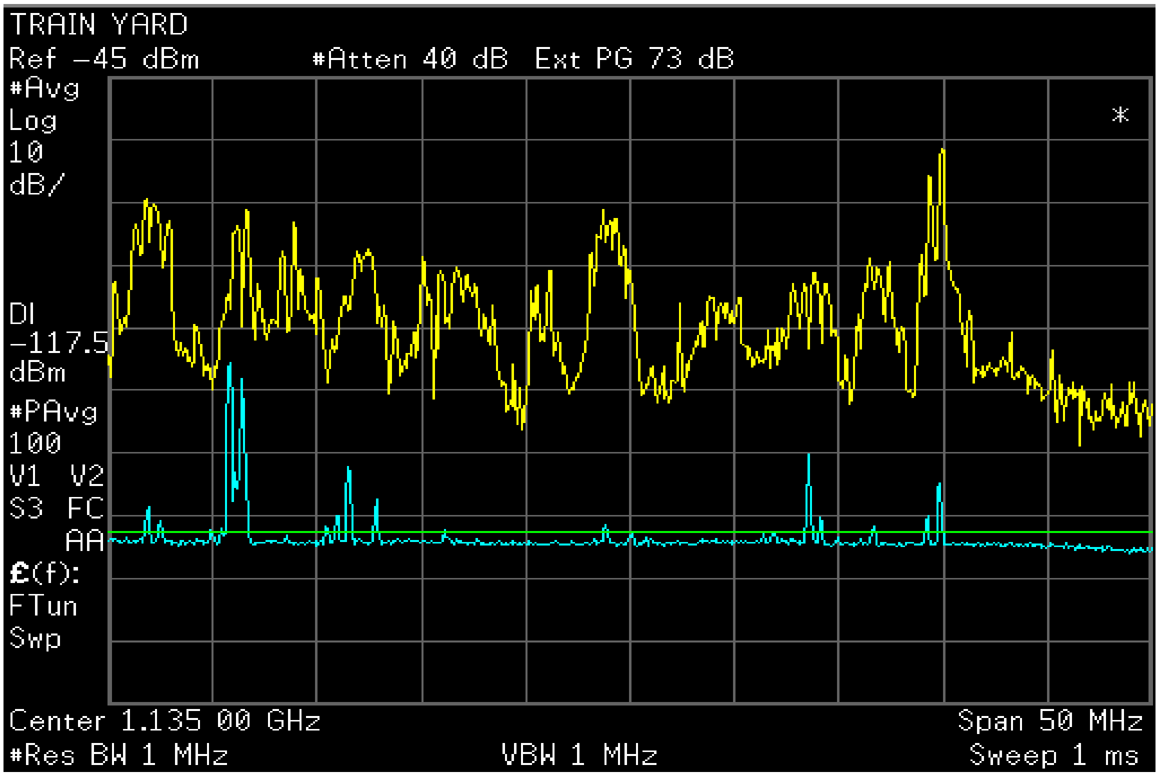


Figure C-56. Ambient Emissions in the 1110-1160 MHz Frequency Band at the Train Yard.

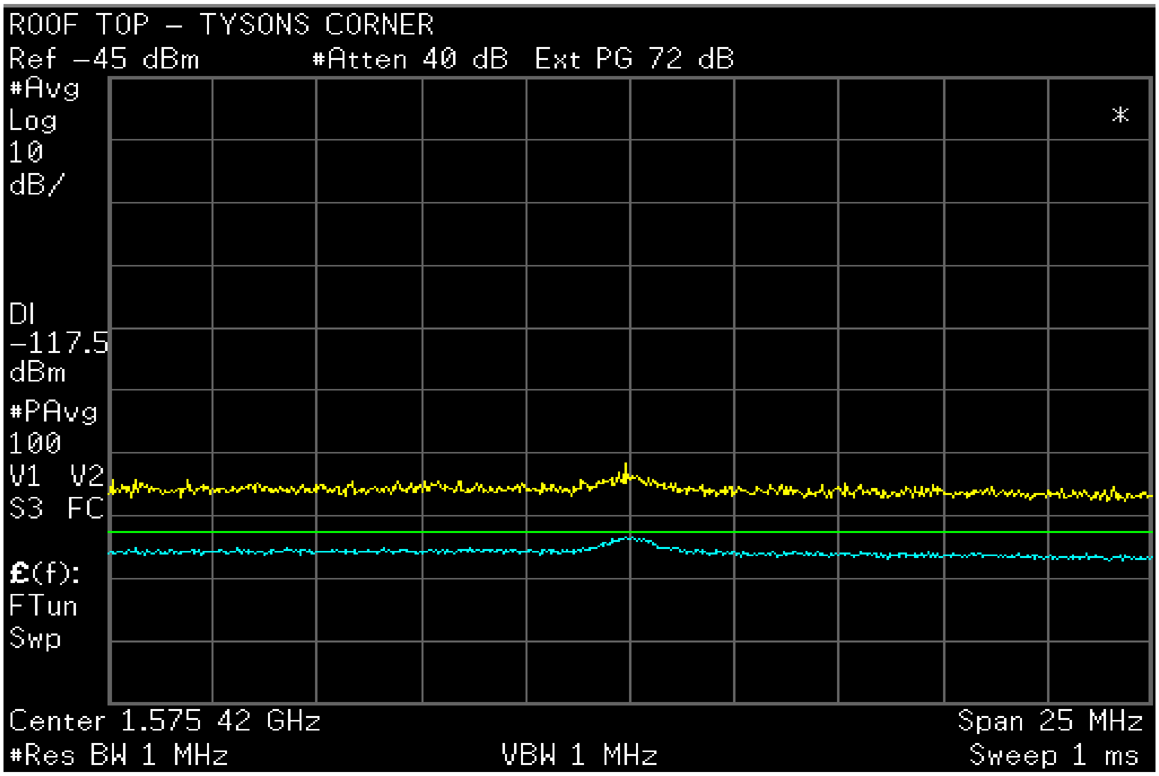


Figure C-57. Ambient Emissions in the GPS L1 Frequency Band at Urban/Industrial Site.

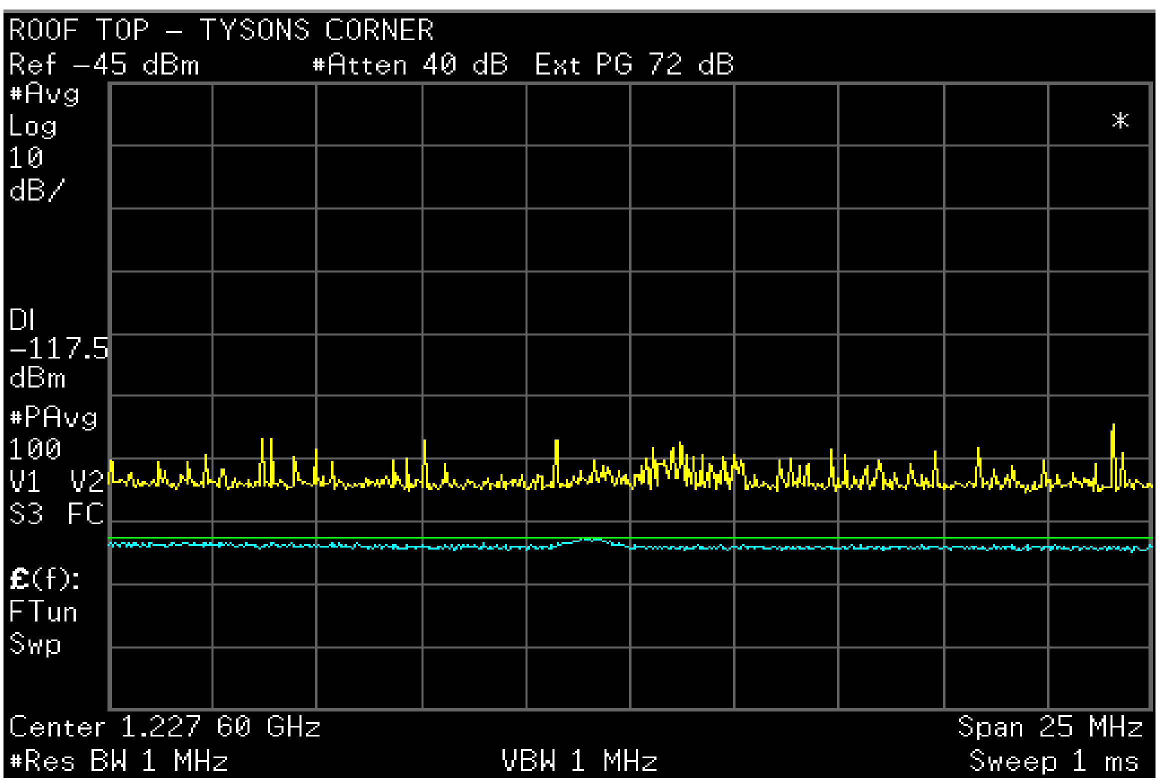


Figure C-58. Ambient Emissions in the GPS L2 Frequency Band at Urban/Industrial Site.

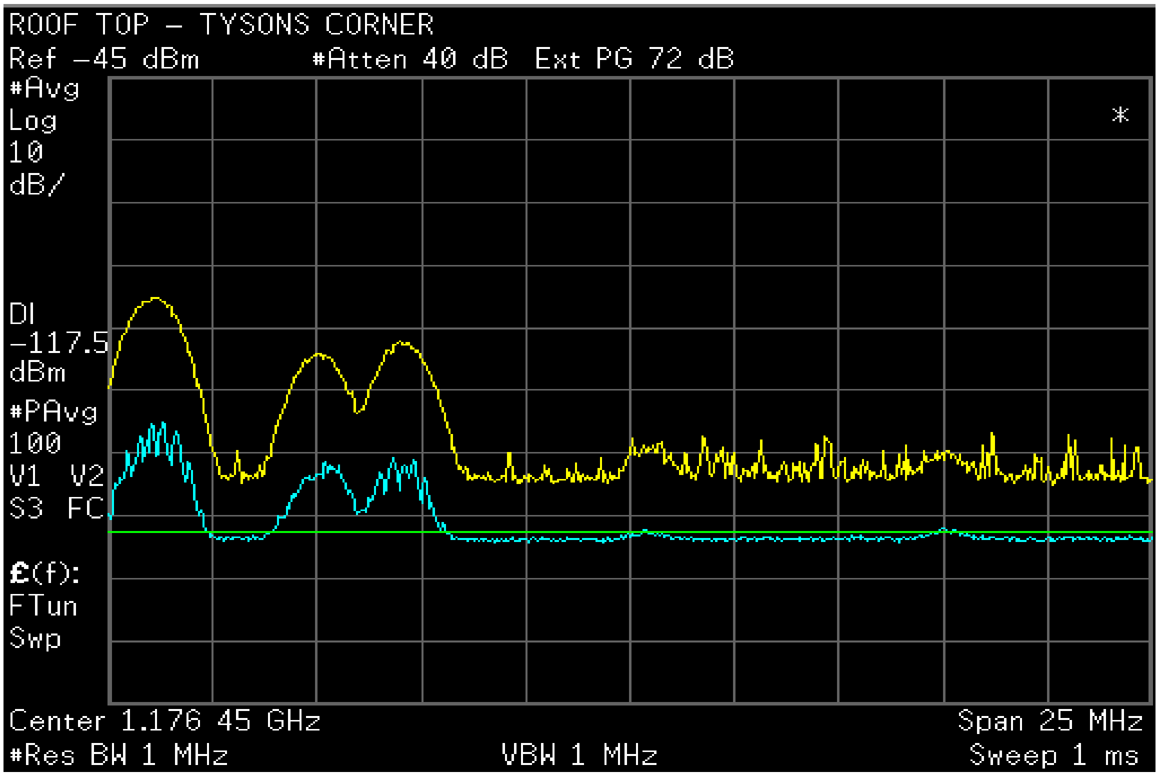


Figure C-59. Ambient Emissions in the GPS L5 Frequency Band at Urban/Industrial Site.

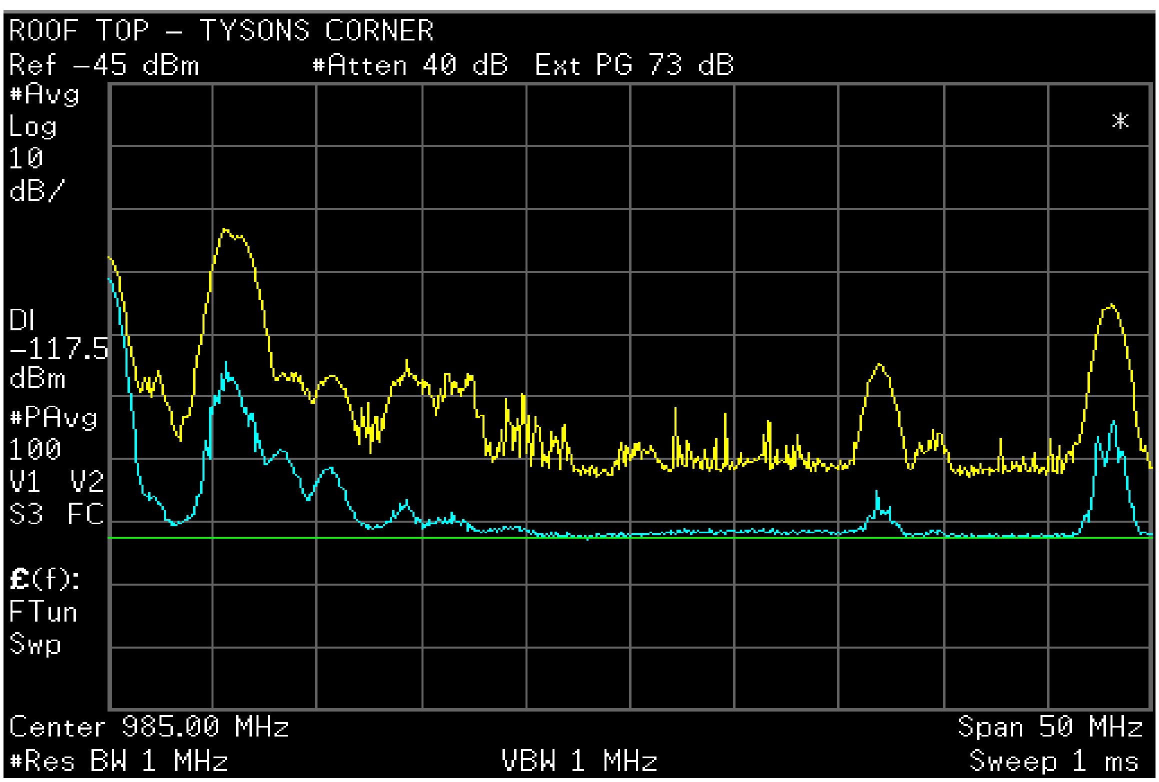


Figure C-60. Ambient Emissions in the 960-1010 MHz Frequency Band at Urban/Industrial Site.

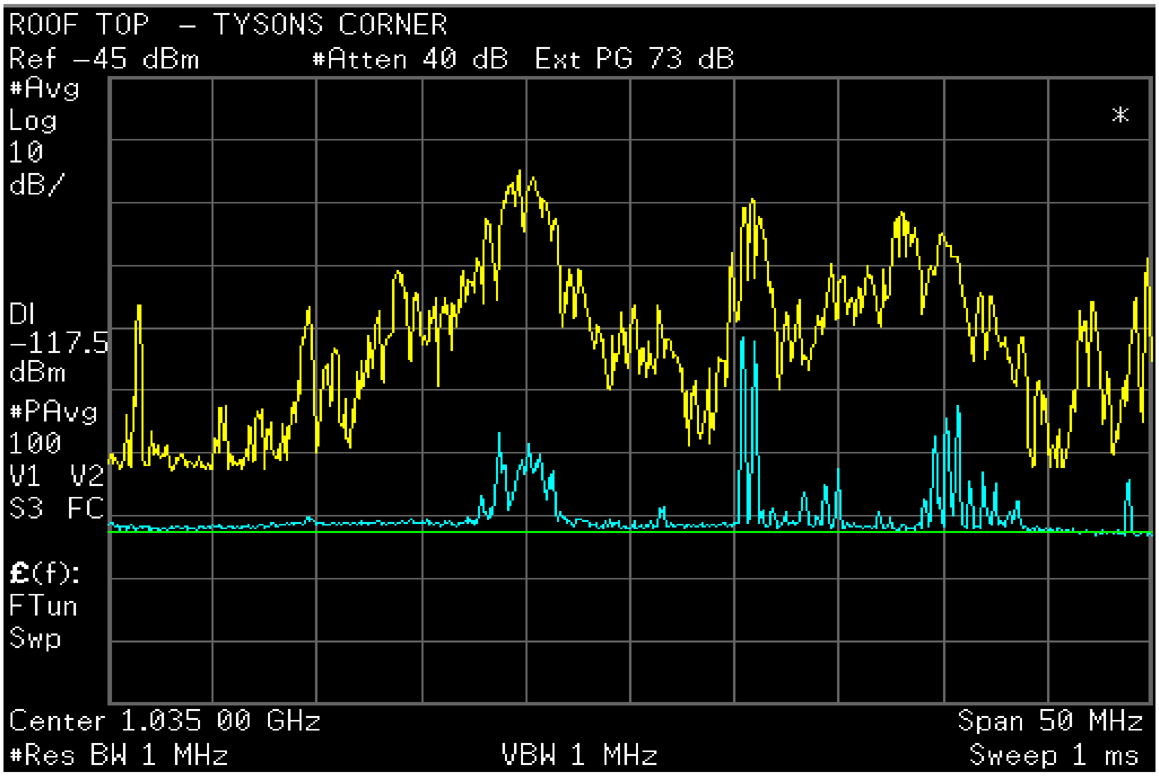


Figure C-61. Ambient Emissions in the 1010-1060 MHz Frequency Band at Urban/Industrial Site.

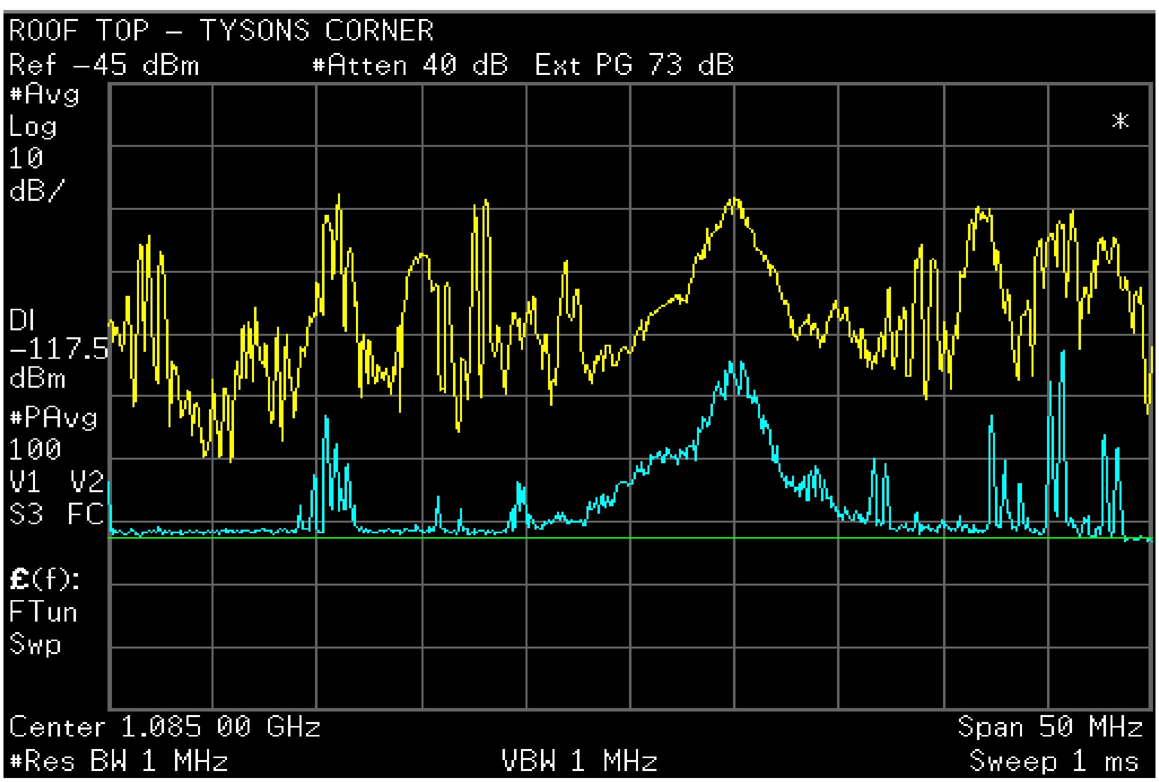


Figure C-62. Ambient Emissions in the 1060-1110 MHz Frequency Band at Urban/Industrial Site.

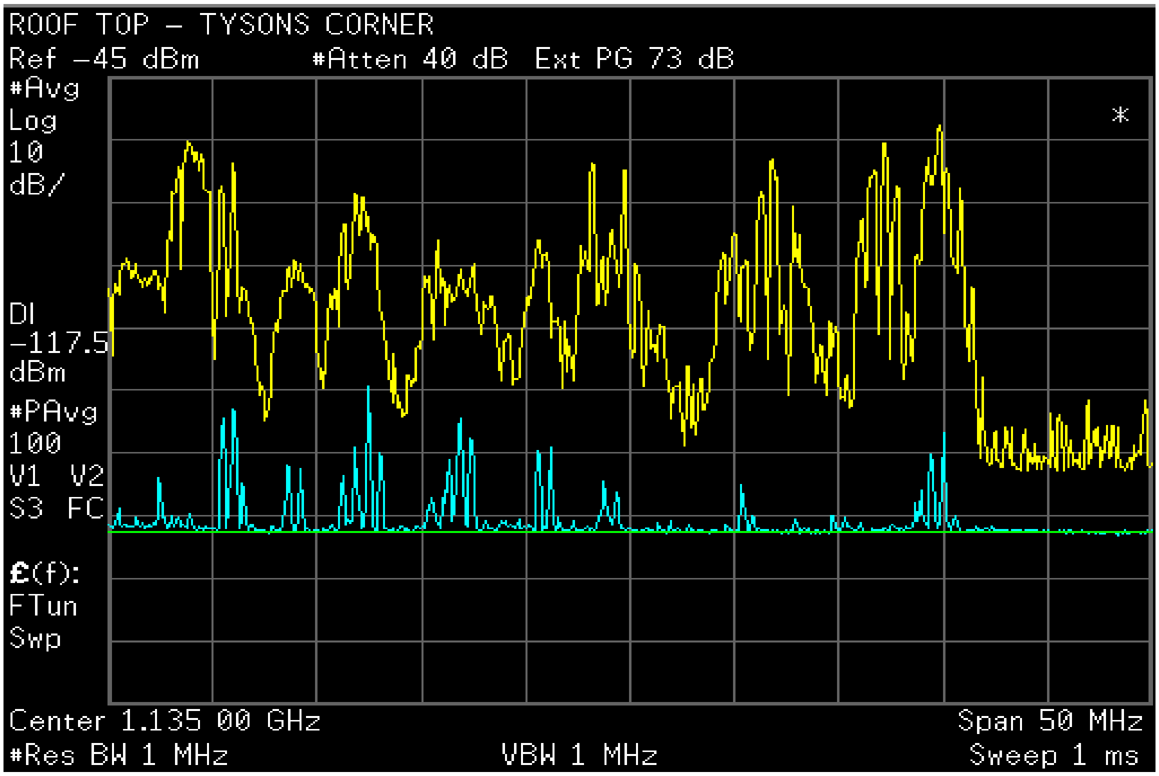


Figure C-63. Ambient Emissions in the 1110-1160 MHz Frequency Band at Urban/Industrial Site.

APPENDIX D
INDOOR AMBIENT EMISSIONS MEASUREMENT DATA

The data plots recorded from the measurement of existing ambient emissions at indoor sites such as office buildings and factory facilities are presented in this appendix. The following paragraphs provide guidance on reading and interpreting these plots.

In each of the figures presented in this appendix, the upper (yellow) trace depicts the ambient emissions measured in the subject frequency band using a peak detector and the maximum hold function (i.e., no averaging employed) over a fifteen-minute period. This trace was generated mainly as a tool for orienting the measurement antenna and for determining the maximum likely emission amplitudes to facilitate decisions pertaining to the necessity of adding additional attenuation in the measurement system so as to prevent overdriving of components. This data was not used for any analytical purposes. The lower (blue) trace represents the measured RMS average emission level over one hundred one-millisecond analyzer sweeps across the measurement band. This is the data used to compare to the assumed interference threshold for enhanced GPS receivers. The constant display line (green) at -117.5 dBm is used as the basis for comparing the measured data to the theoretical enhanced GPS interference threshold.

All external measurement system parameters (e.g., amplifier gains, cable loss, and antenna gain) are accounted for in the spectrum analyzer display and are provided on each plot under the tag Ext PG located at the top of the display. At some measurement locations, it was necessary to add additional attenuation in the measurement system due to the presence of relatively high-amplitude signals. In those cases where additional external attenuation was required, the Ext PG value was adjusted accordingly. Thus, the levels shown on the amplitude axis of the spectrum analyzer plots represent the actual RMS average power as measured in a 1 MHz bandwidth at the measurement system antenna.

In each of these plots, the horizontal axis represents frequency and the vertical axis represents amplitude. For measurements in the GPS frequency bands, a span of 25 MHz was used to encompass the 24 MHz registered frequency band. For a 25 MHz span, each vertical graticule line represents a 2.5 MHz deviation in frequency (25 MHz/10 graticule lines). For the measurements performed in the 960-1160 MHz (ARNS) band, a span of 50 MHz was used, the maximum that could be achieved within the pass band of the pre-select filter. In these plots, each vertical graticule line represents a frequency deviation of 5 MHz (50 MHz/10 graticule lines).

On the amplitude axis, each horizontal graticule line represents a 10 dB decrement from the reference level amplitude shown in the upper left-hand corner of the plot.

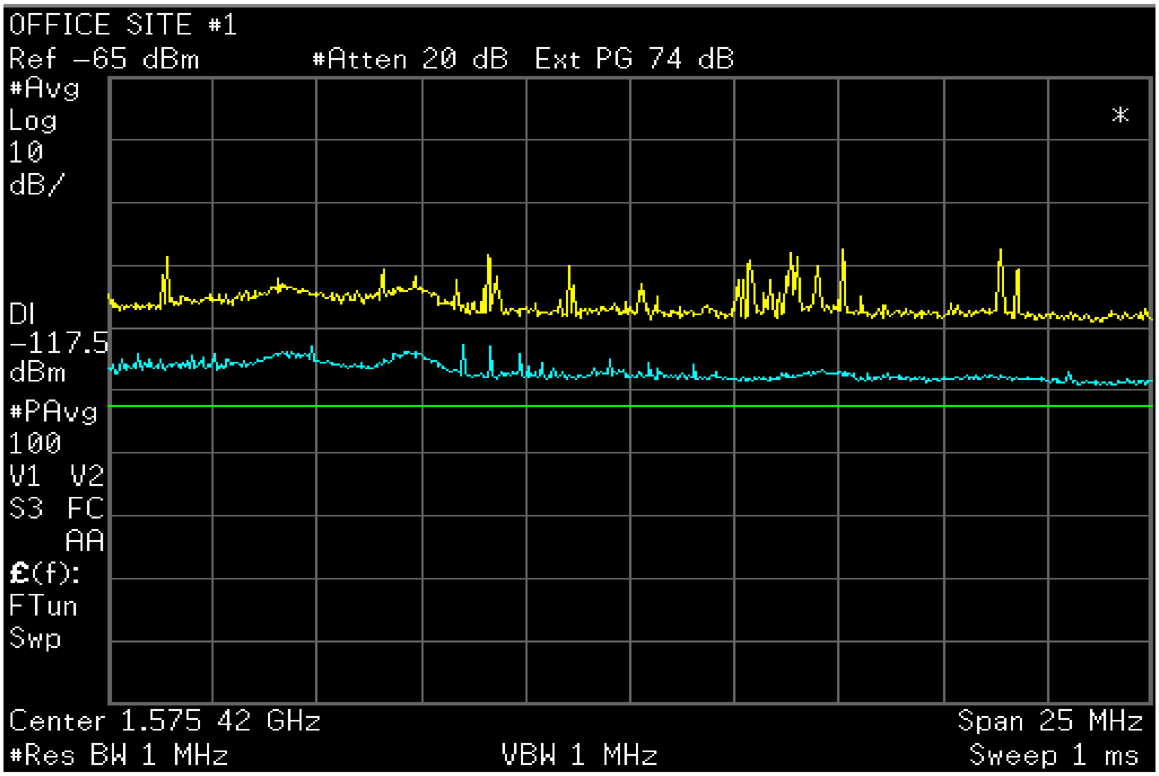


Figure D-64. Ambient Emissions in GPS L1 Frequency Band Office Building #1.

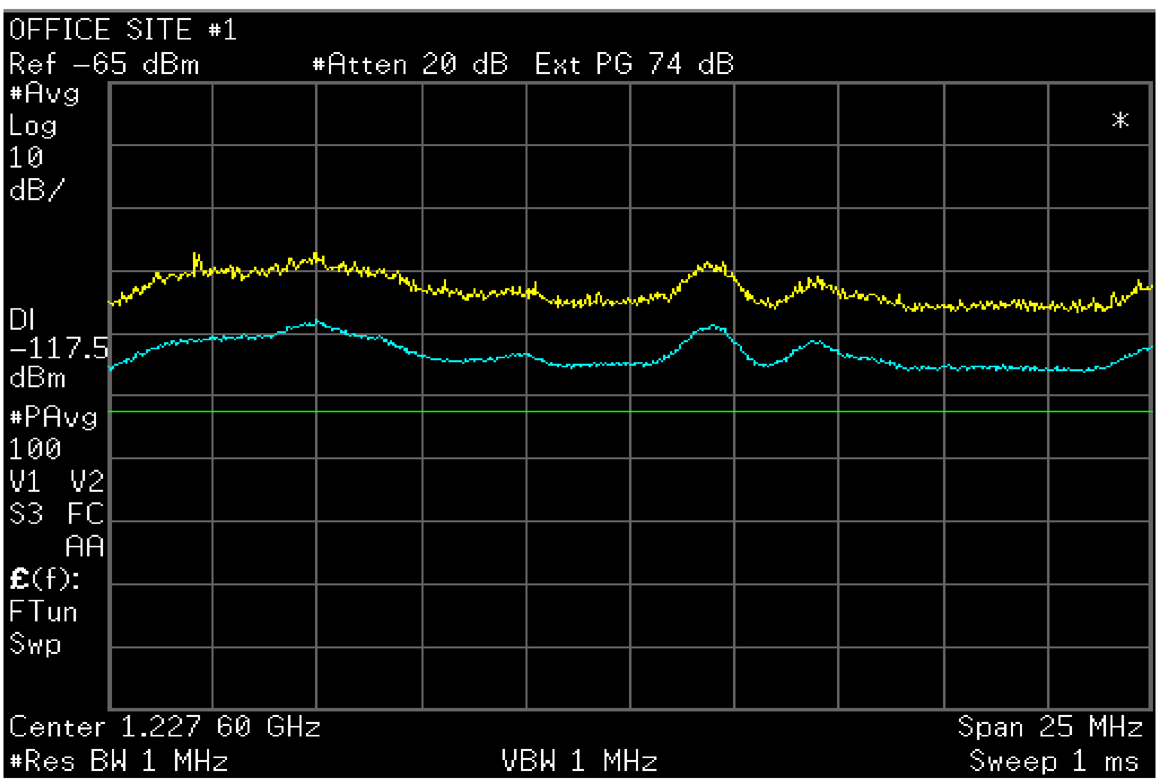


Figure D-65. Ambient Emissions in GPS L2 Frequency Band Office Building #1.

Figure D-66. Ambient Emissions in GPS L5 Frequency Band Office Building #1.

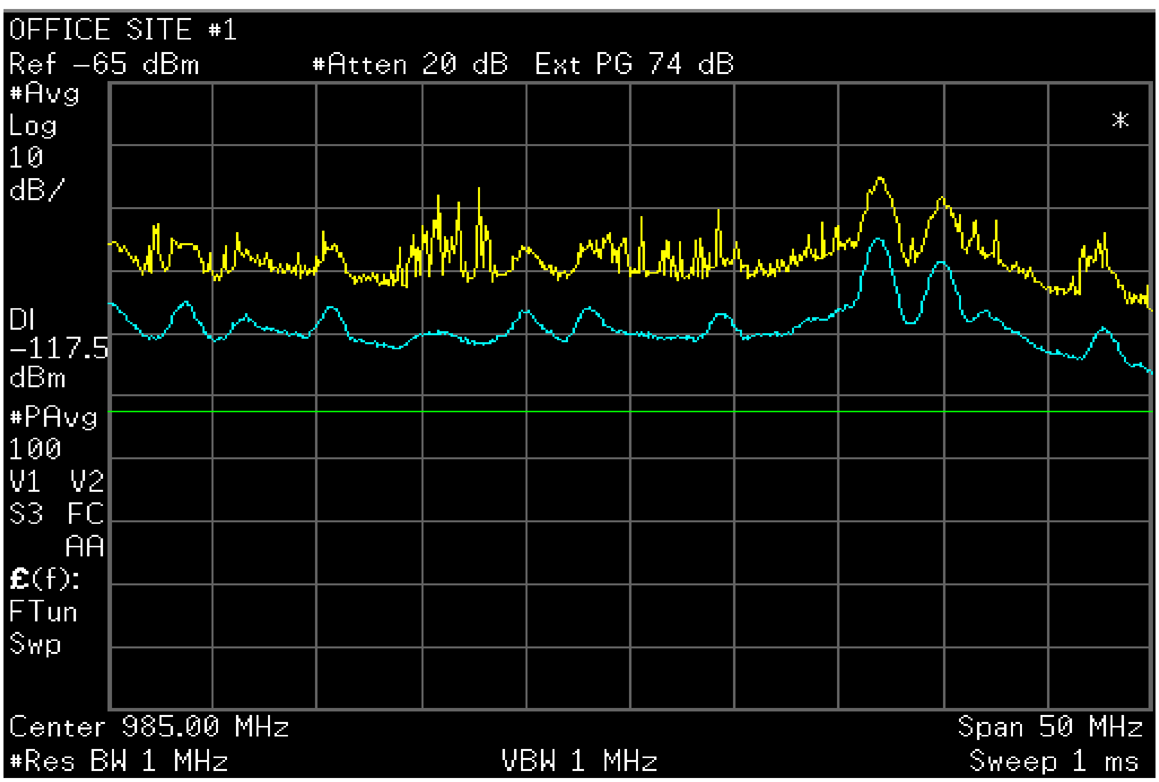


Figure D-67. Ambient Emissions in 960-1010 MHz Frequency Band at Office Building #1.

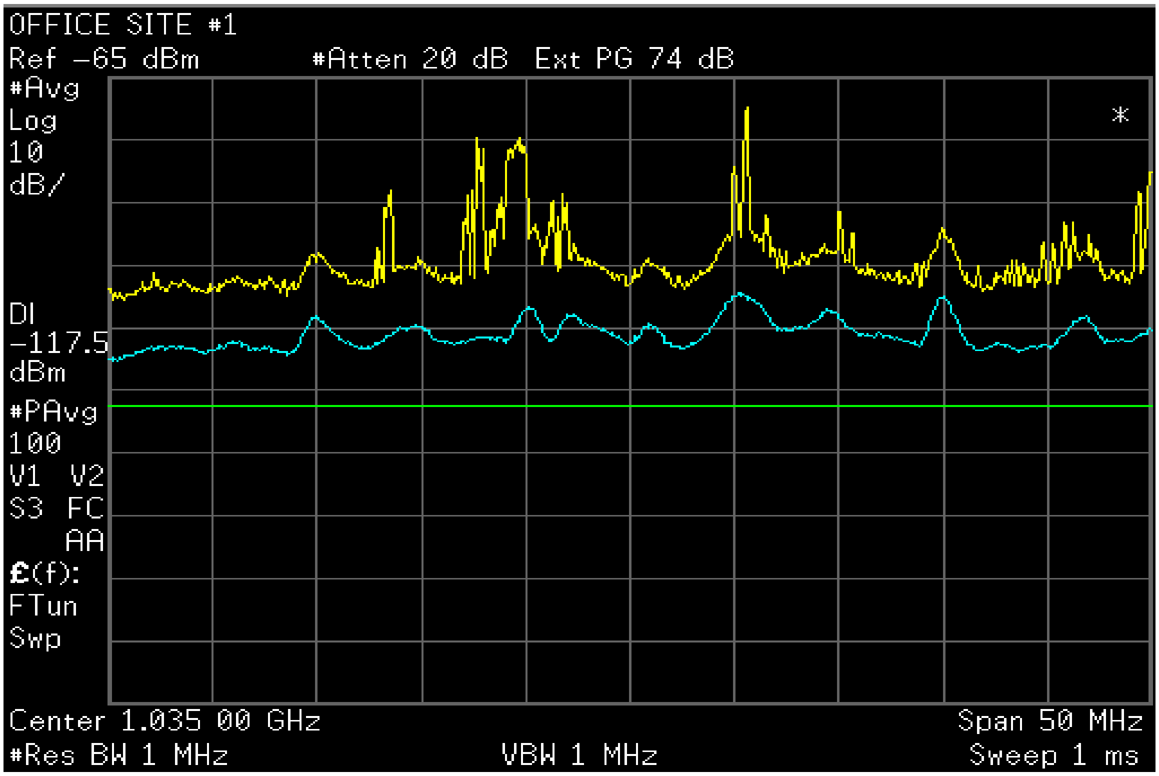


Figure D-68. Ambient Emissions in 1010-1060 MHz Frequency Band at Office Site #1.

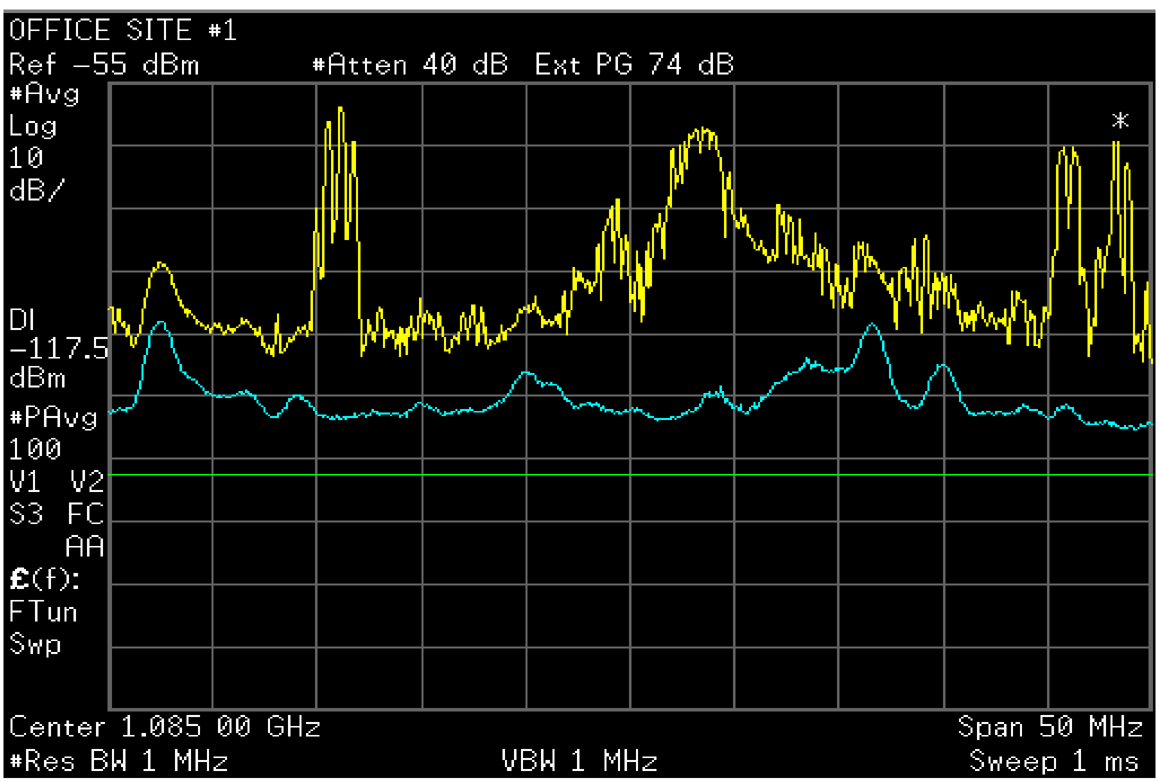


Figure D-69. Ambient Emissions in 1060-1110 MHz Frequency Band at Office Site #1.

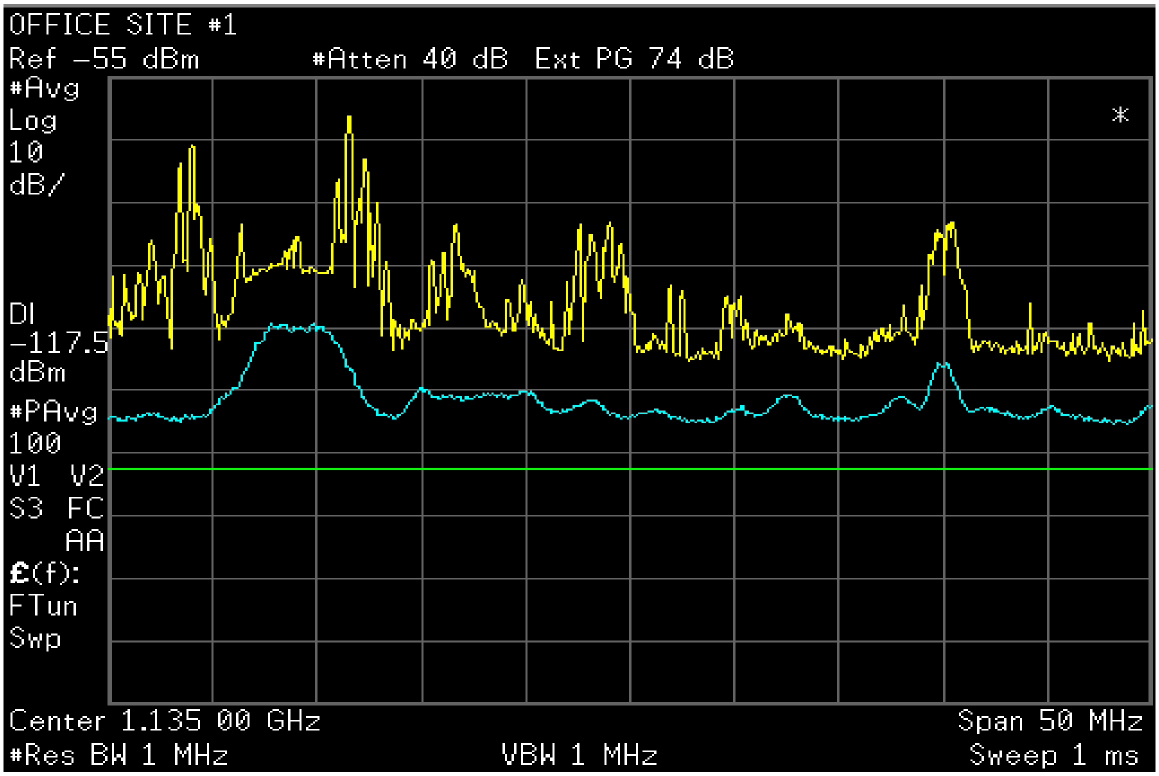


Figure D-70. Ambient Emissions in 1110-1160 MHz Frequency Band at Office Site #1.

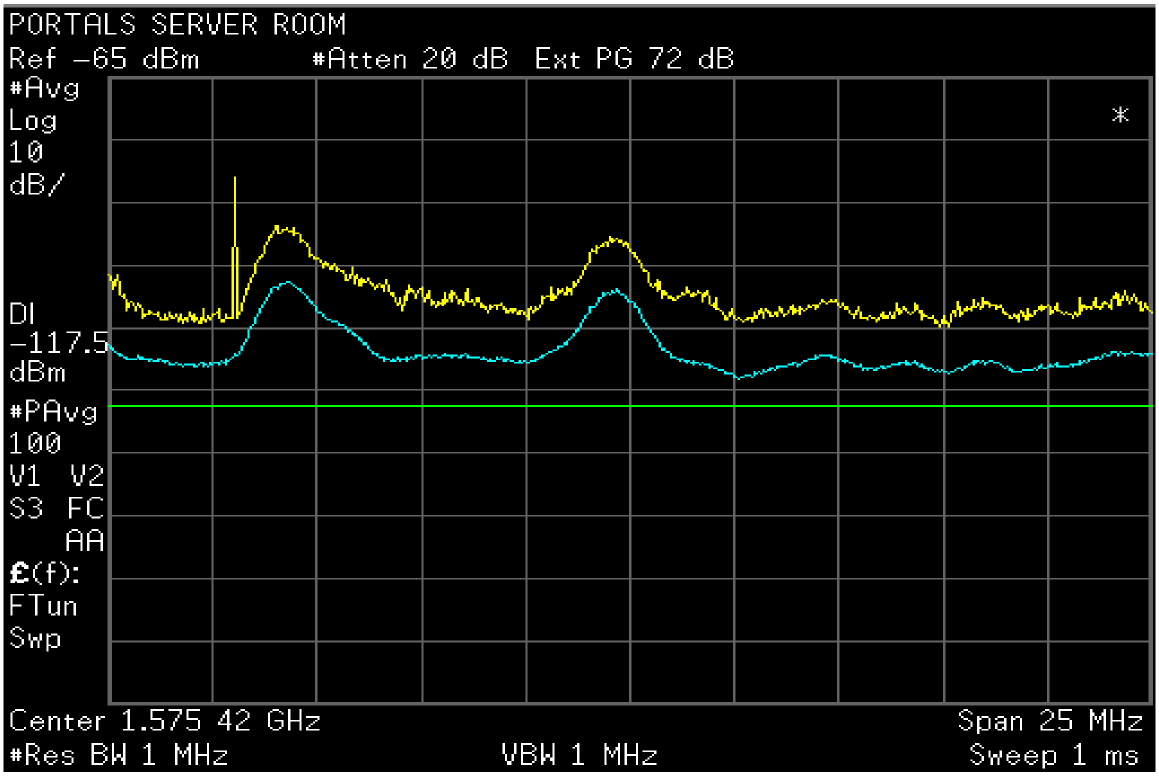


Figure D-71. Ambient Emissions in GPS L1 Frequency Band at Office Site #2.

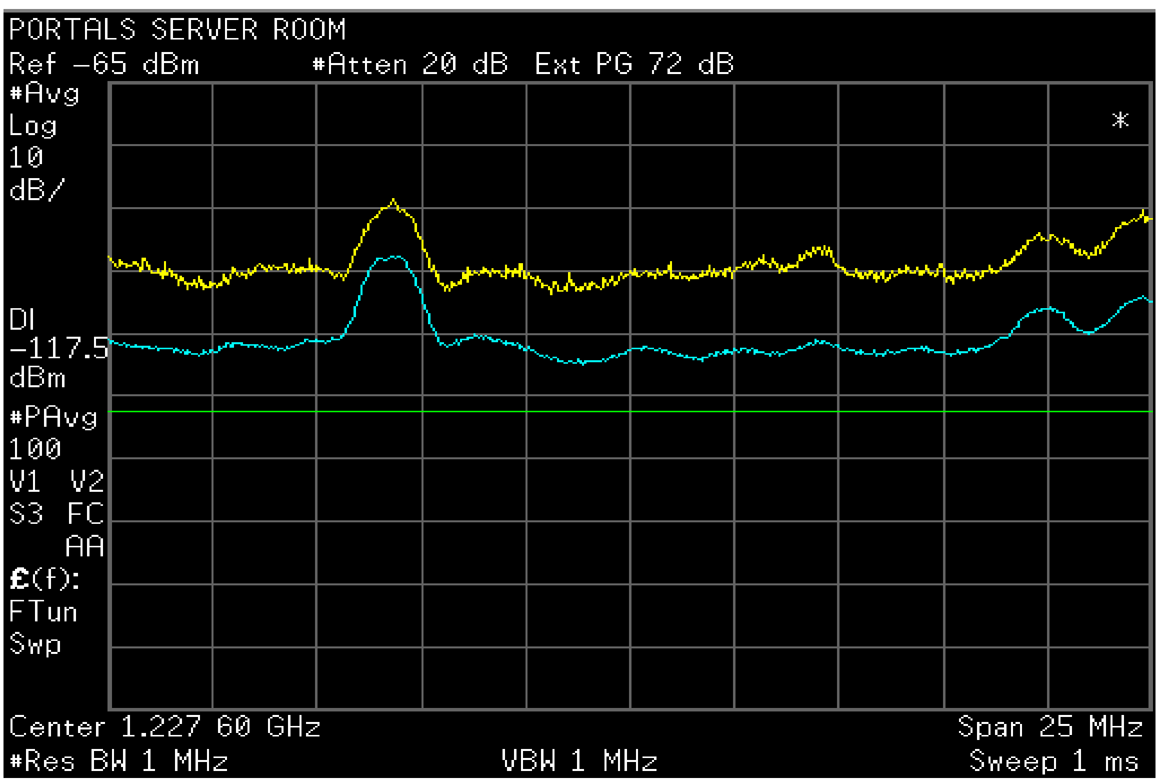


Figure D-72. Ambient Emissions in GPS L2 Frequency Band at Office Site #2.

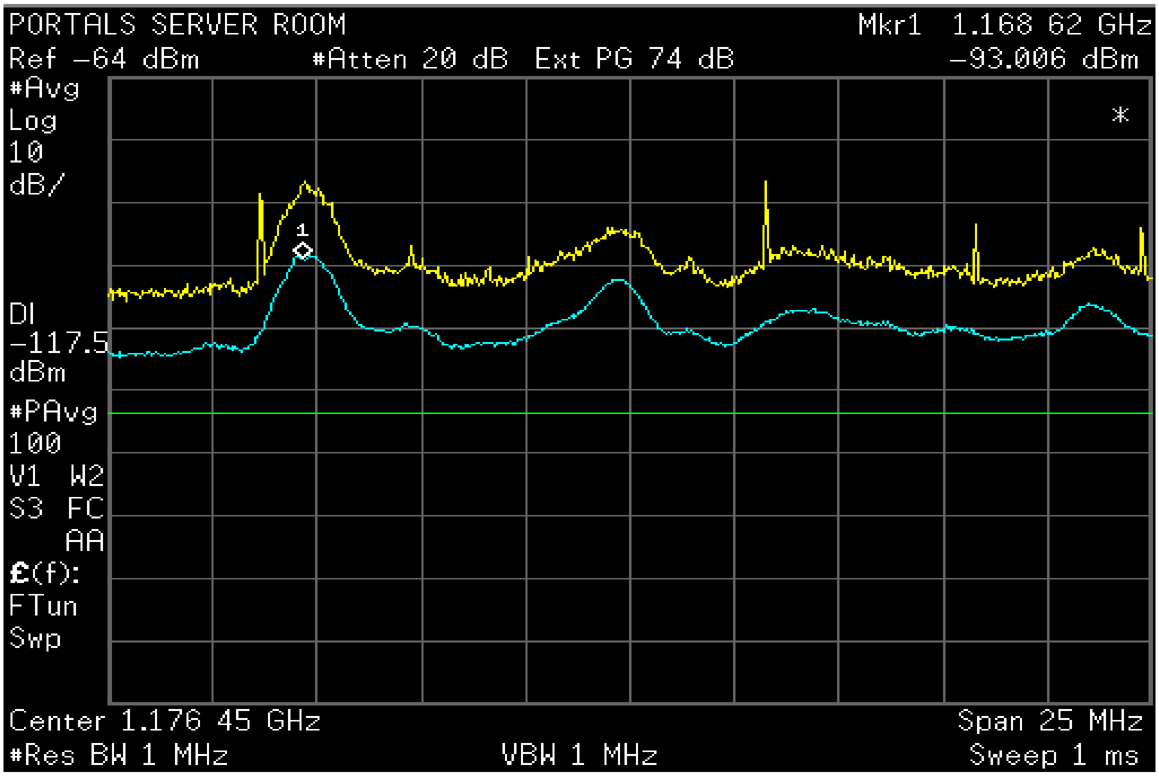


Figure D-73. Ambient Emissions in GPS L5 Frequency Band at Office Site #2.

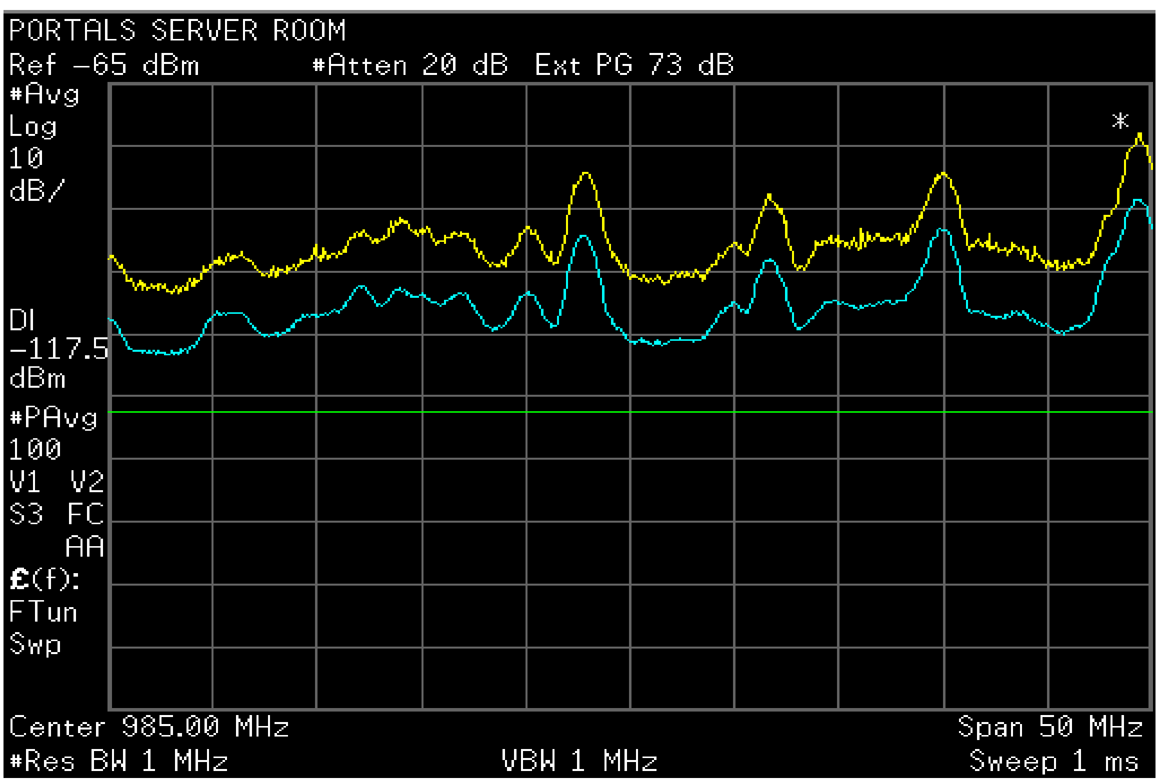


Figure D-74. Ambient Emissions in 960-1010 MHz Frequency Band at Office Site #2.

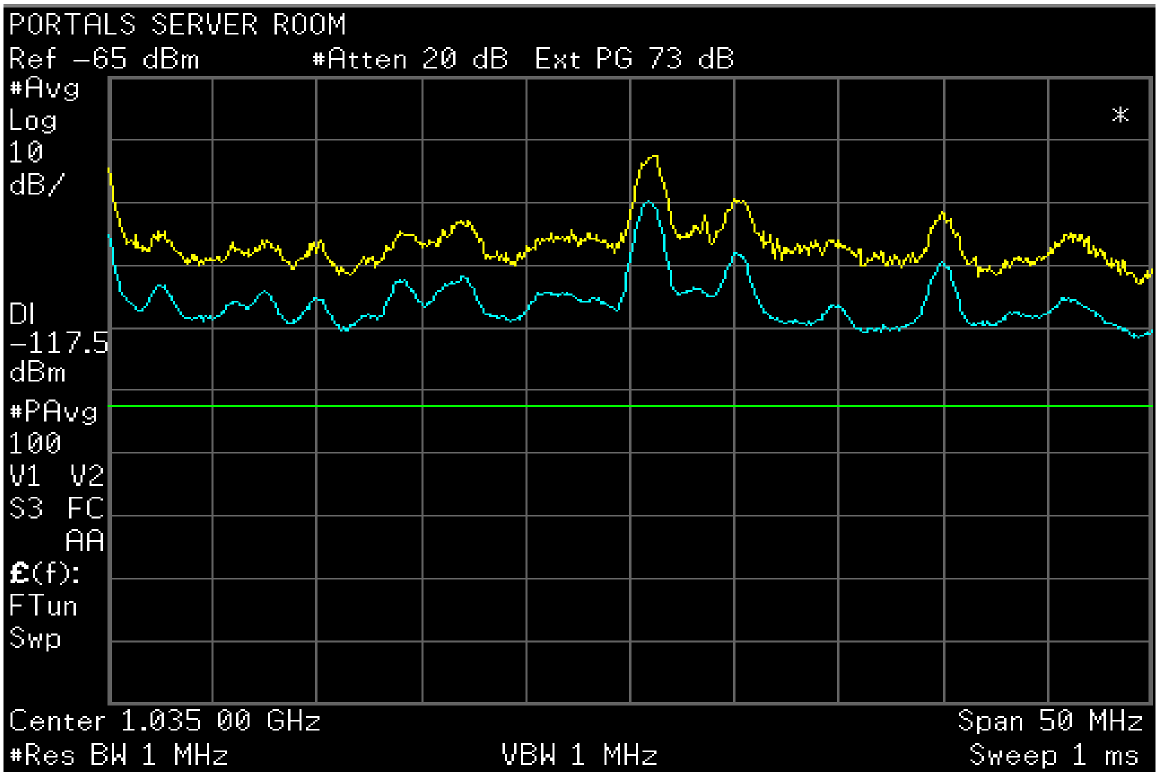


Figure D-75. Ambient Emissions in 1010-1060 MHz Frequency Band at Office Site #2.

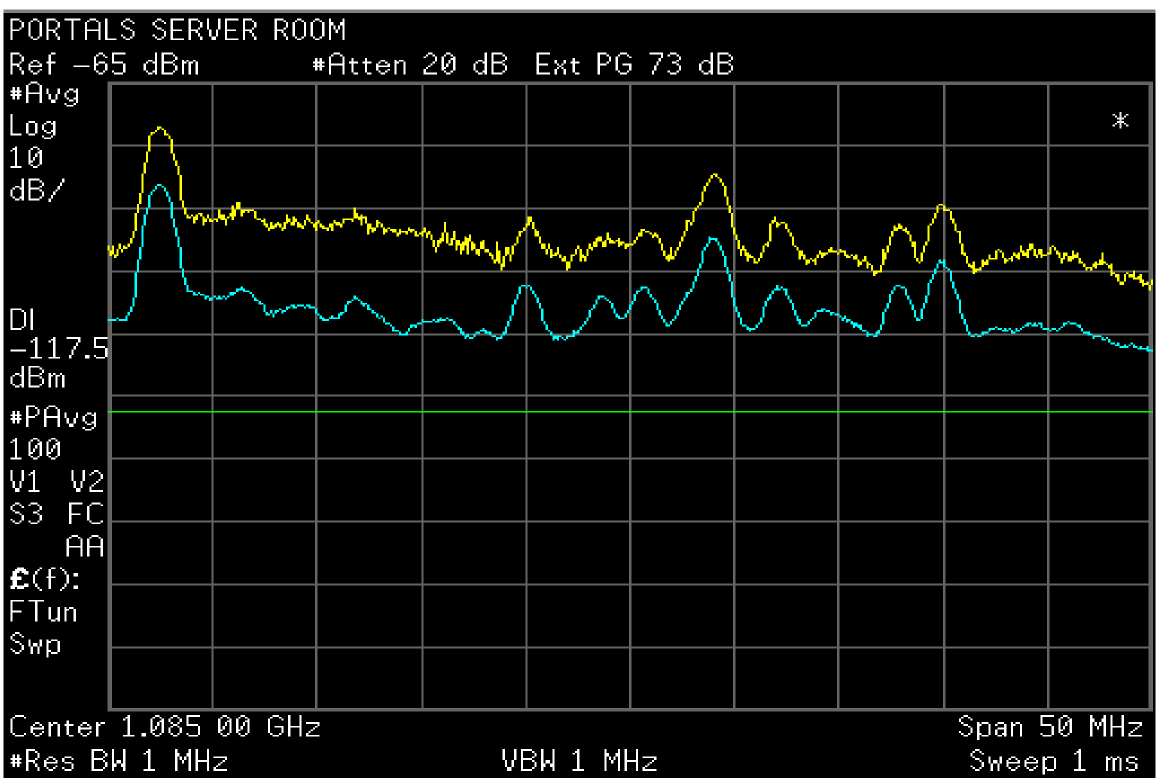


Figure D-76. Ambient Emissions in 1060-1110 MHz Frequency Band at Office Site #2.

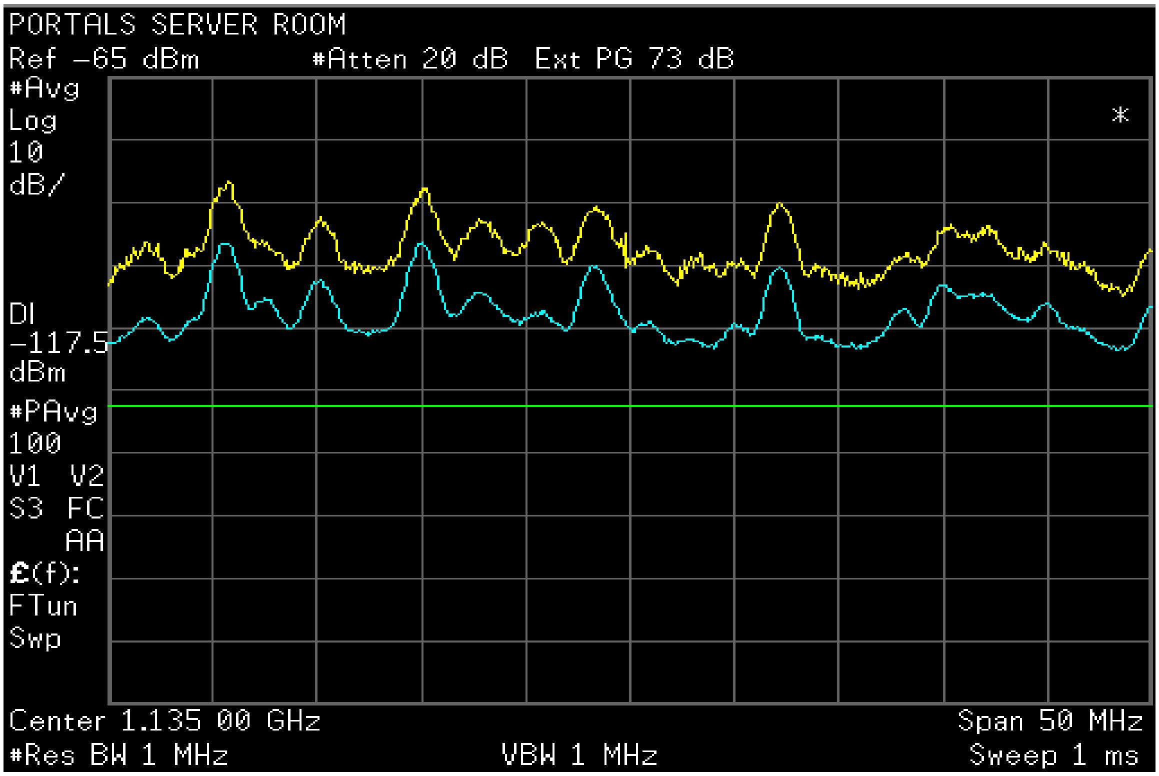


Figure D-77. Ambient Emissions in 1110-1160 MHz Frequency Band at Office Site #2.

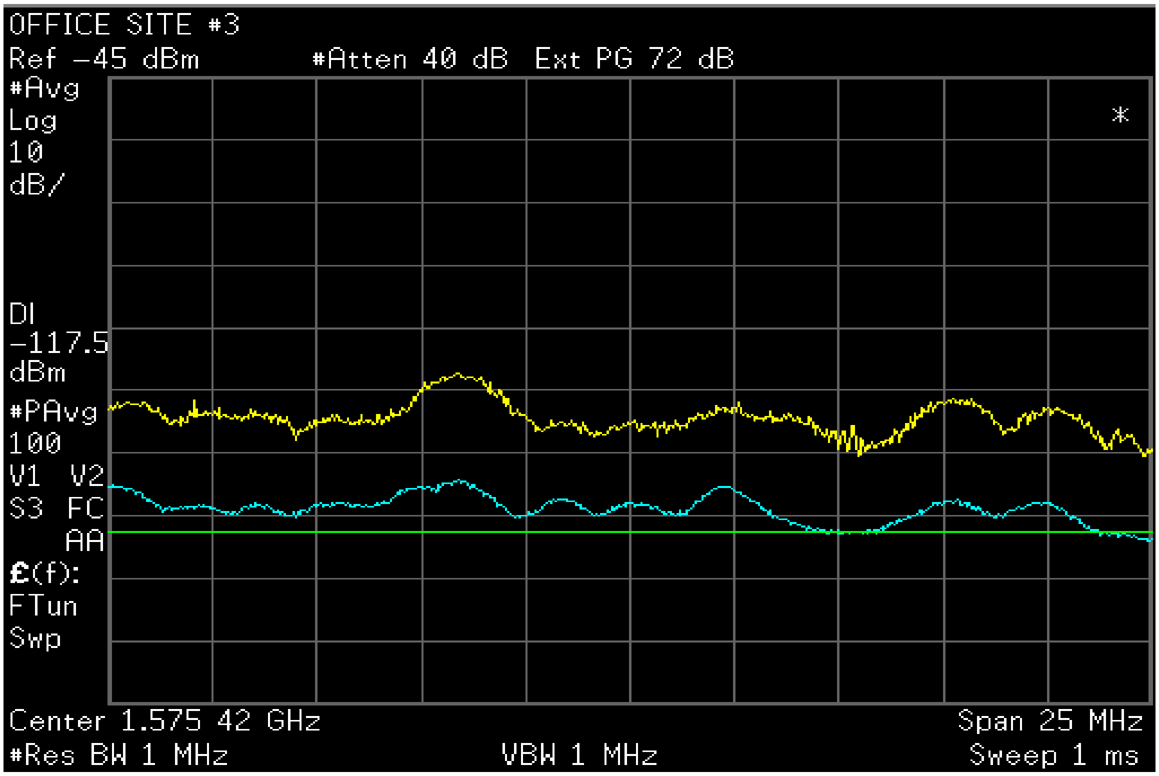


Figure D-78. Ambient Emissions in GPS L1 Frequency Band at Office Site #3.

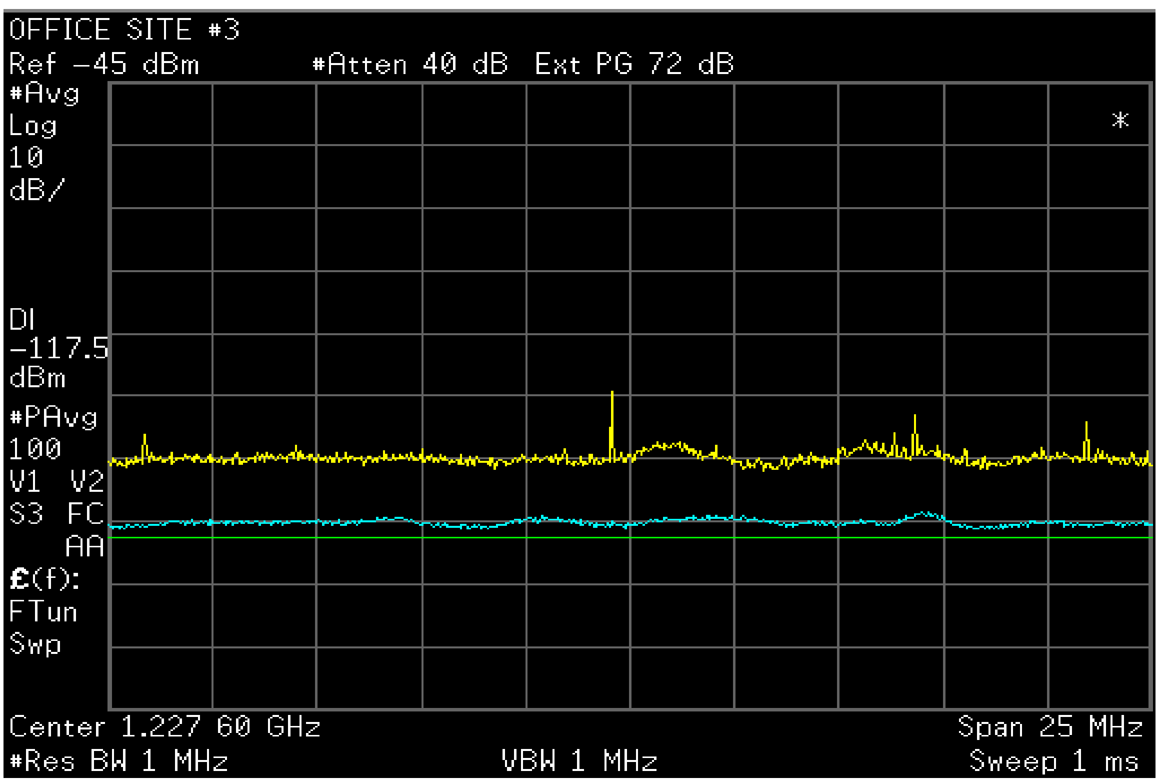


Figure D-79. Ambient Emissions in GPS L2 Frequency Band at Office Site #3.

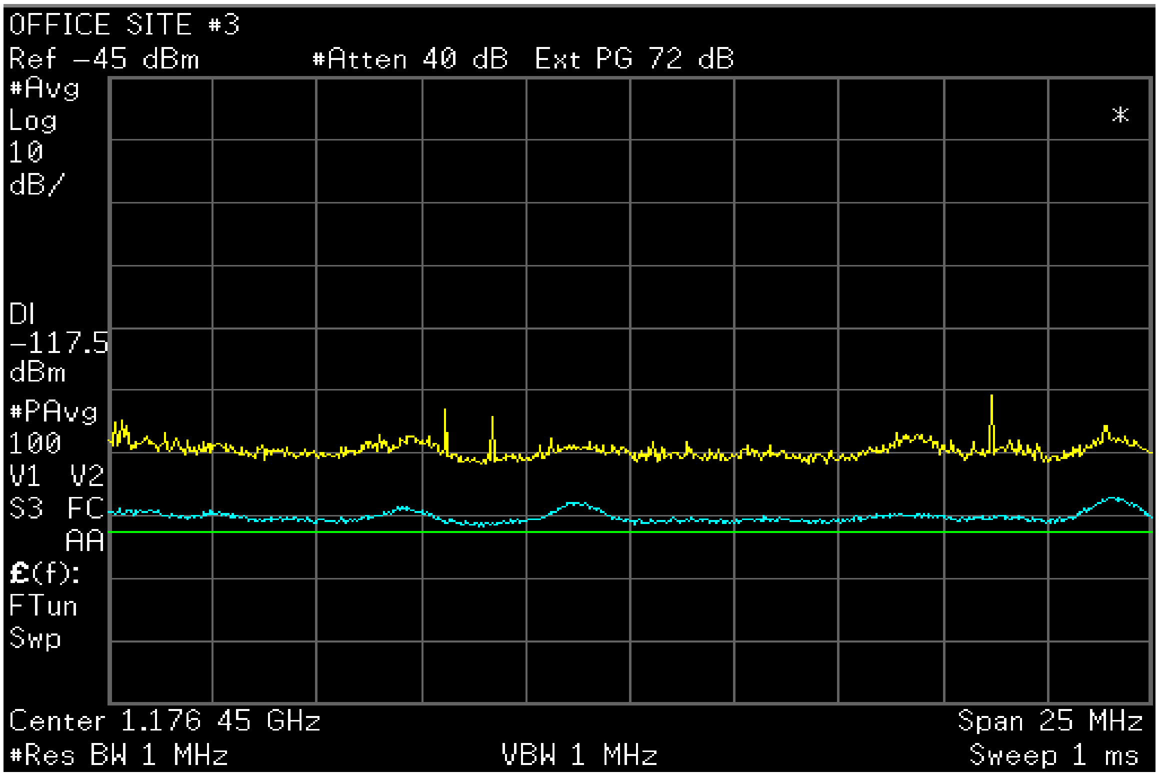


Figure D-80. Ambient Emissions in GPS L5 Frequency Band at Office Site #3.

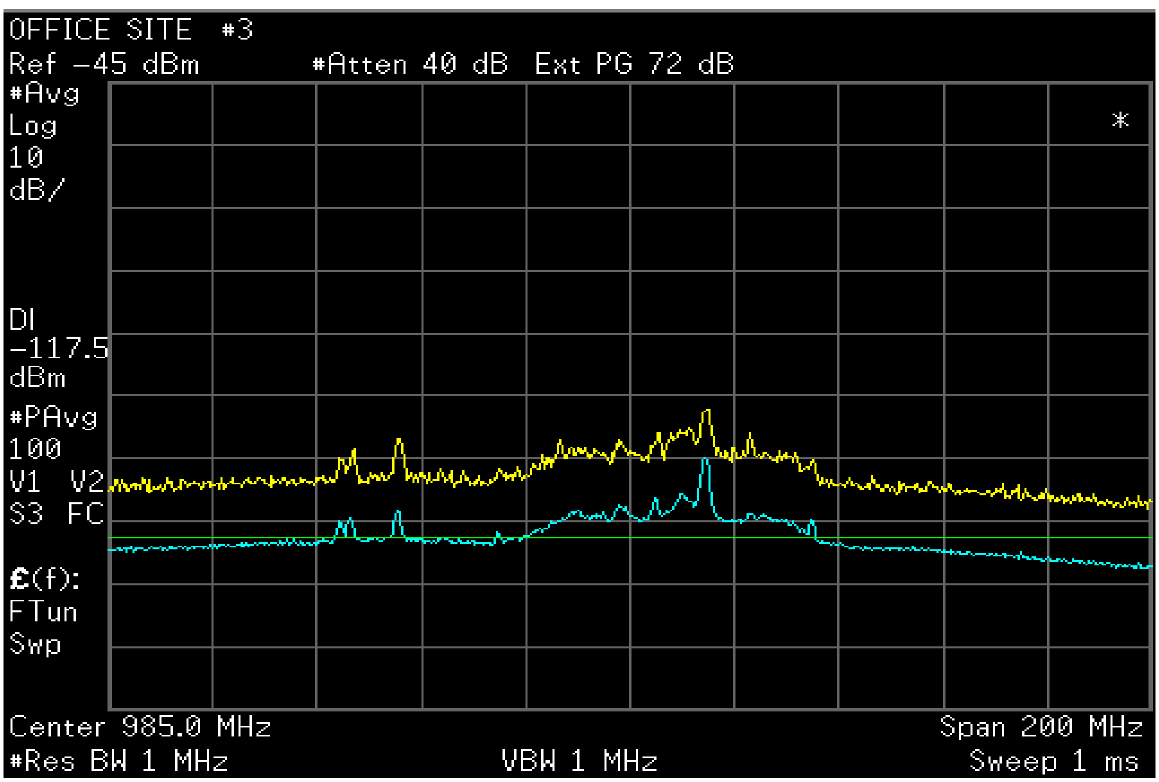


Figure D-81. Ambient Emissions in 960-1010 MHz Frequency Band at Office Site #3.

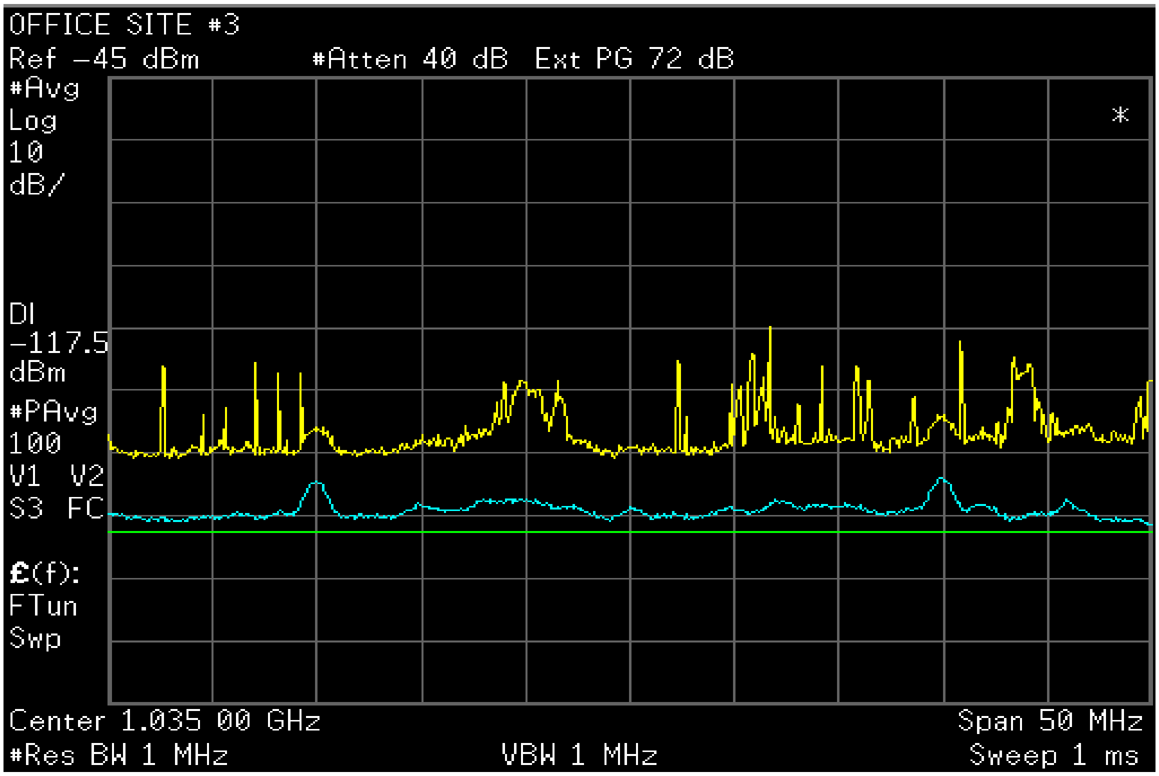


Figure D-82. Ambient Emissions in 1010-1060 MHz Frequency Band at Office Site #3.

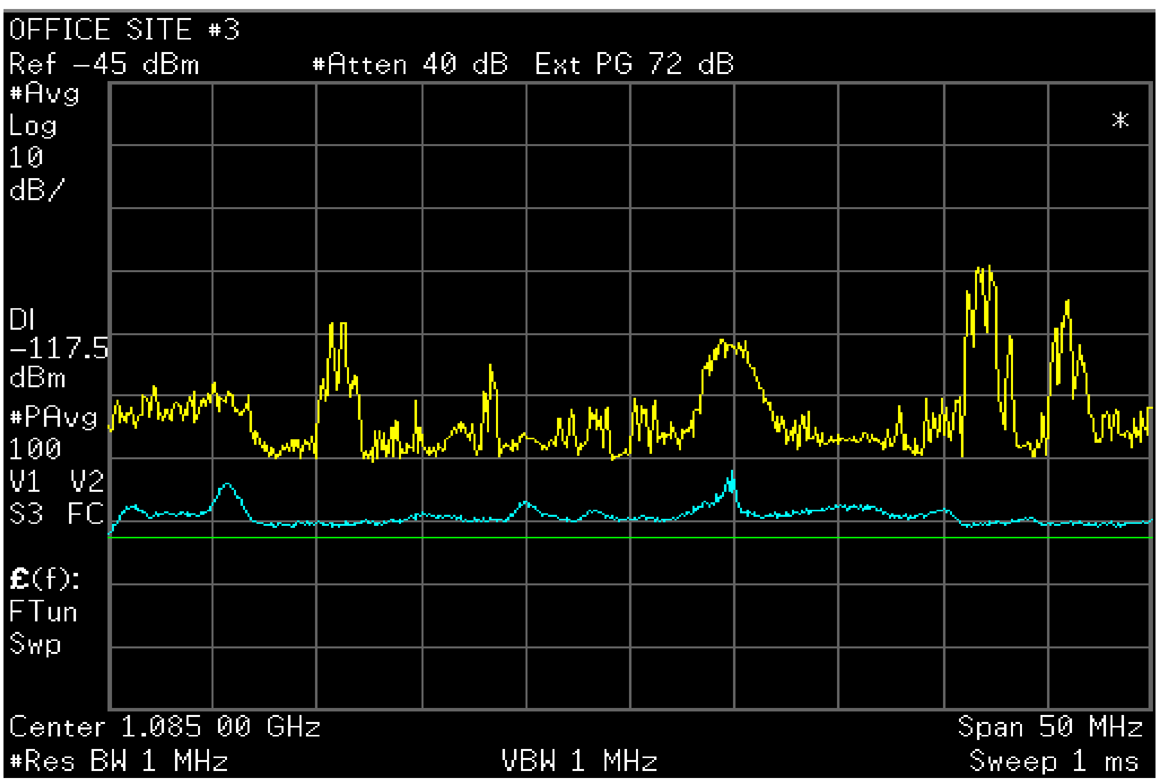


Figure D-83. Ambient Emissions in 1060-1110 MHz Frequency Band at Office Site #3.

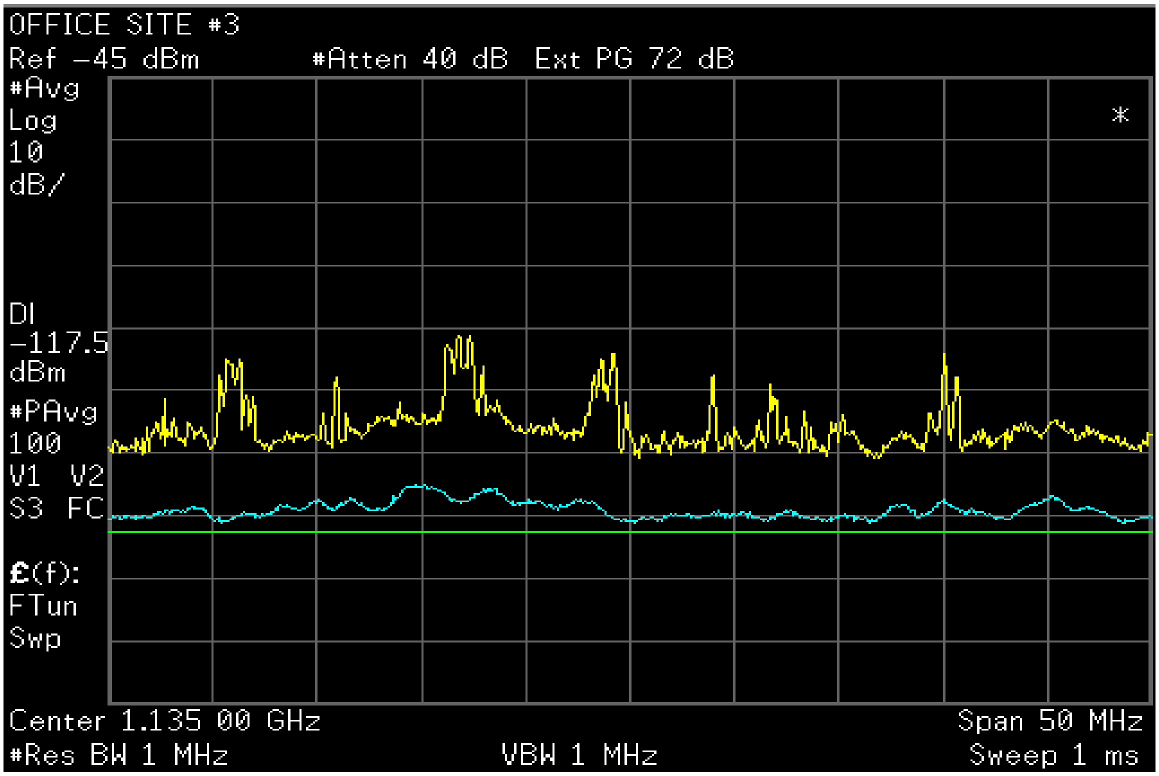


Figure D-84. Ambient Emissions in 1110-1160 MHz Frequency Band at Office Site #3.

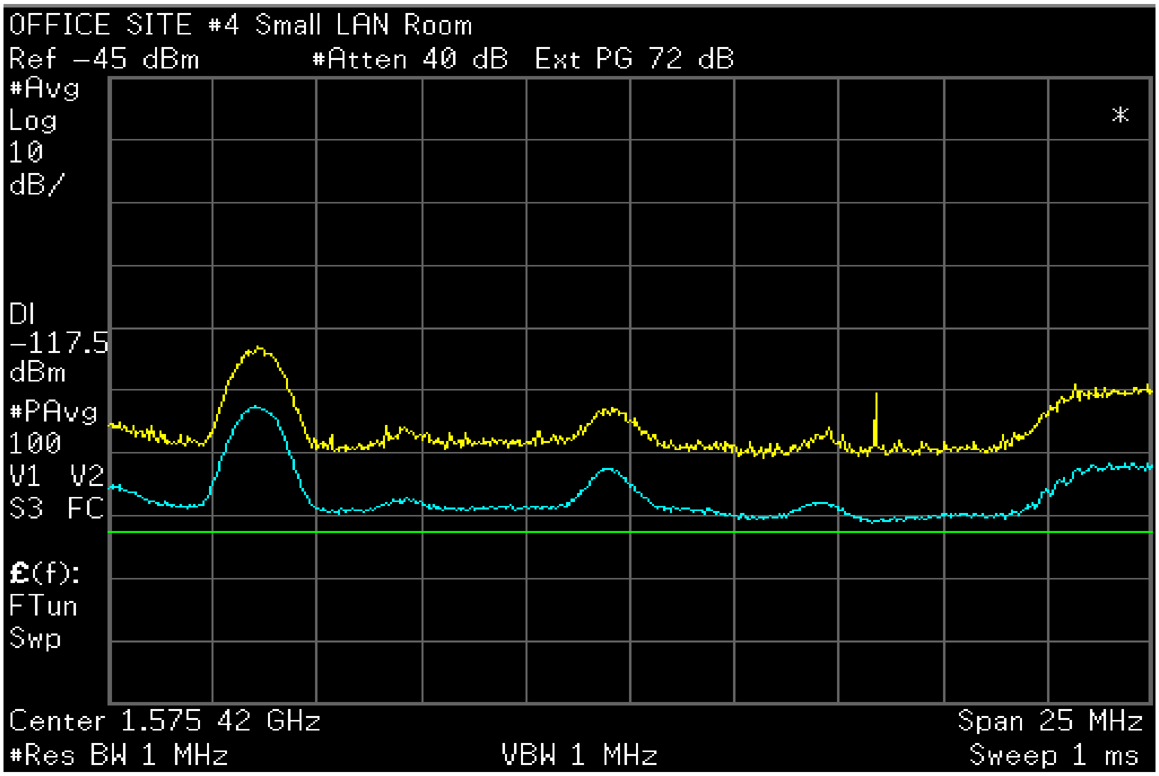


Figure D-85. Ambient Emissions in GPS L1 Frequency Band at Office Site #4.

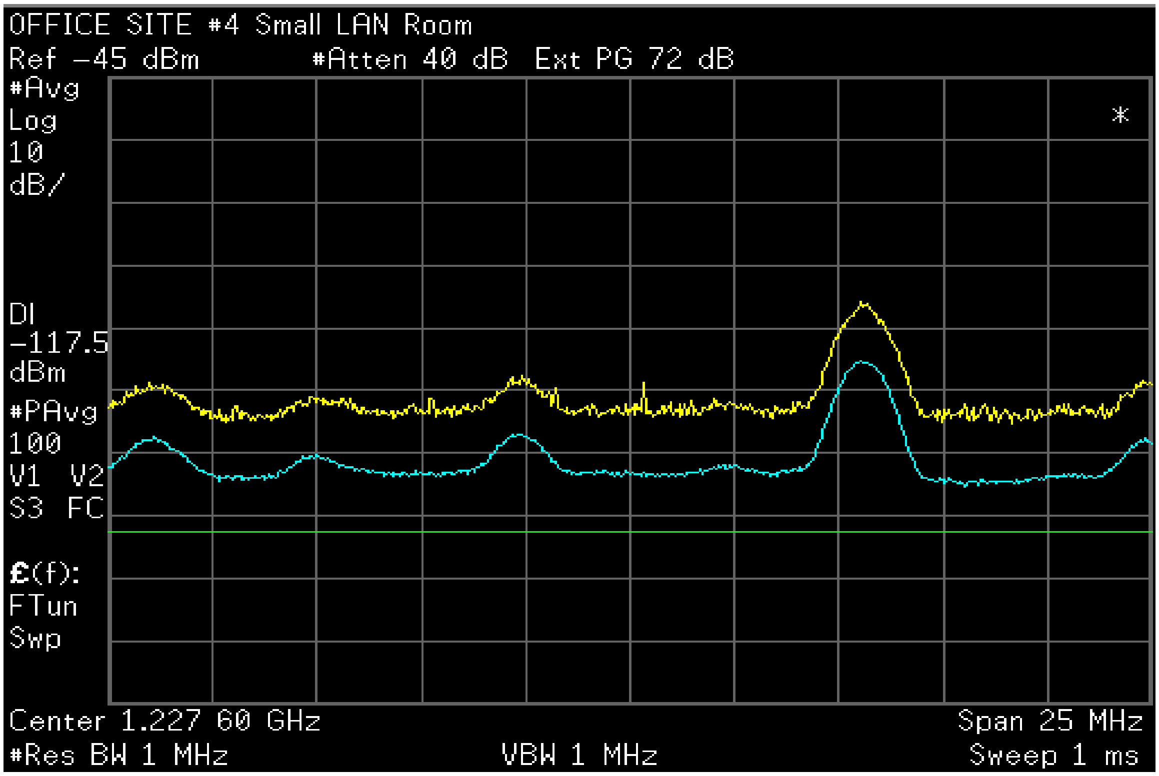


Figure D-86. Ambient Emissions in GPS L2 Frequency Band at Office Site #4.

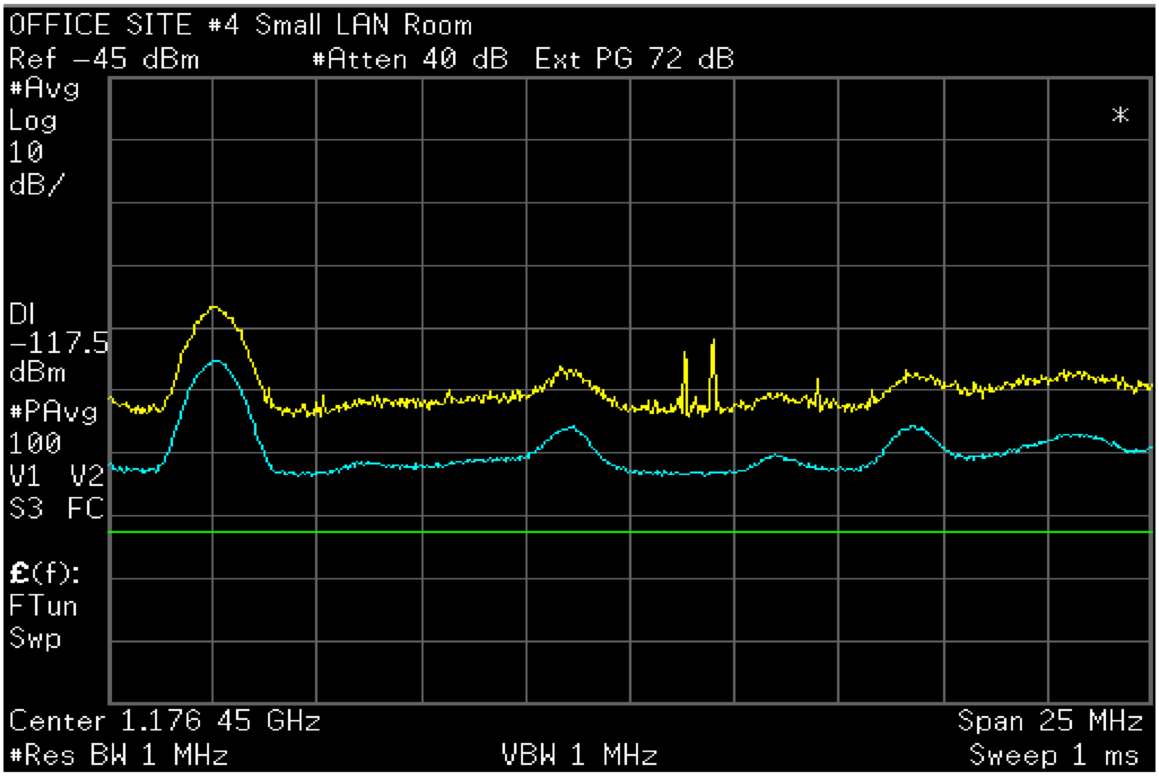


Figure D-87. Ambient Emissions in GPS L5 Frequency Band at Office Site #4.

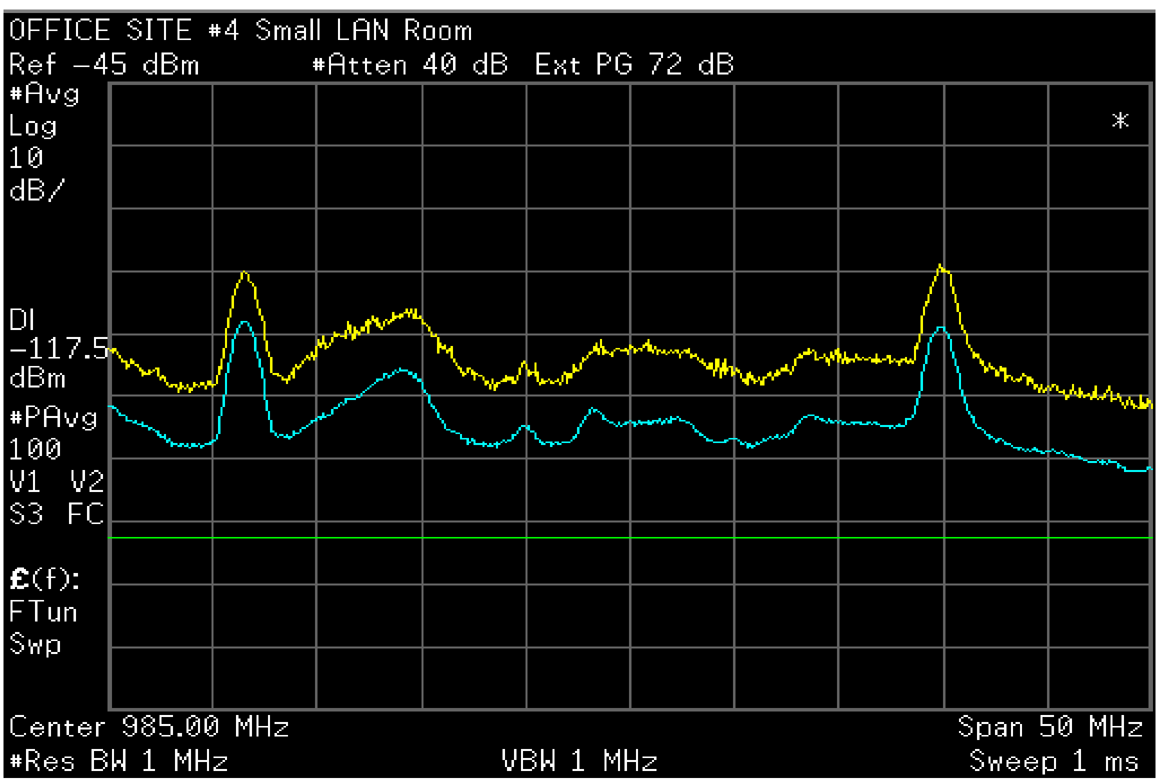


Figure D-88. Ambient Emissions in 960-1010 MHz Frequency Band at Office Site #4.

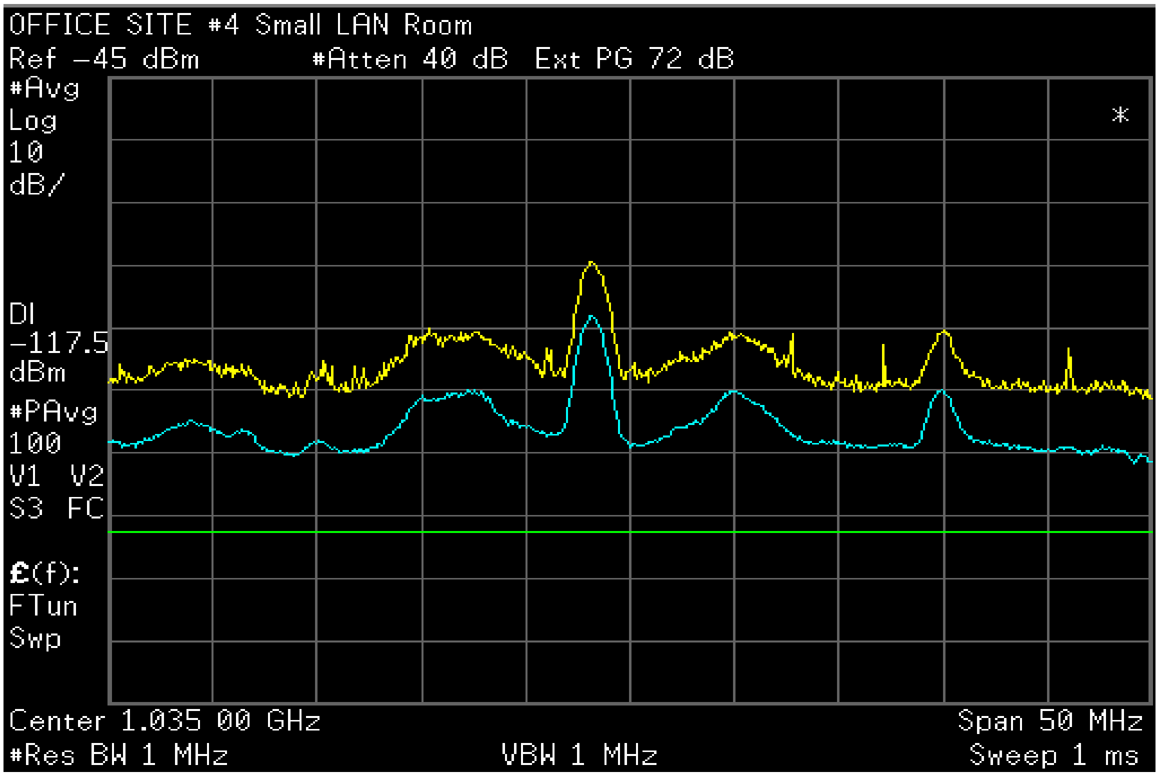


Figure D-89. Ambient Emissions in 1010-1060 MHz Frequency Band at Office Site #4.

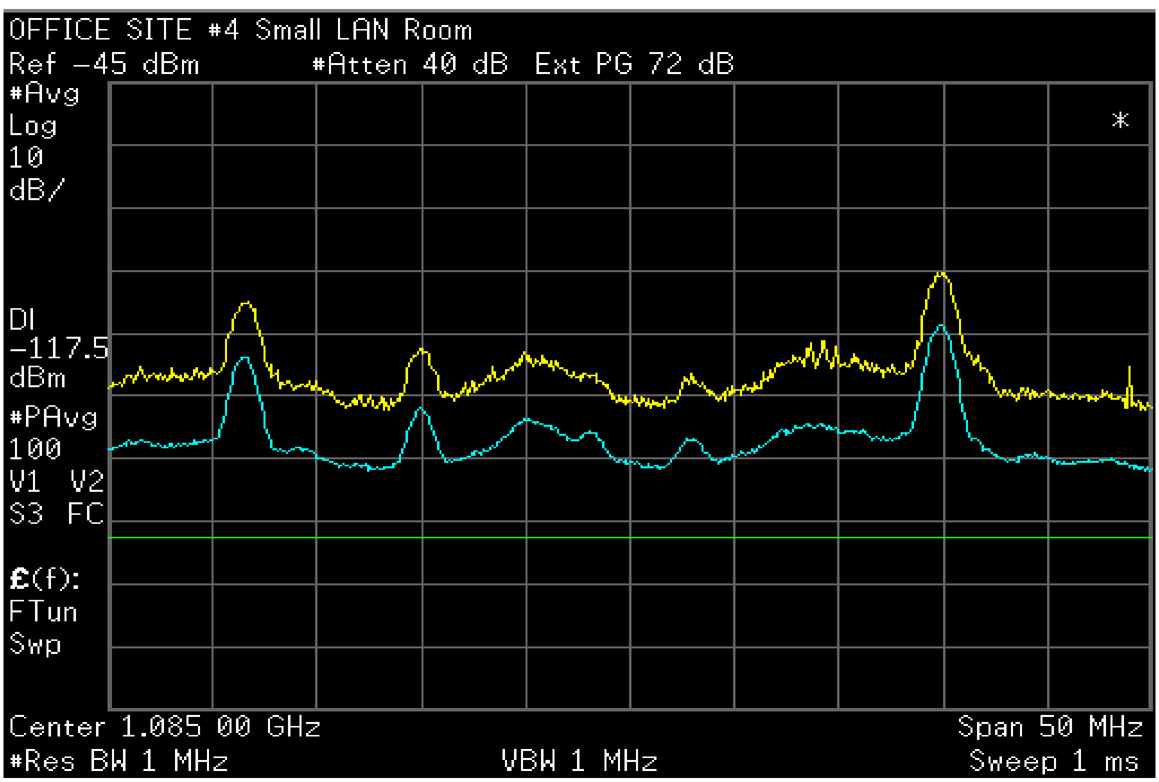


Figure D-90. Ambient Emissions in 1060-1110 MHz Frequency Band at Office Site #4.

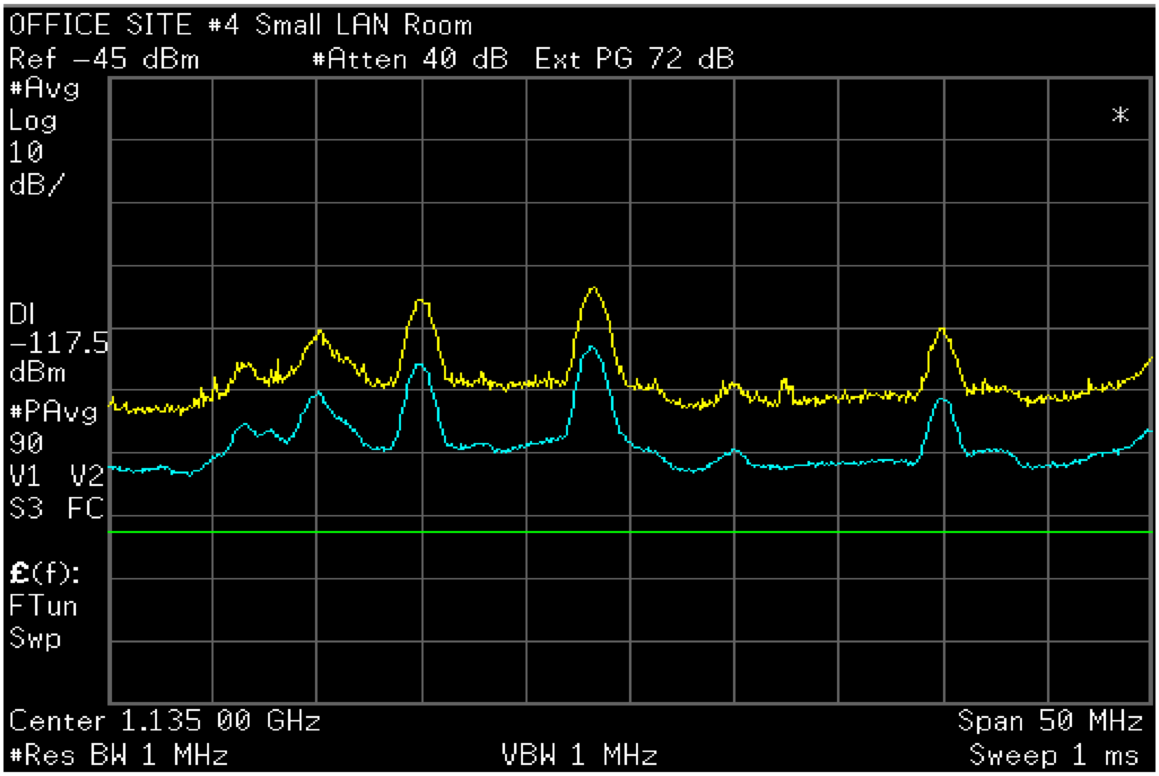


Figure D-91. Ambient Emissions in 1110-1160 MHz Frequency Band at Office Site #4.

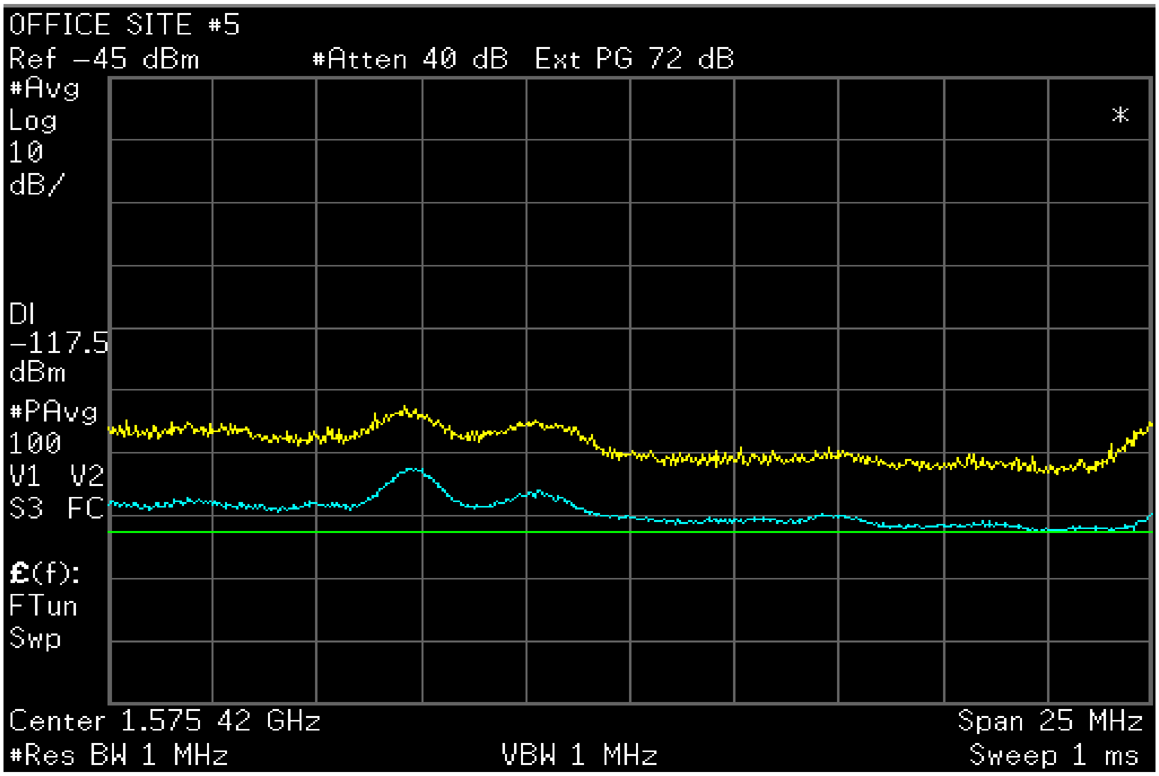


Figure D-92. Ambient Emissions in GPS L1 Frequency Band at Office Site #5.

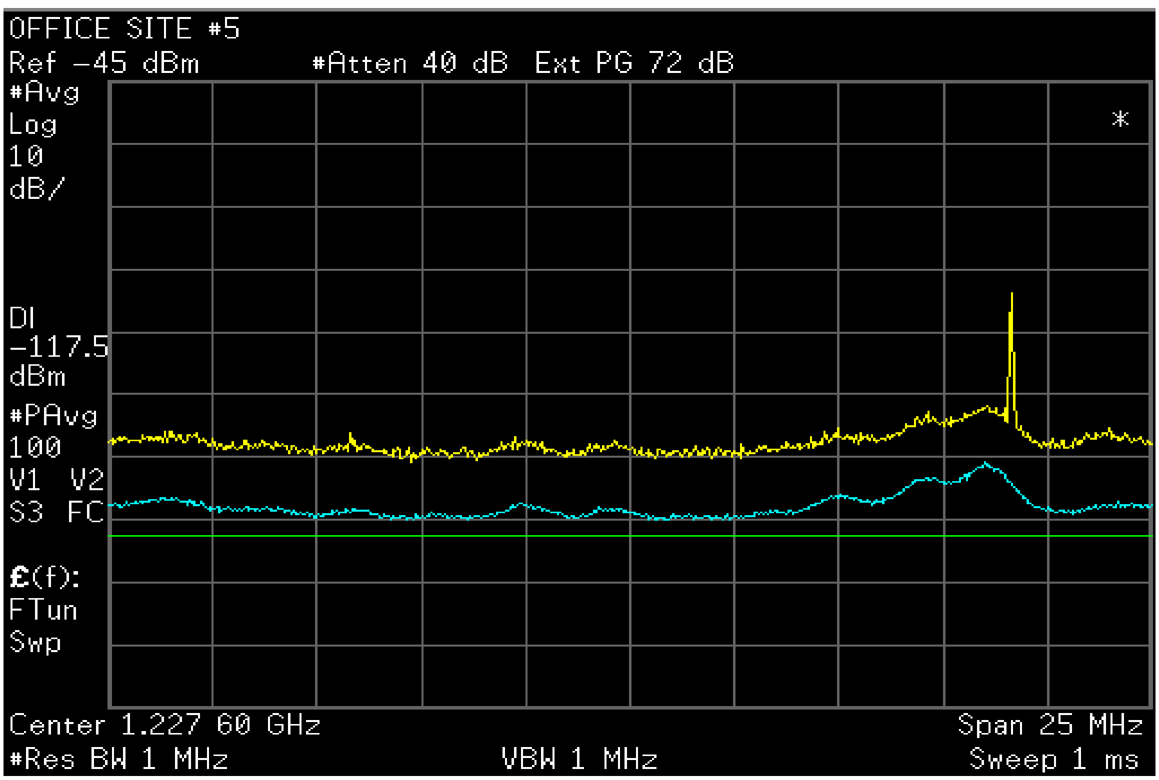


Figure D-93. Ambient Emissions in GPS L2 Frequency Band at Office Site #5.

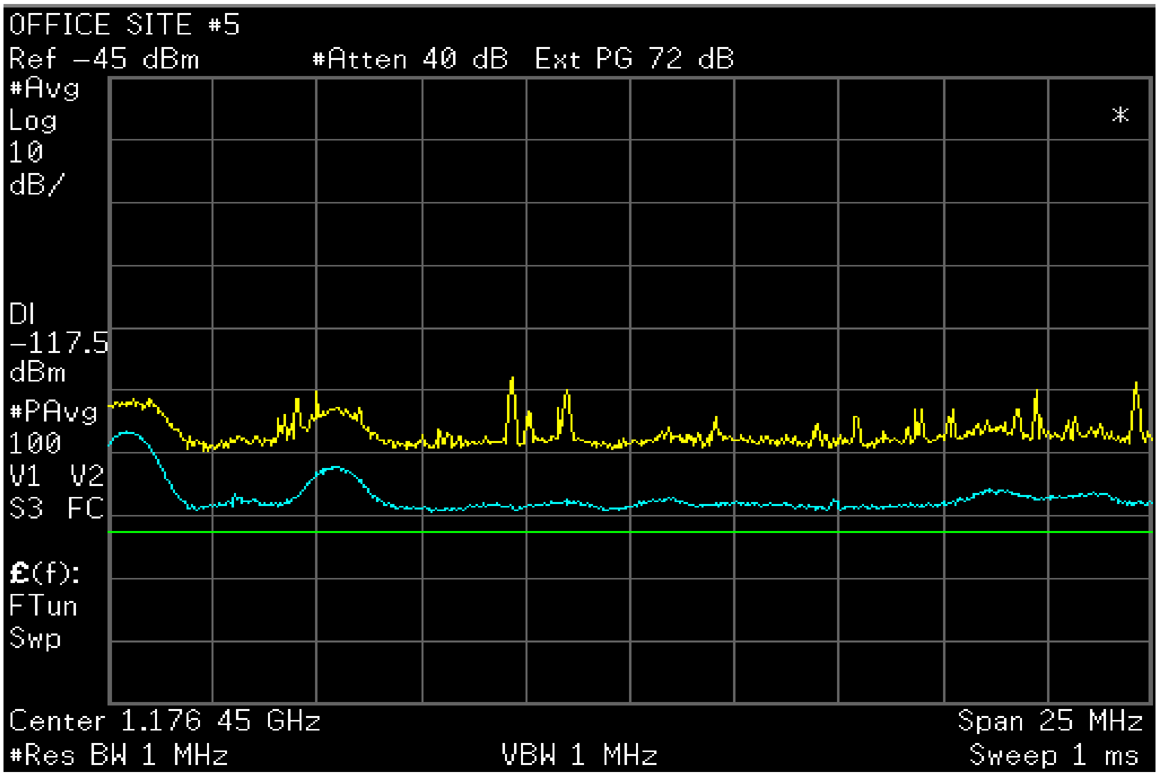


Figure D-94. Ambient Emissions in GPS L5 Frequency Band at Office Site #5.

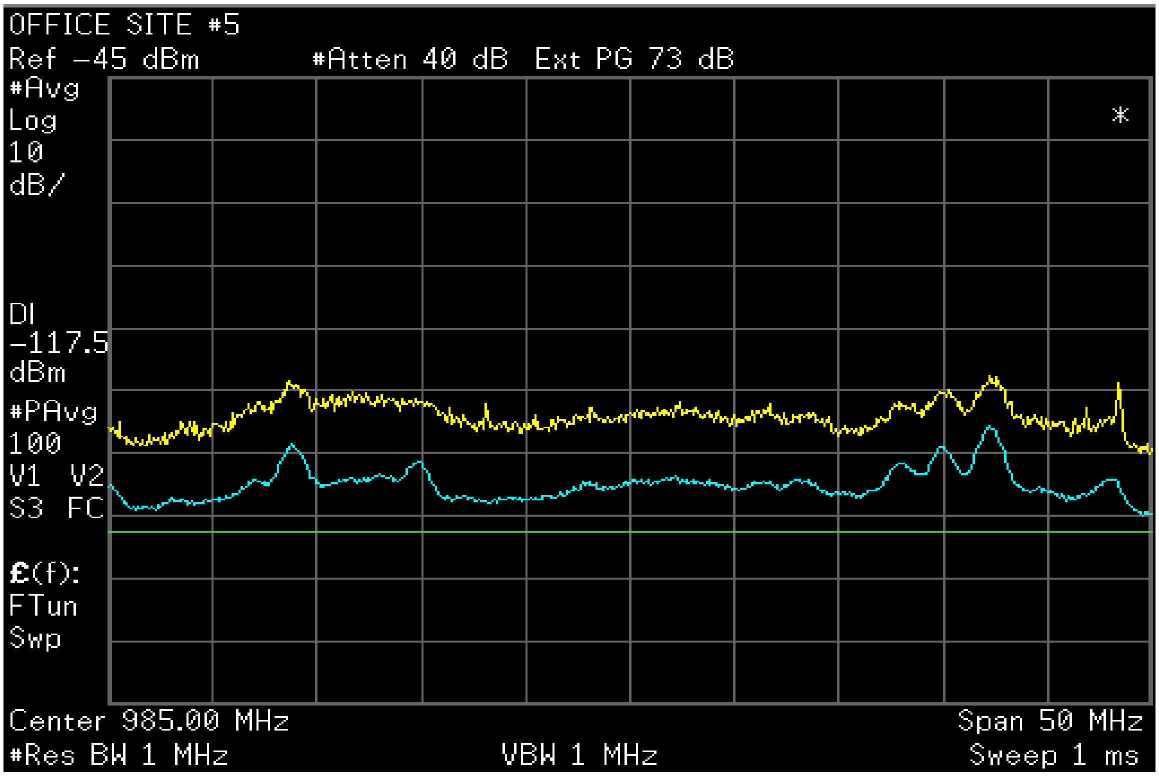


Figure D-95. Ambient Emissions in 960-1010 MHz Frequency Band at Office Site #5.

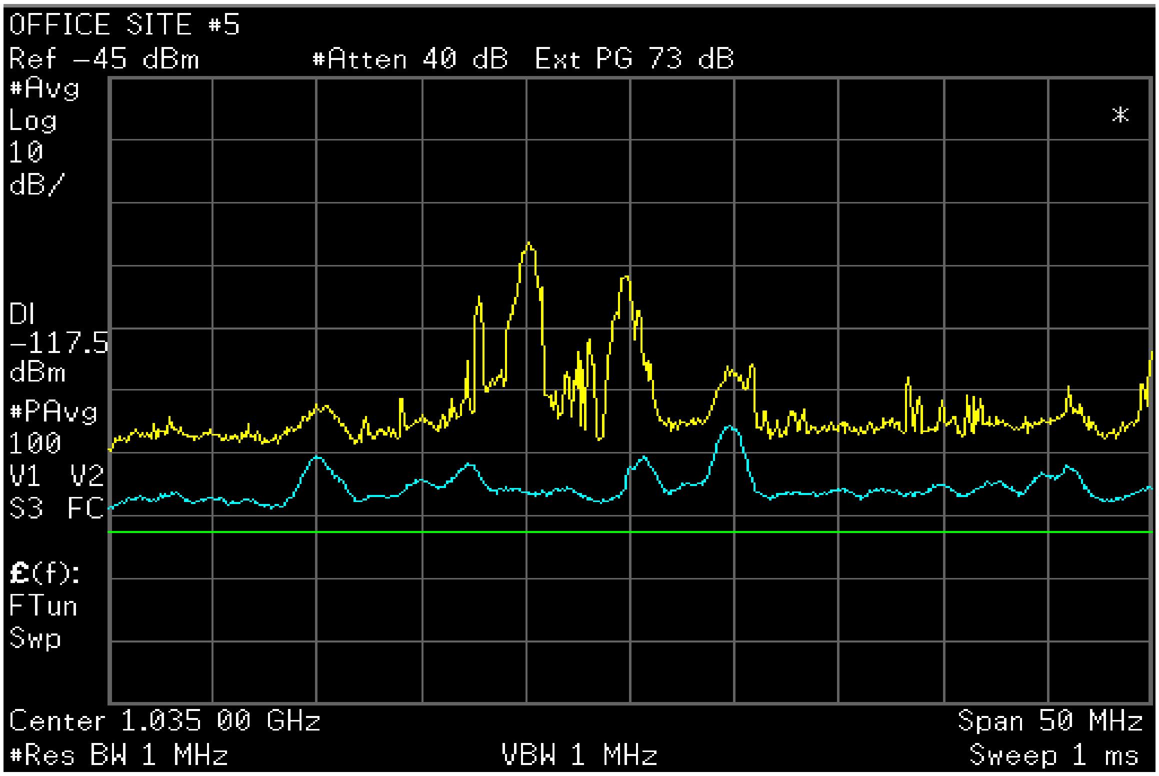


Figure D-96. Ambient Emissions in 1010-1060 MHz Frequency Band at Office Site #5.

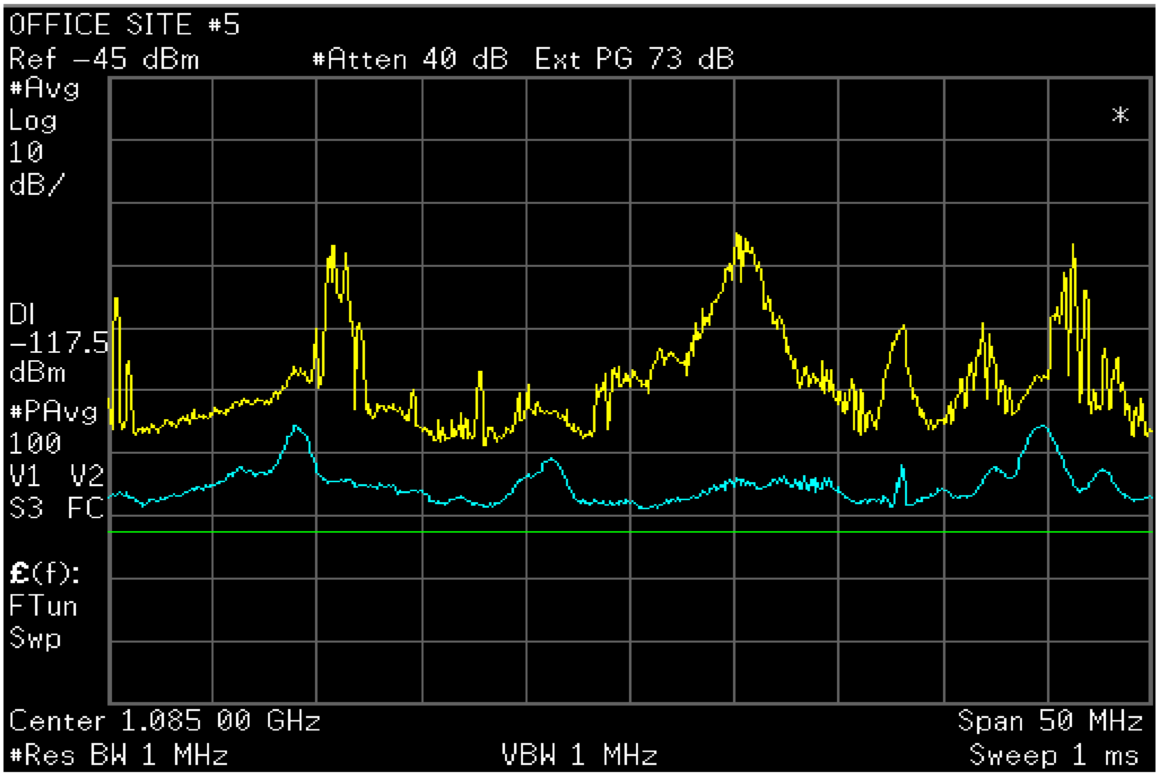


Figure D-97. Ambient Emissions in 1060-1110 MHz Frequency Band at Office Site #5.

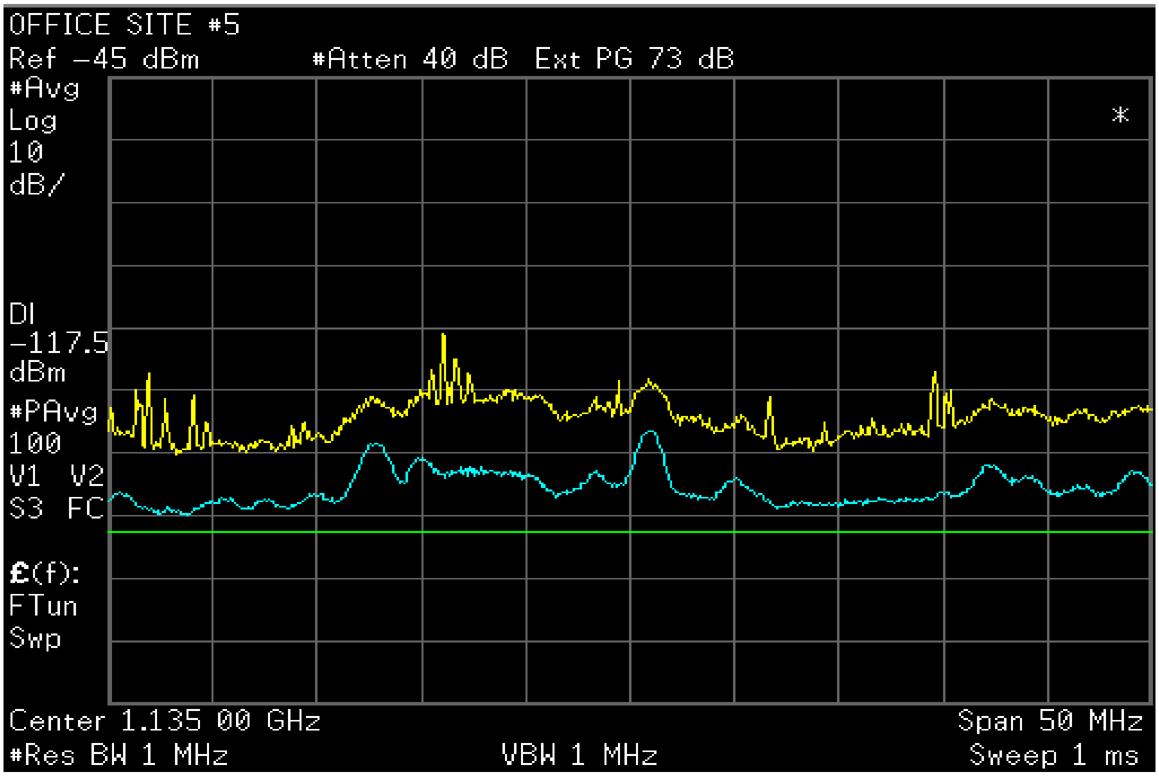


Figure D-98. Ambient Emissions in 1110-1160 MHz Frequency Band at Office Site #5.

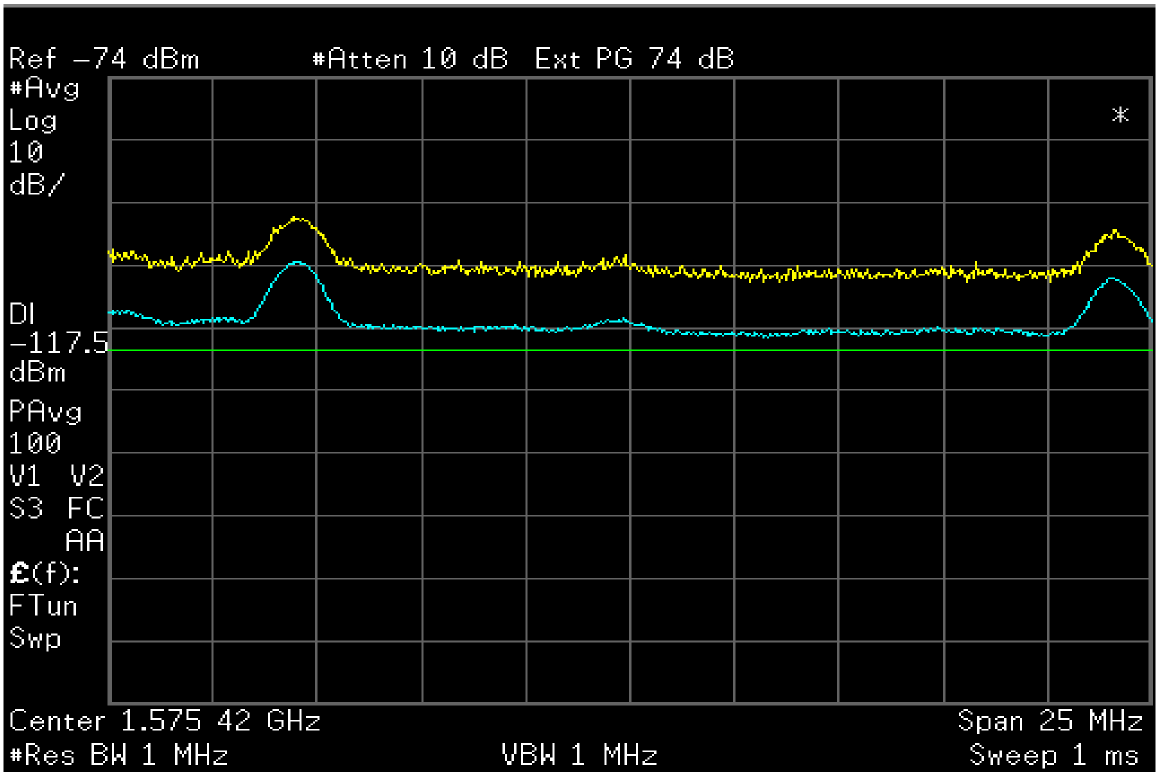


Figure D-99. Ambient Emissions in GPS L1 Frequency Band at Factory Site #1.

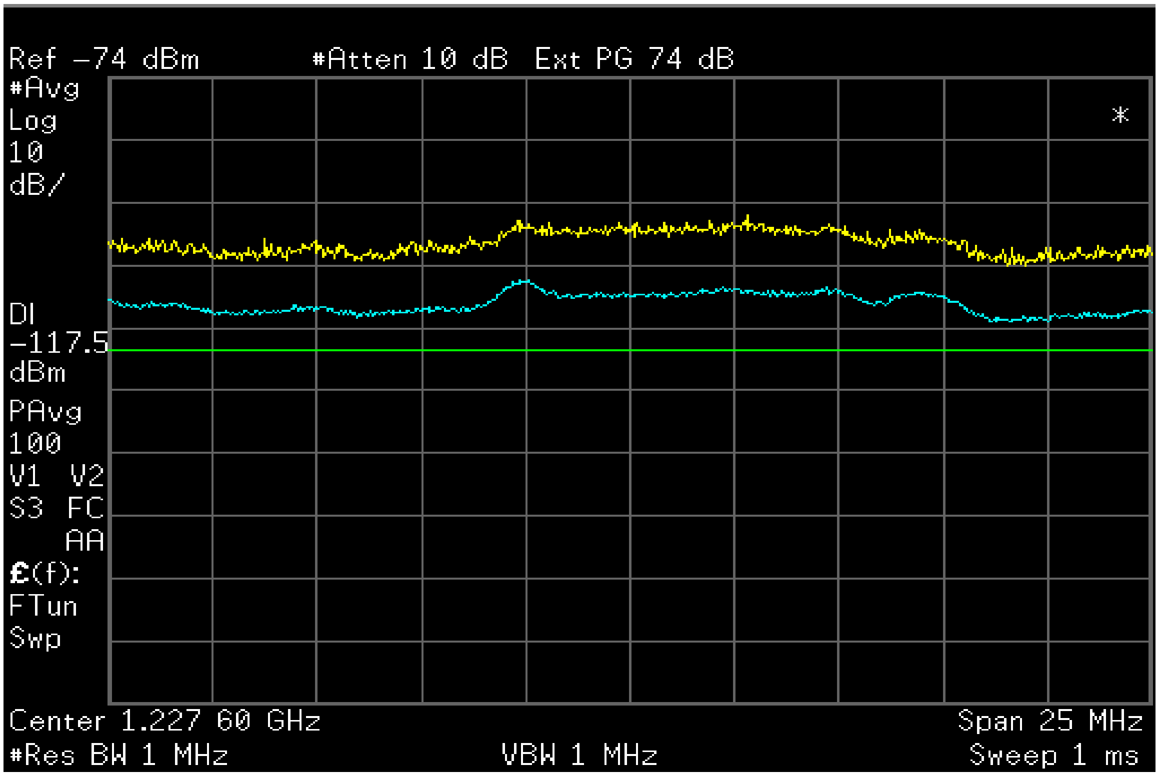


Figure D-100. Ambient Emissions in GPS L2 Frequency Band at Factory Site #1.

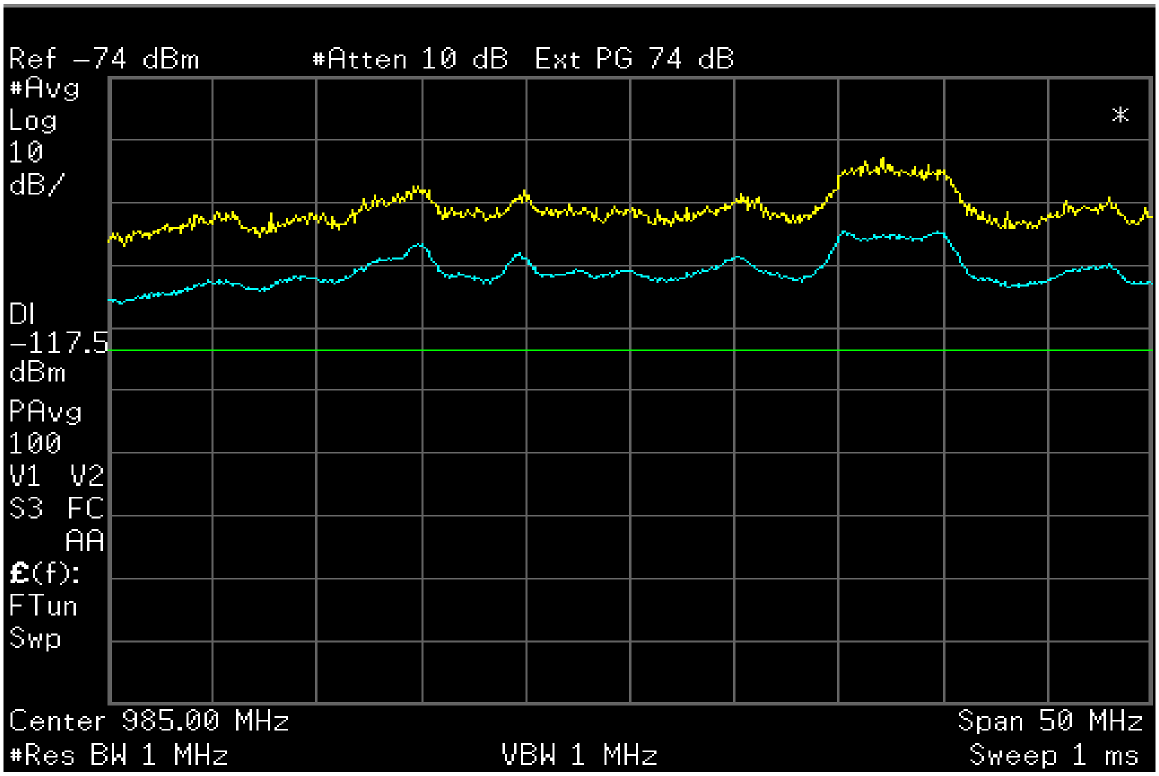


Figure D-101. Ambient Emissions in 960-1010 MHz Frequency Band at Factory Site #1.

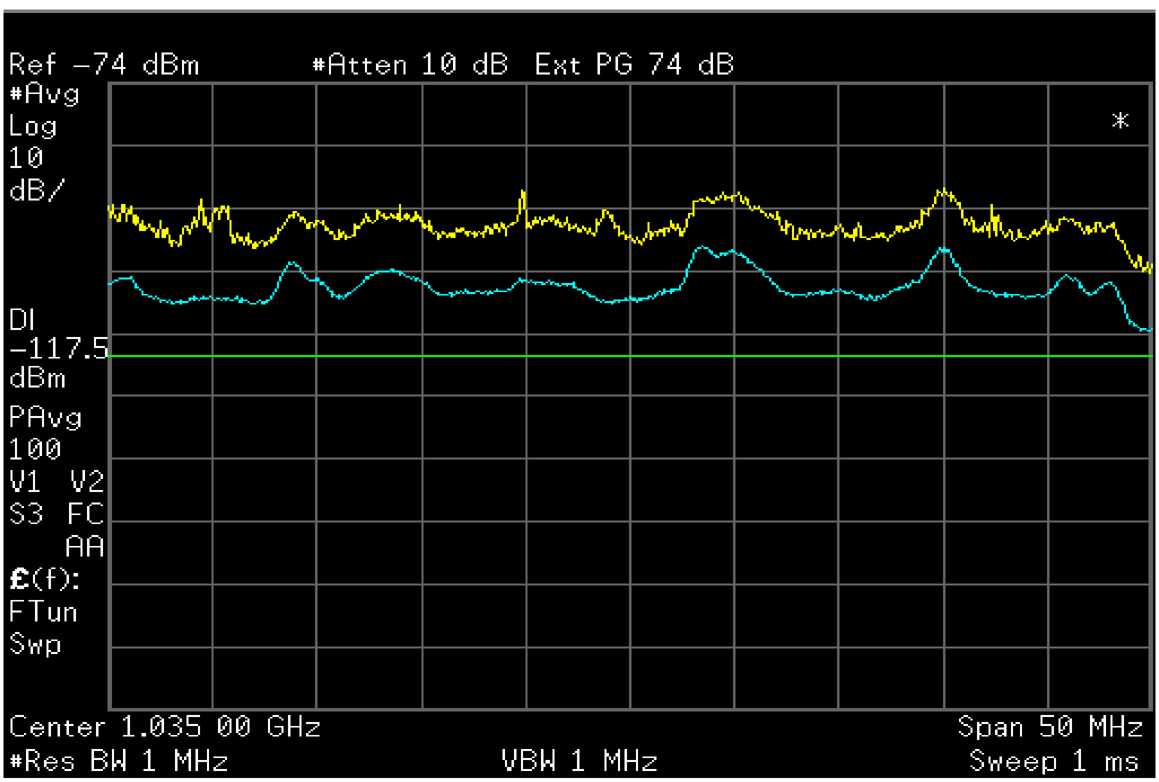


Figure D-102. Ambient Emissions in 1010-1060 MHz Frequency Band at Factory Site #1.

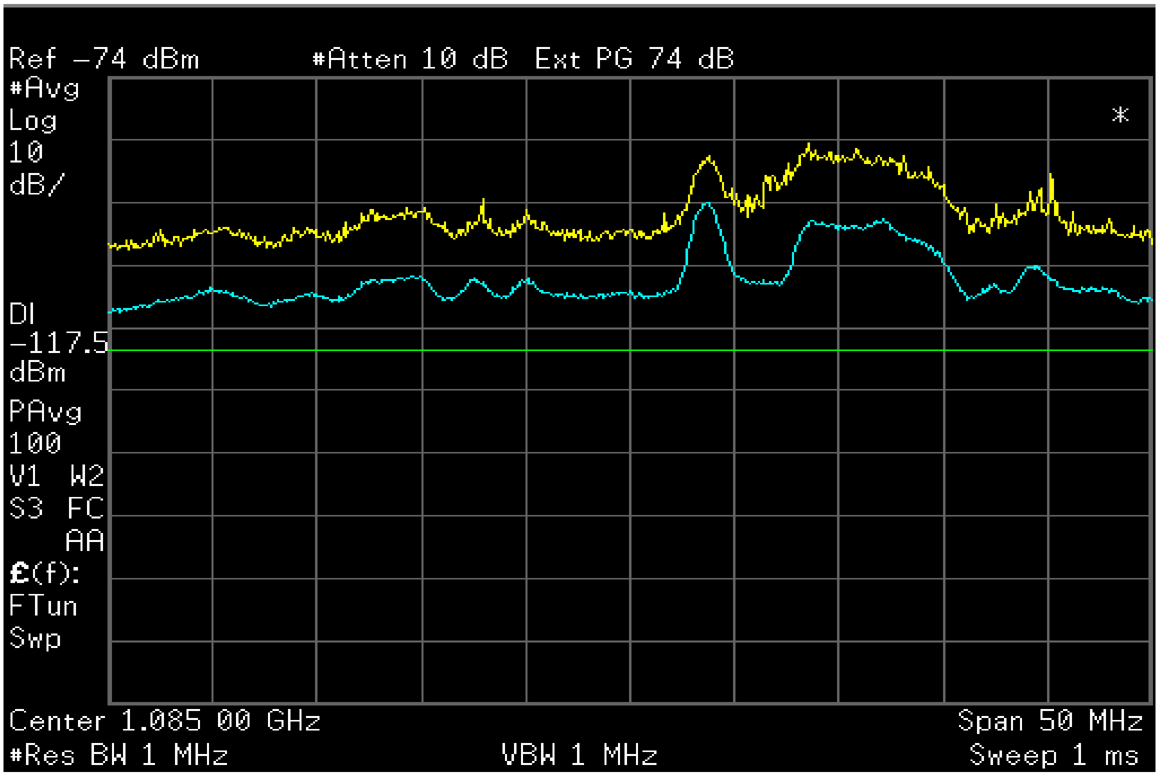


Figure D-103. Ambient Emissions in 1060-1110 MHz Frequency Band at Factory Site #1.

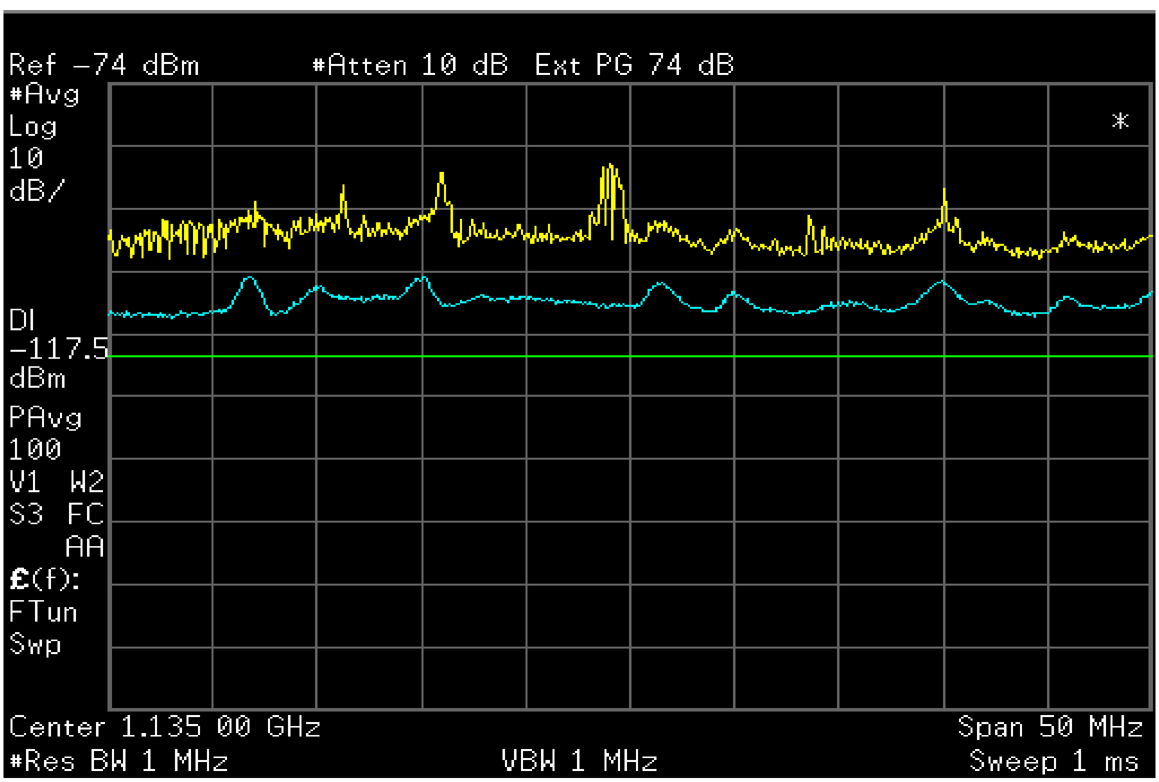


Figure D-104. Ambient Emissions in 1110-1160 MHz Frequency Band at Factory Site #1.

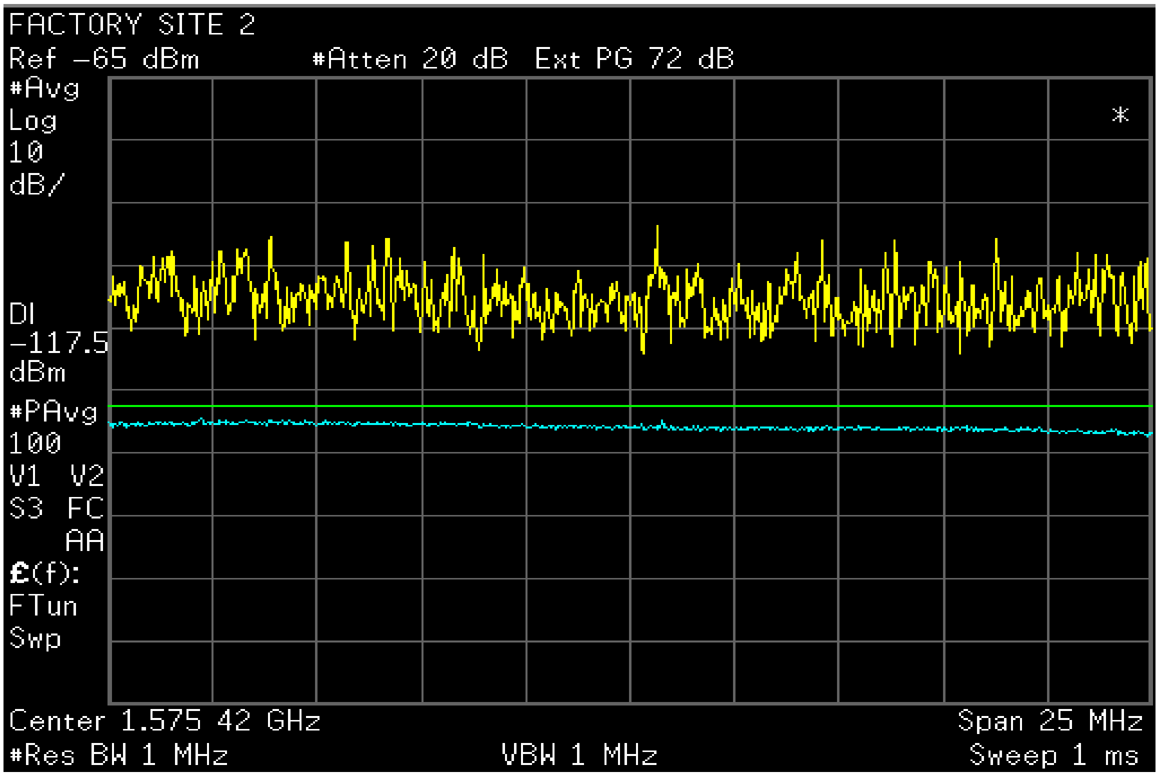


Figure D-105. Ambient Emissions in GPS L1 Frequency Band at Factory Site #2.

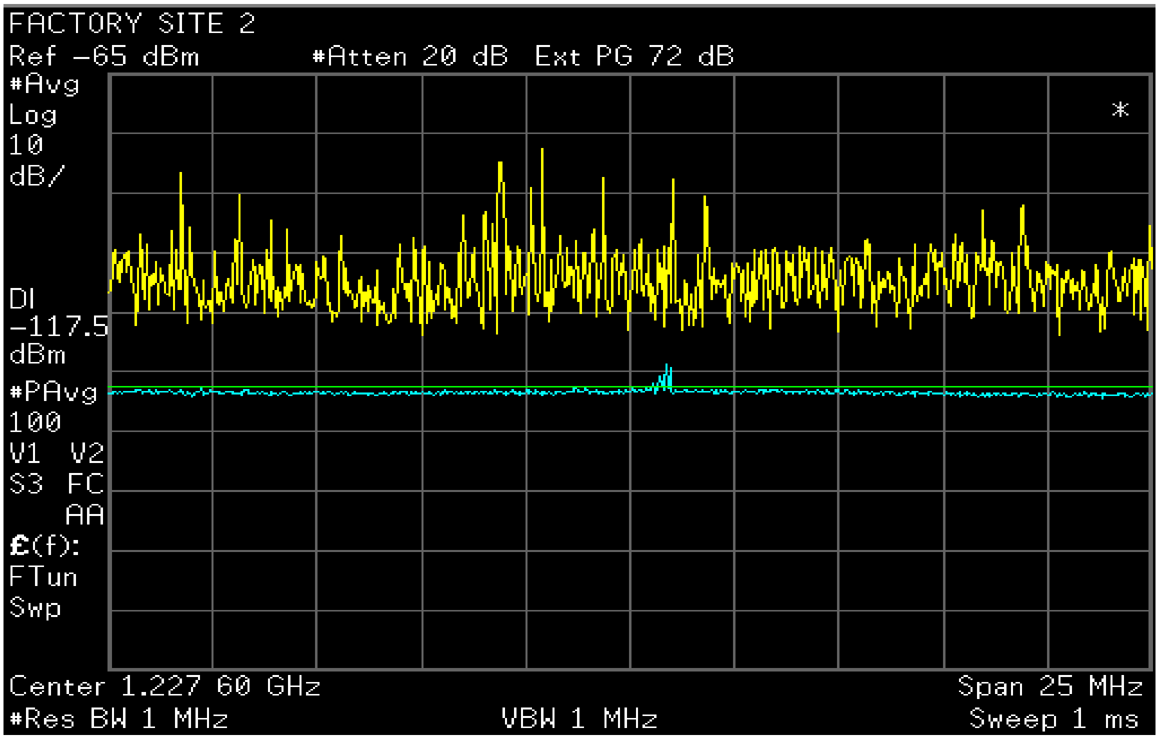


Figure D-106. Ambient Emissions in GPS L2 Frequency Band at Factory Site #2.

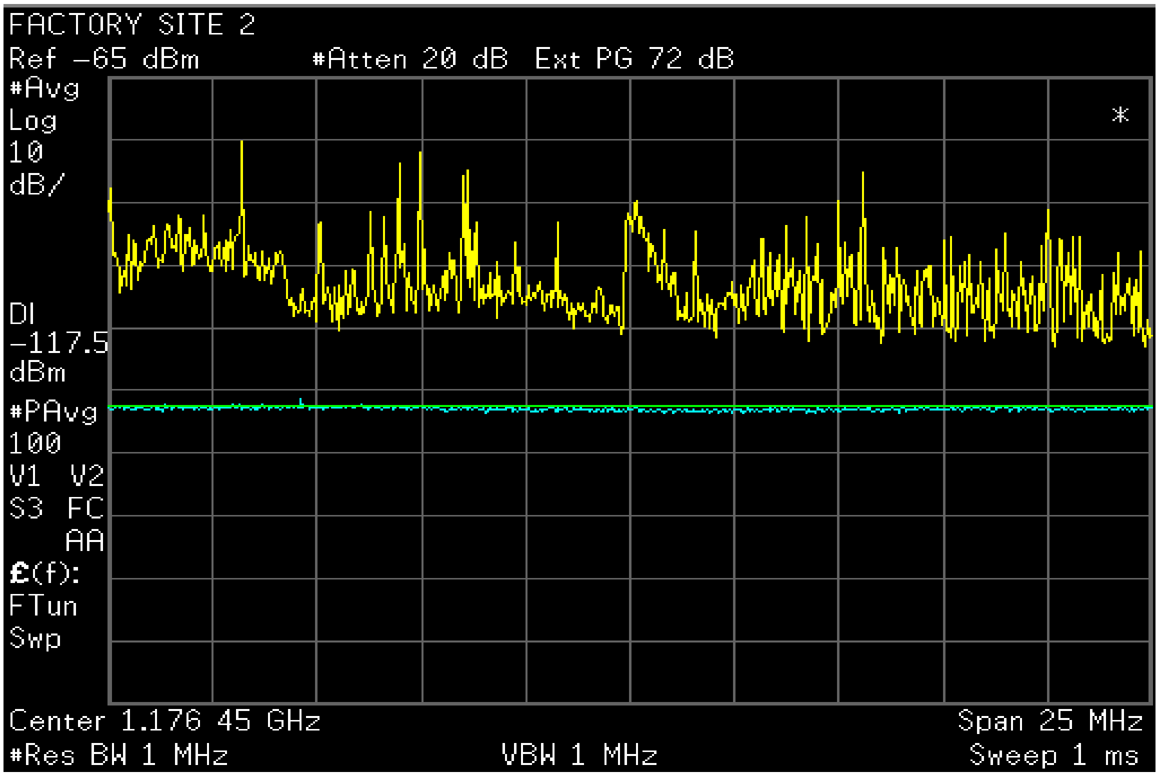


Figure D-107. Ambient Emissions in GPS L5 Frequency Band at Factory Site #2.

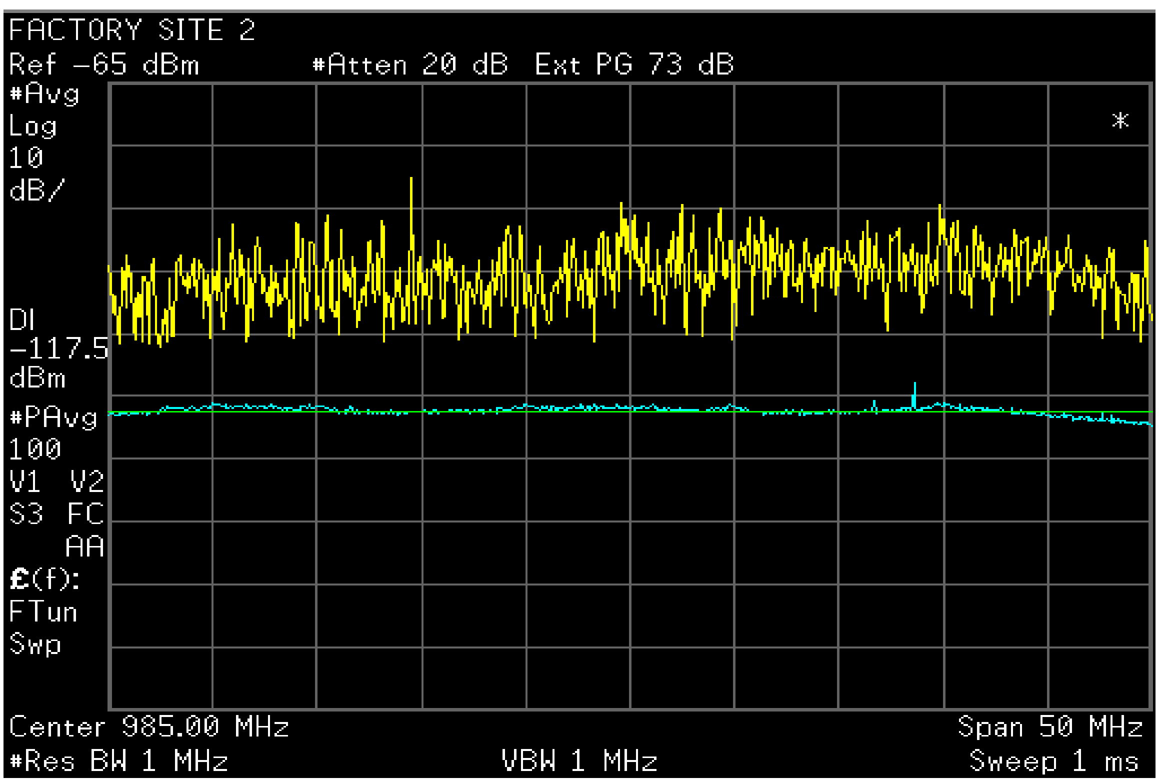


Figure D-108. Ambient Emissions in 960-1010 MHz Frequency Band at Factory Site #2.

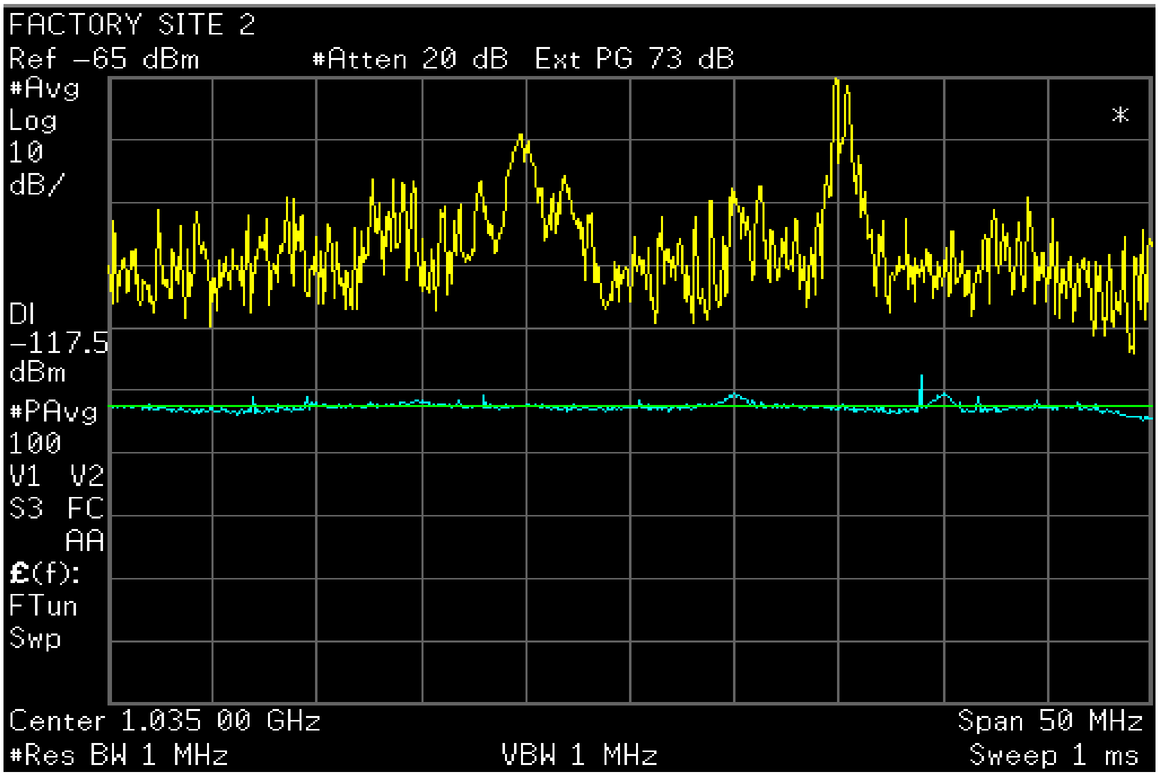


Figure D-109. Ambient Emissions in 1010-1060 MHz Frequency Band at Factory Site #2.

Figure D-110. Ambient Emissions in 1060-1110 MHz Frequency Band at Factory Site #2.

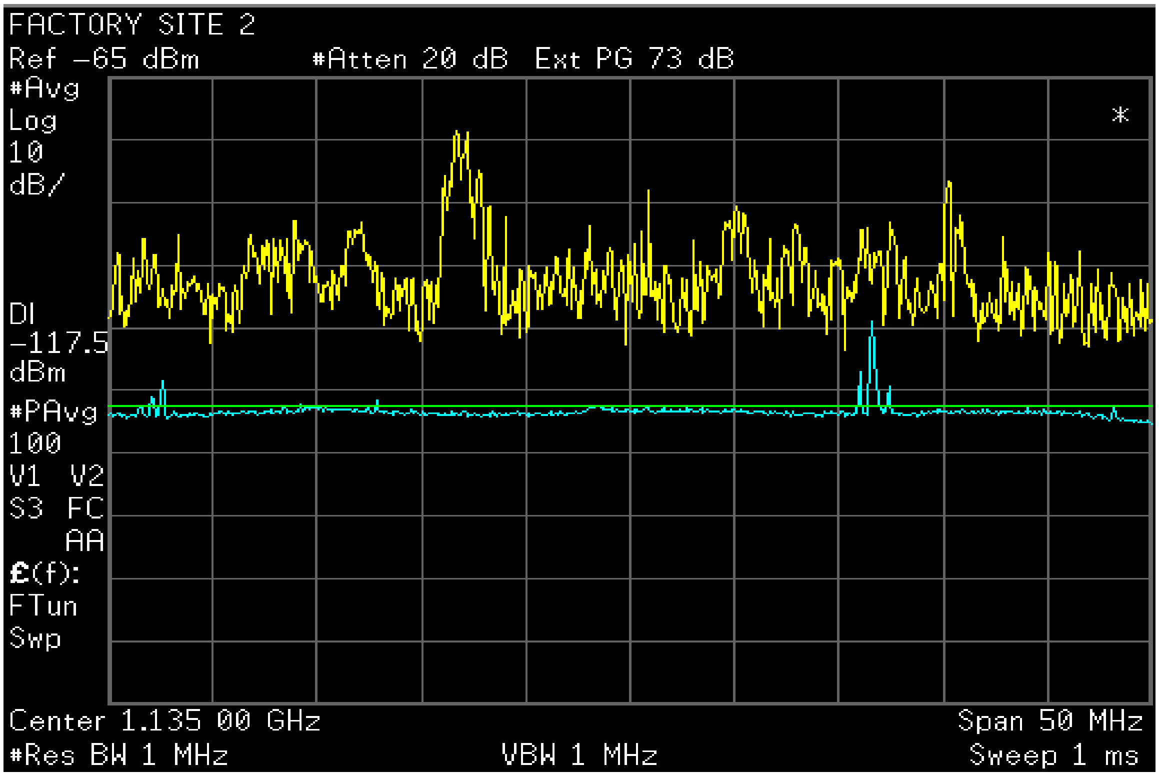


Figure D-111. Ambient Emissions in 1110-1160 MHz Frequency Band at Factory Site #2.

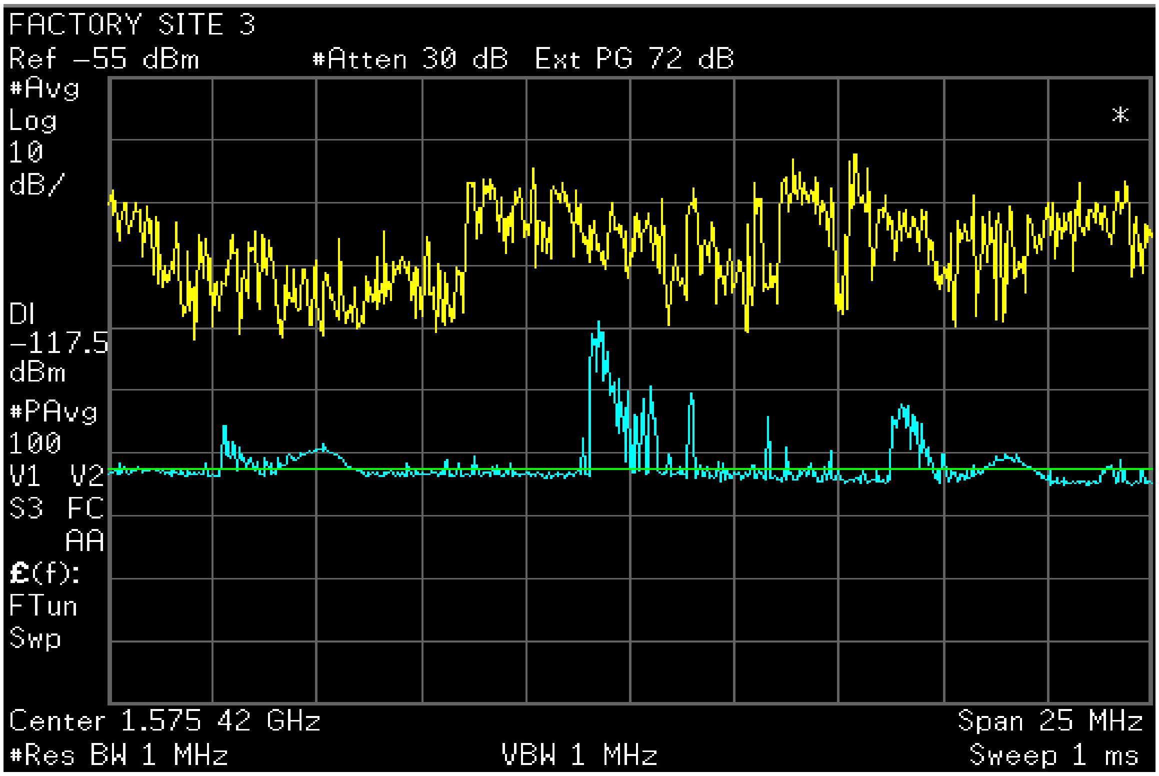


Figure D-112. Ambient Emissions in GPS L1 Frequency Band at Factory Site #3.

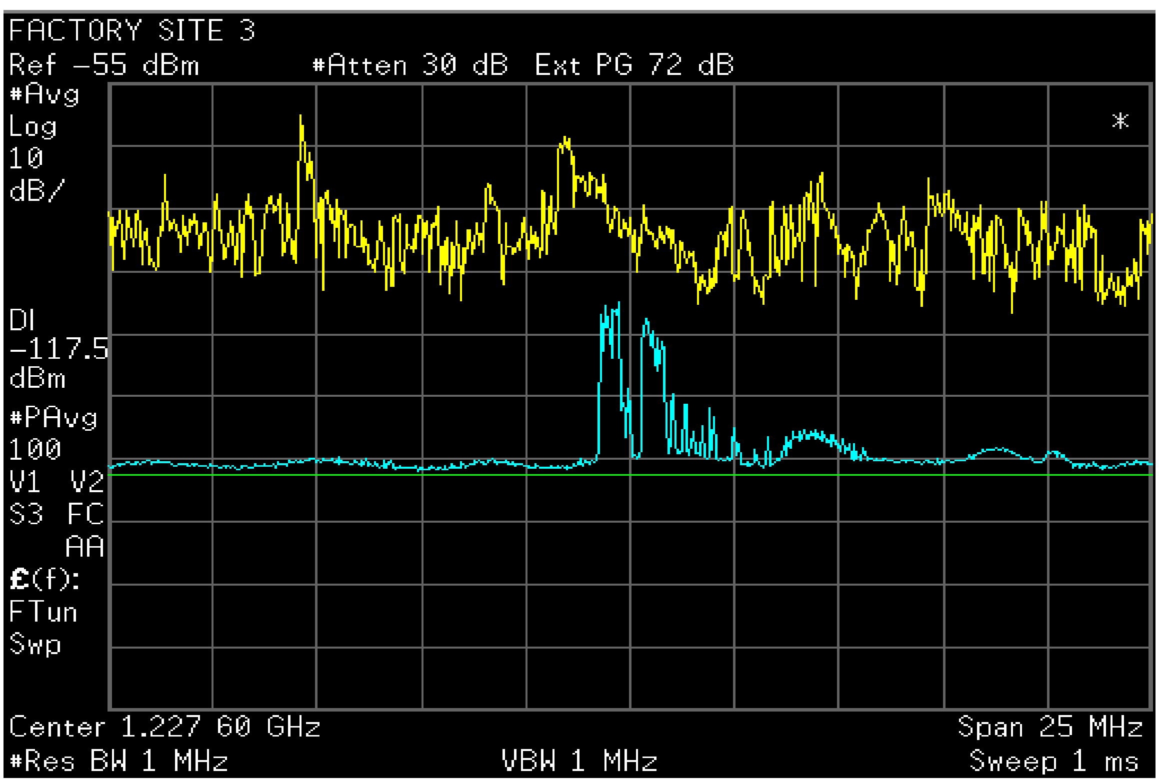


Figure D-113. Ambient Emissions in GPS L2 Frequency Band at Factory Site #3.

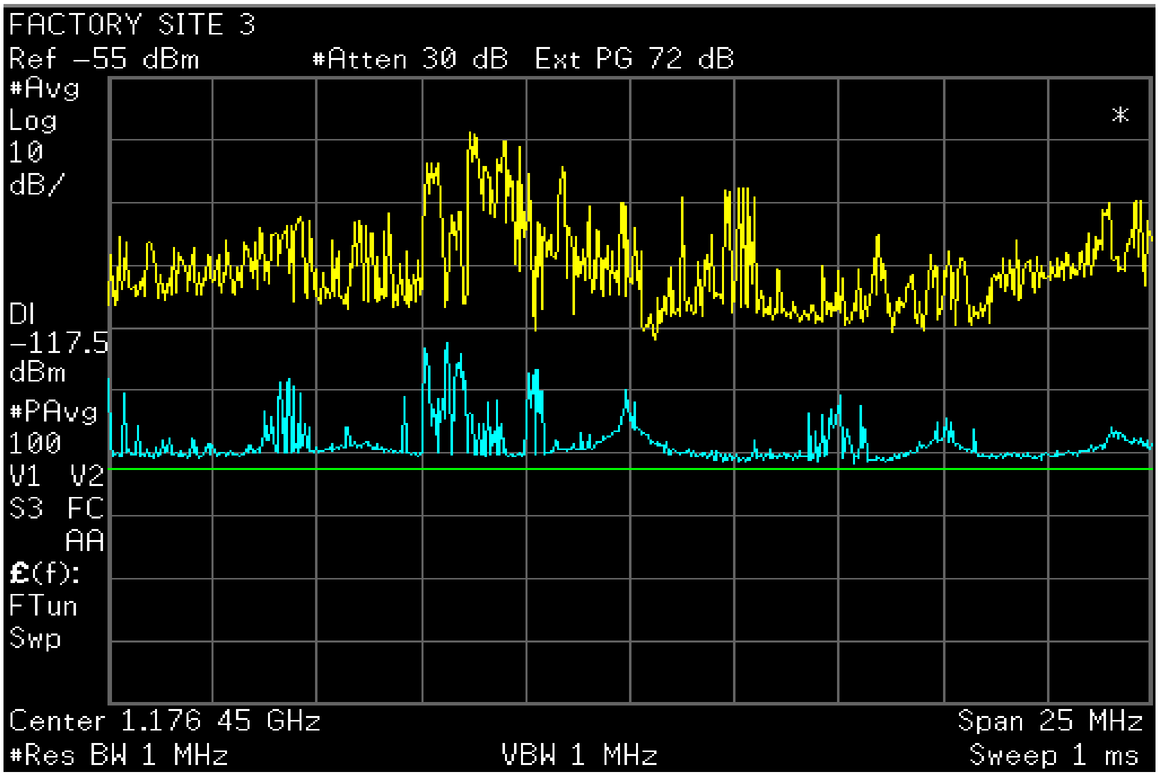


Figure D-114. Ambient Emissions in GPS L5 Frequency Band at Factory Site #3.

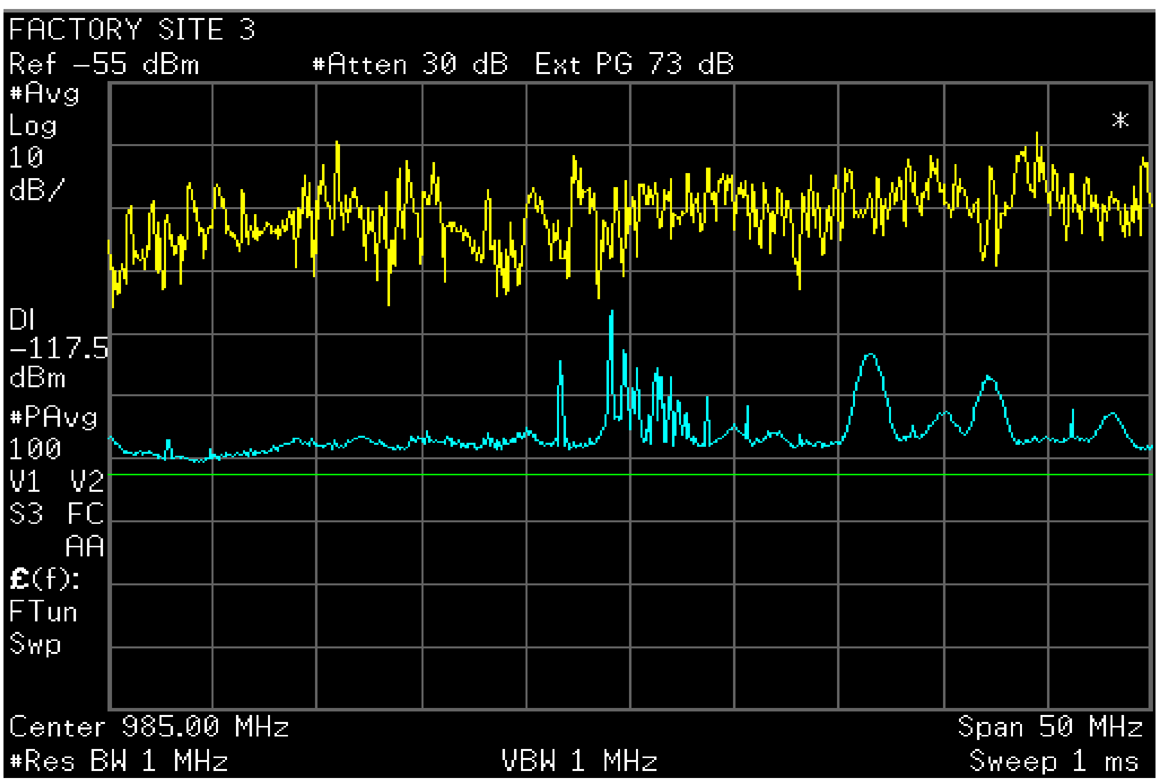


Figure D-115. Ambient Emissions in 960-1010 MHz Frequency Band at Factory Site #3.

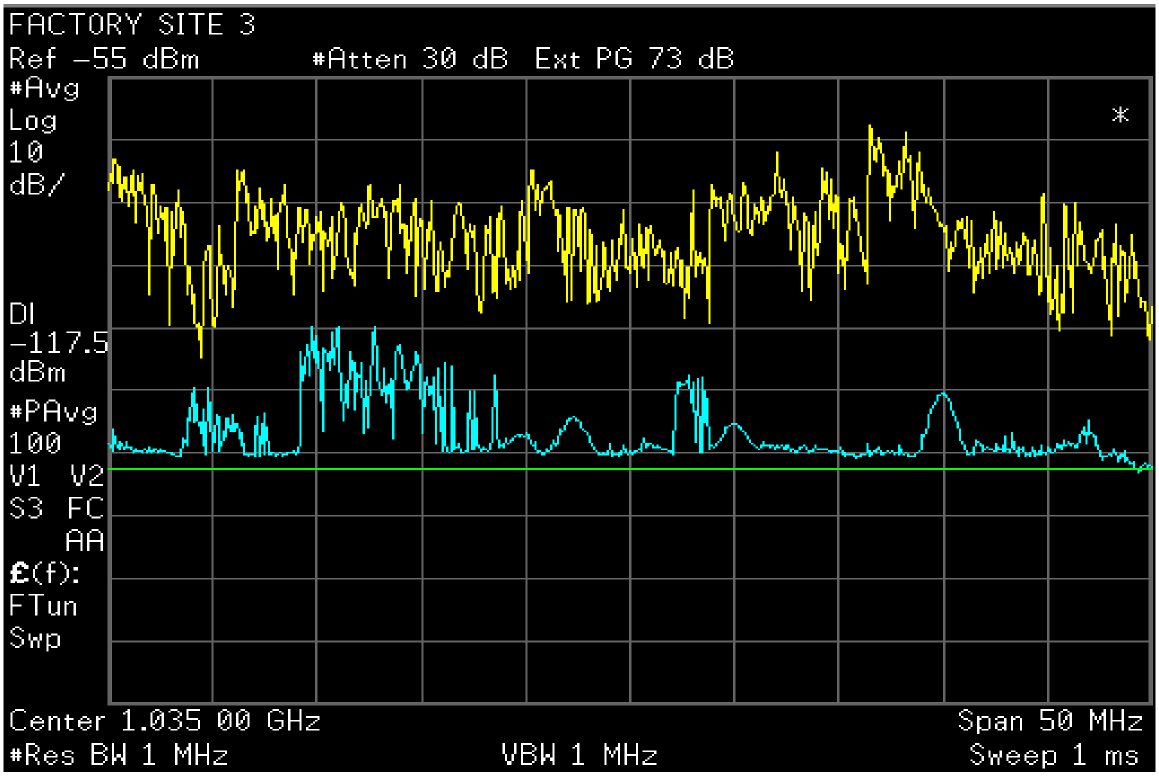


Figure D-116. Ambient Emissions in 1010-1060 MHz Frequency Band at Factory Site #3.

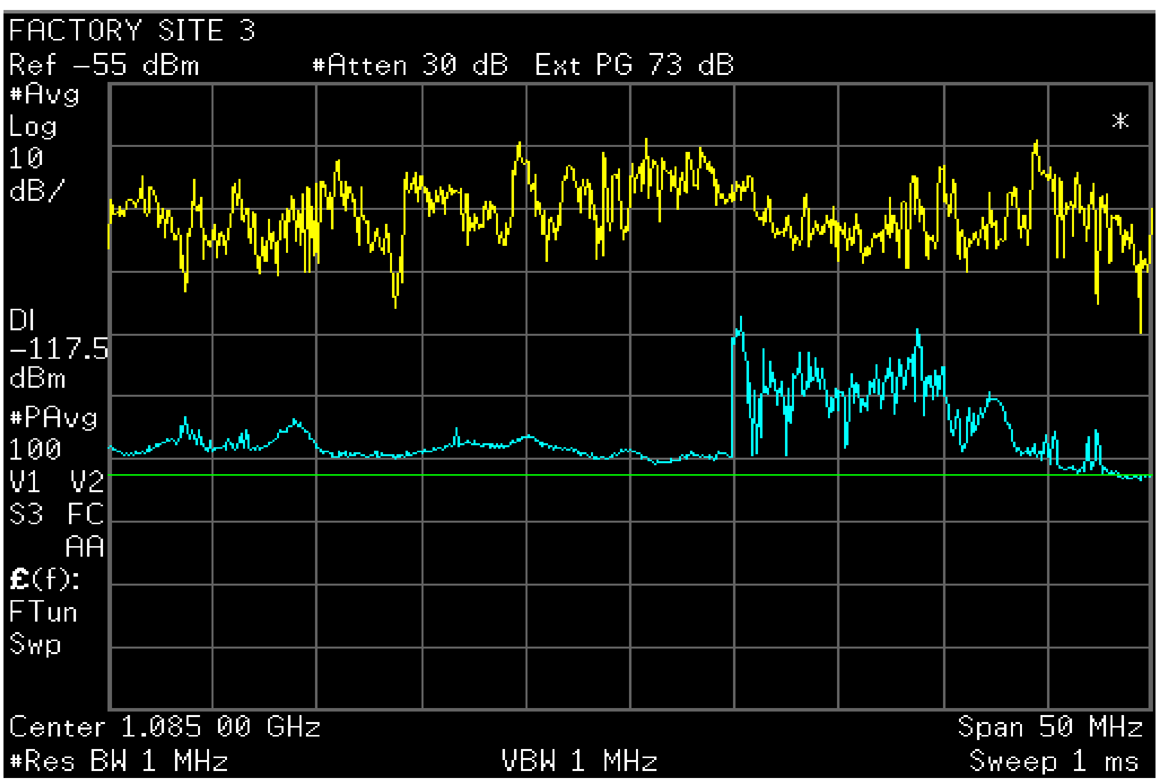


Figure D-117. Ambient Emissions in 1060-1110 MHz Frequency Band at Factory Site #3.

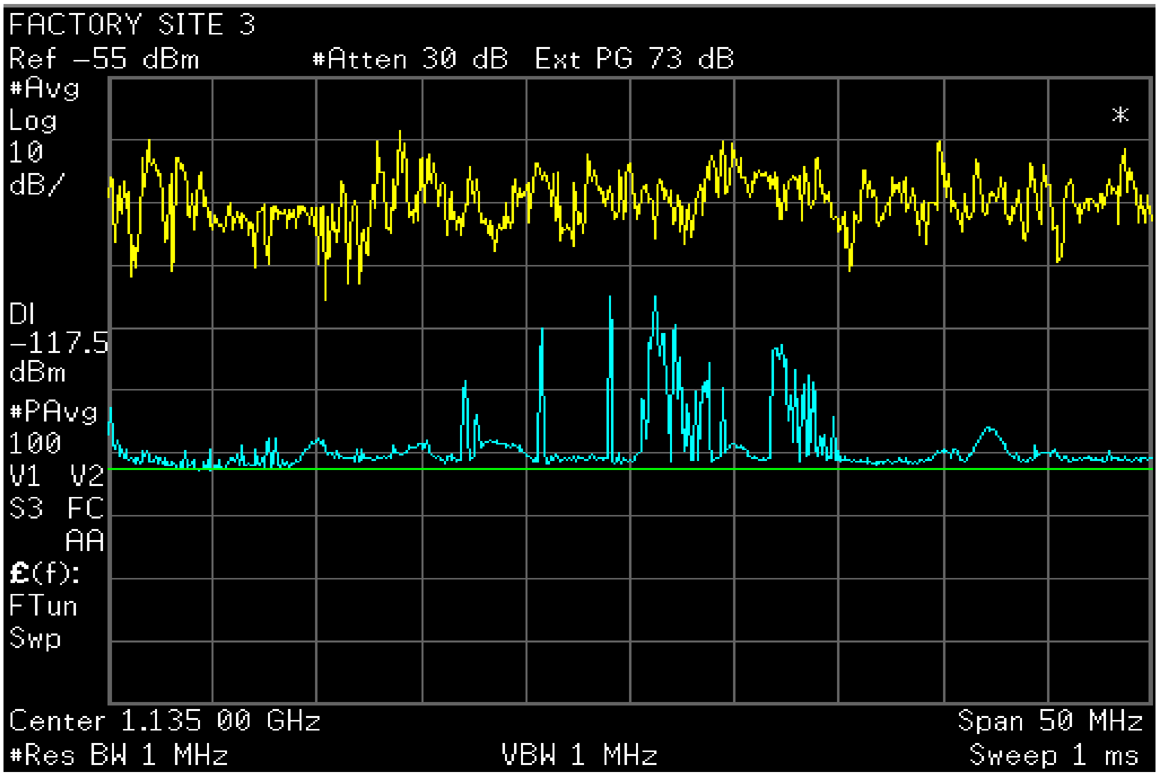


Figure D-118. Ambient Emissions in 1110-1160 MHz Frequency Band at Factory Site #3.

APPENDIX E
RADIATED EMISSIONS MEASUREMENT DATA

The data plots recorded from the measurements of radiated emissions from common consumer electronic/electrical devices are presented in this appendix.

In each of the spectrum analyzer plots presented in this Appendix, two measurement traces are shown. The lower (yellow) trace represents the background (ambient) emissions in the frequency band under examination with the DUT turned off. The upper (blue) trace represents the sum of the RMS average emissions radiated from the DUT and the existing background (ambient) emissions. A constant display line (green) is also shown in each plot. This is set to a level of -117.5 dBm to represent the received power equivalent to the UWB EIRP limit of -75.3 dBm/MHz at a distance of two meters.

All external measurement system parameters (e.g., amplifier gains, cable loss, and antenna gain) are accounted for in the spectrum analyzer display and are provided on each plot under the tag Ext PG located at the top of the display.

In each of these plots, the horizontal axis represents frequency and the vertical axis represents amplitude. A span of 25 MHz was used to encompass the 24 MHz registered GPS frequency band. For a 25 MHz span, each vertical graticule line represents a 2.5 MHz deviation in frequency (25 MHz/10 graticule lines). On the amplitude axis, each horizontal graticule line represents a 10 dB decrement from the reference level amplitude shown in the upper left-hand corner of the plot. Note that some of these plots utilize other than 10 dB per vertical division (graticule line). This was done to facilitate better resolution of the signals under examination. These plots are read the same way as described previously except that each vertical line may represent a deviation of 2, 3, or 5 dB from the reference level. The dB-per-division scale, applicable to each plot, is shown in the upper left-hand margin.

An important consideration in the interpretation of this data is the fact that the radiated spurious power captured by the measurement system is actually the sum of the ambient emissions already present and those spurious emissions introduced when the DUT is turned on. Since the emissions under consideration in this study are often very close to the ambient noise floor, the contribution of the noise floor to this sum can be significant. Within this study, if the difference between the measured ambient level and the corresponding radiated-plus-ambient level is 3 dB, then the DUT emission amplitude level is interpreted as being equivalent to the ambient level. Accordingly, if the difference between the DUT radiated-plus-ambient emission level and the corresponding ambient emission level is less than 3 dB, then the DUT emission level is interpreted as being less than the ambient level. Emissions that are more than 3 dB above the corresponding ambient level are attributed to spurious emissions from the DUT.

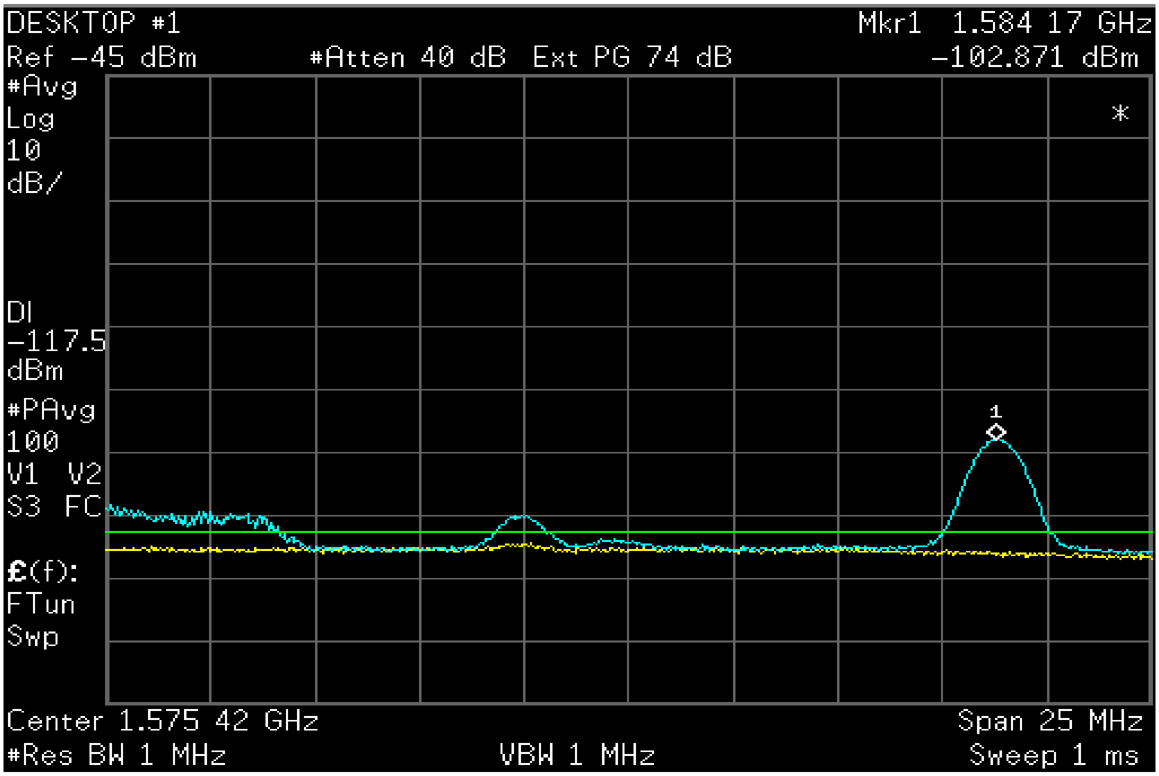


Figure E-119. Desktop Computer #1 Radiated Emissions in GPS L1 Frequency Band.

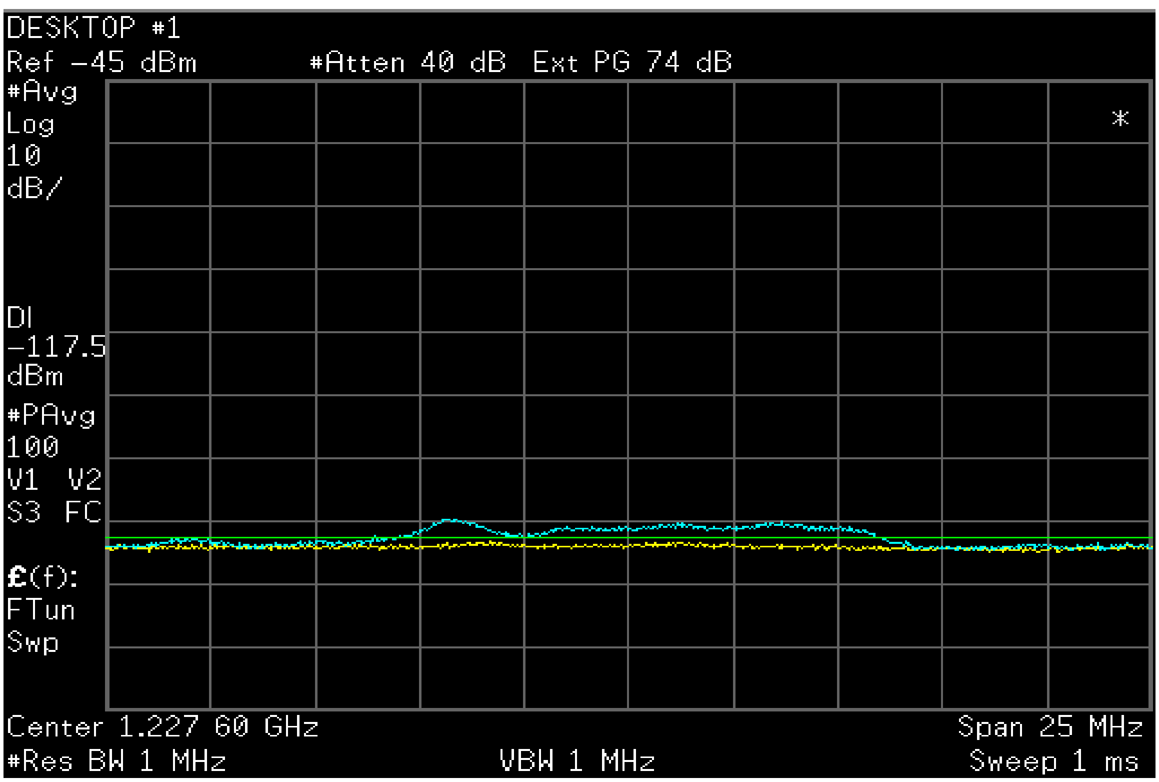


Figure E-120. Desktop Computer #1 Radiated Emissions in GPS L2 Frequency Band.

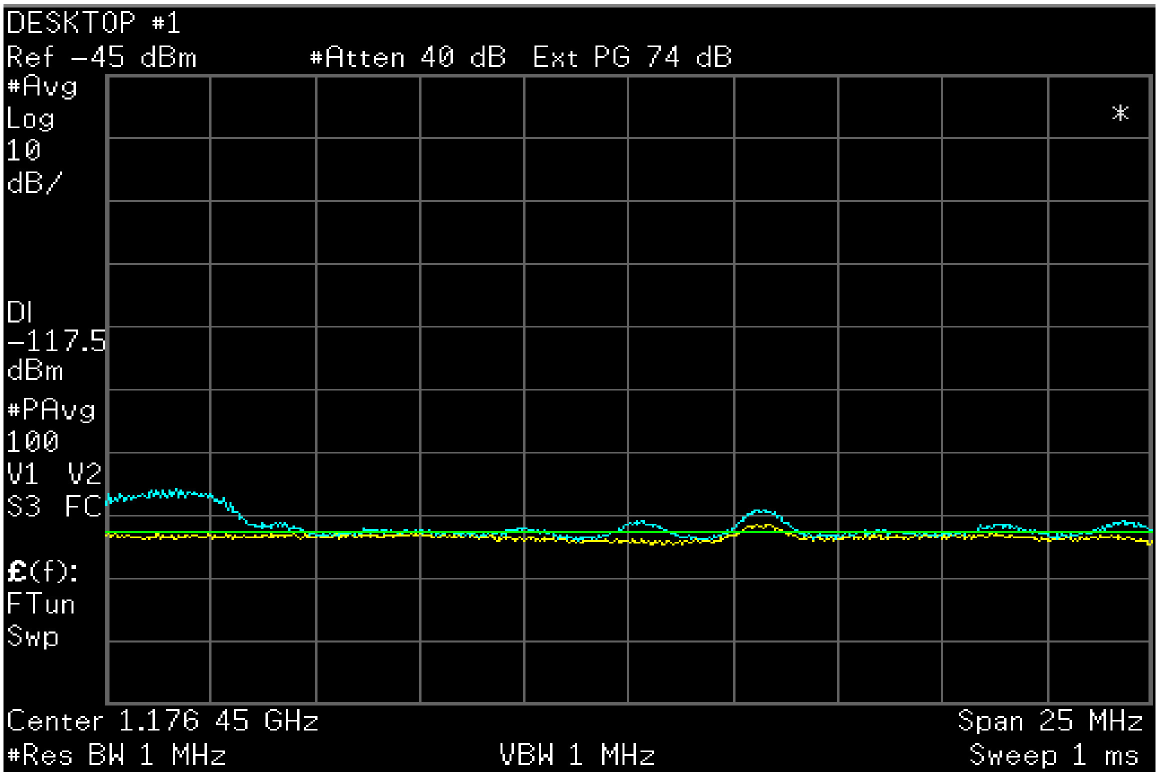


Figure E-121. Desktop Computer #1 Radiated Emissions in GPS L5 Frequency Band.

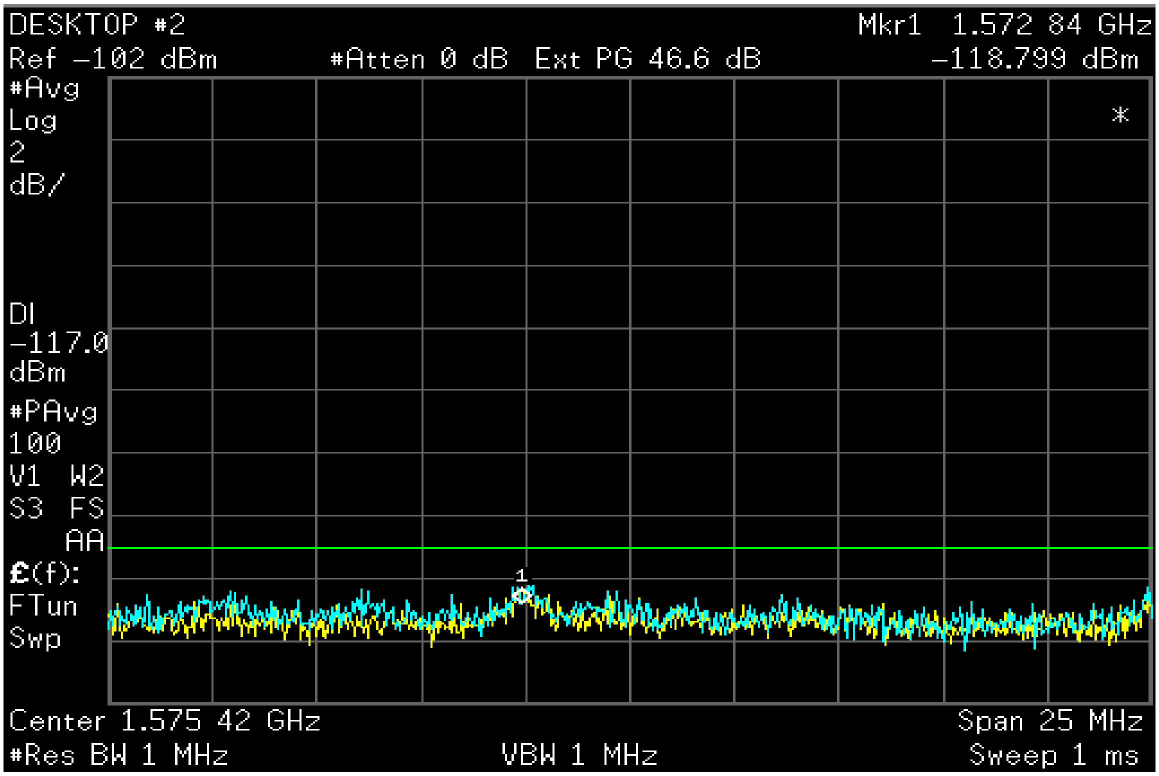


Figure E-122. Desktop Computer #2 Radiated Emissions in GPS L1 Frequency Band.

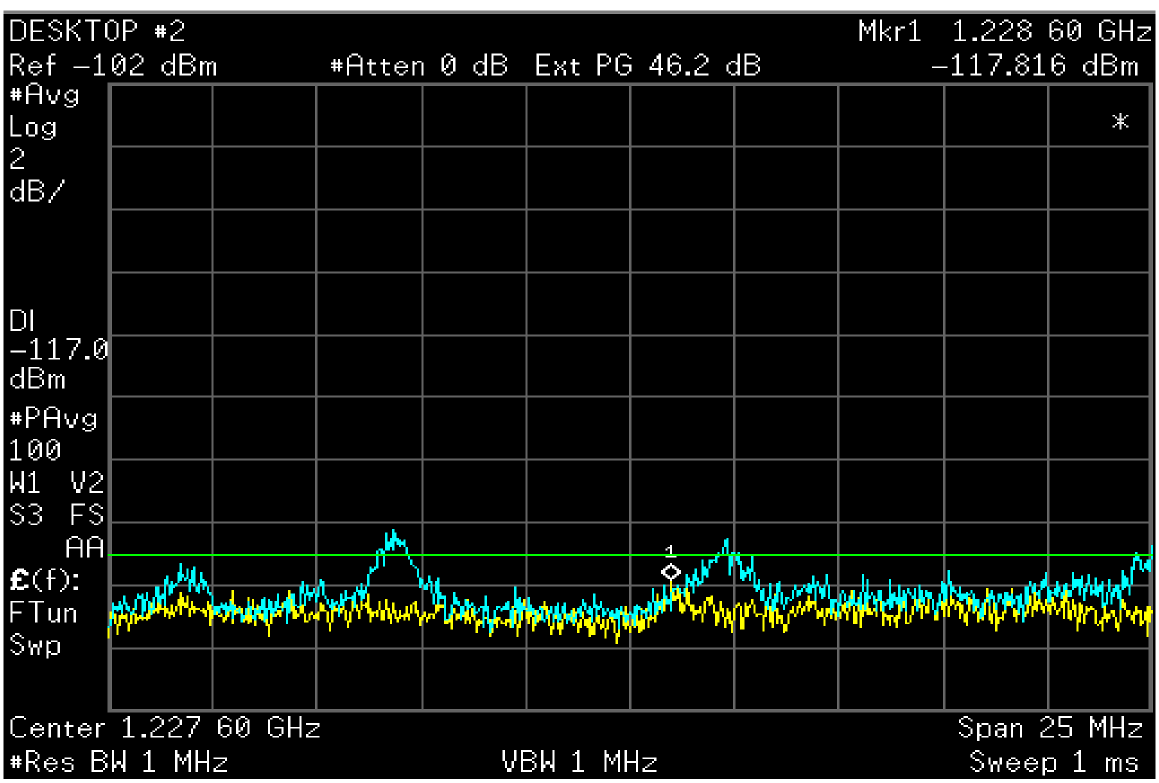


Figure E-123. Desktop Computer #2 Radiated Emissions in GPS L2 Frequency Band.

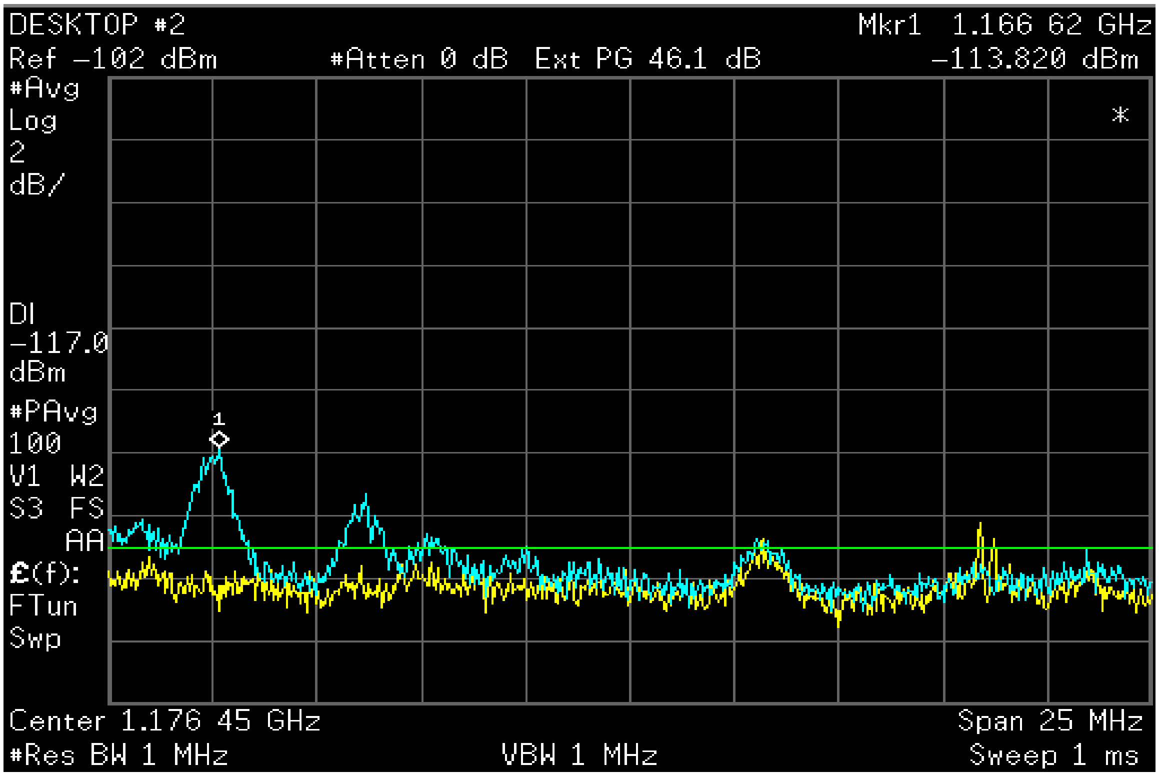


Figure E-124. Desktop Computer #2 Radiated Emissions in GPS L5 Frequency Band.

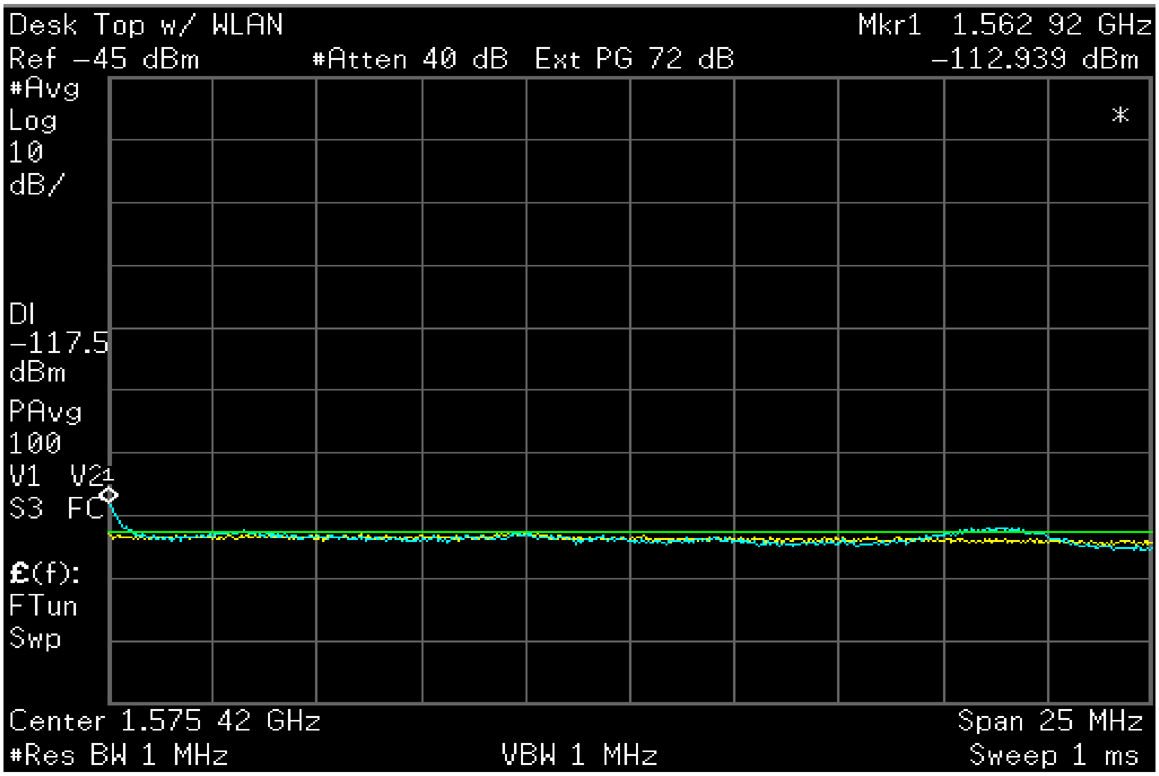


Figure E-125. Desktop Computer #3 Radiated Emissions in GPS L1 Frequency Band.

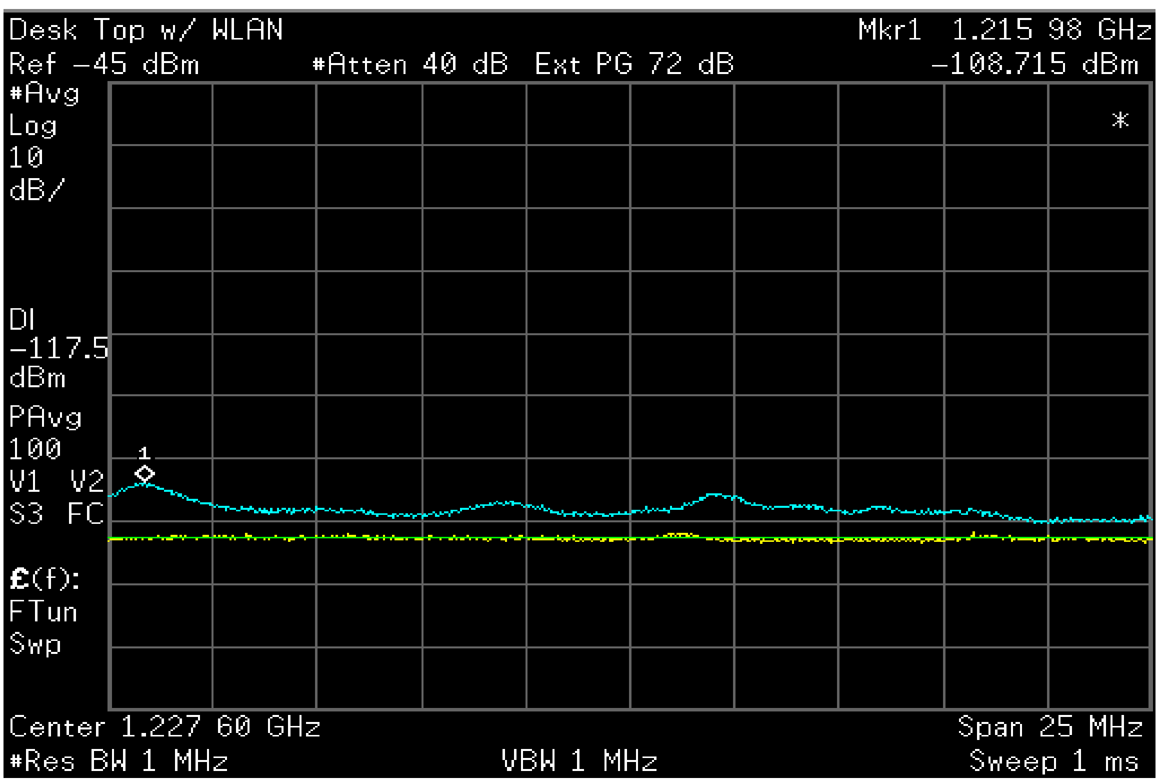


Figure E-126. Desktop Computer #3 Radiated Emissions in GPS L2 Frequency Band.

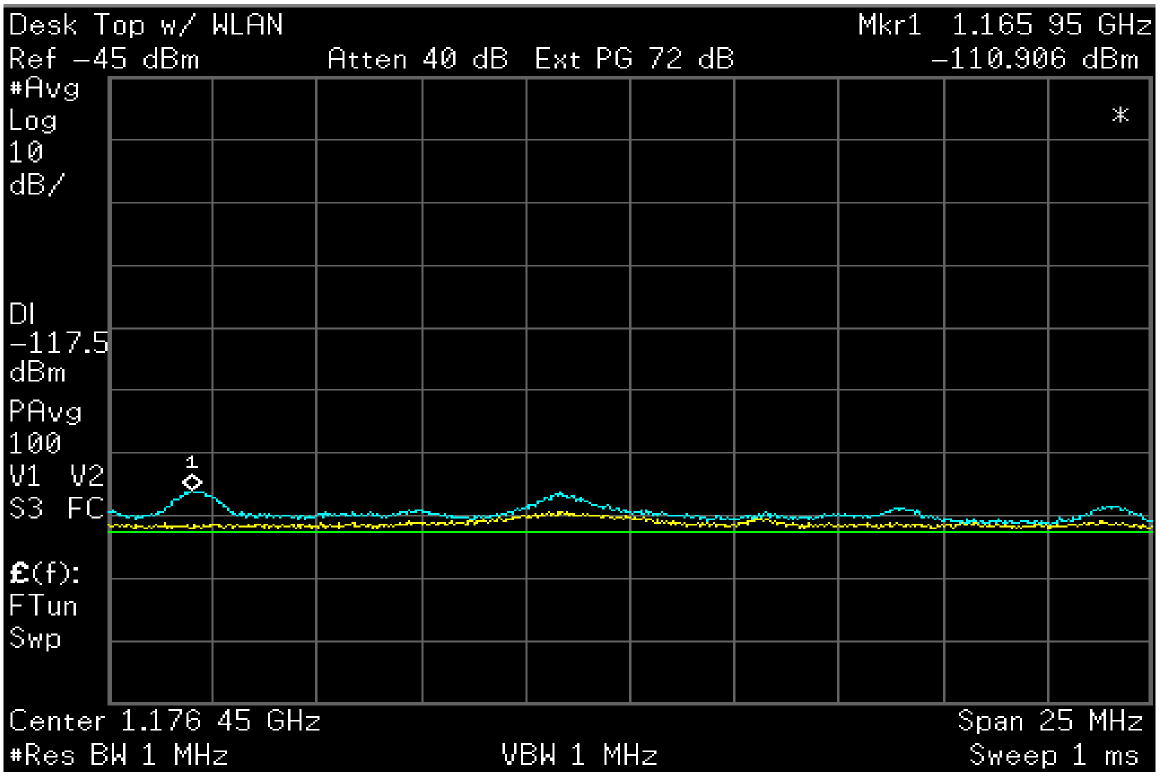


Figure E-127. Desktop Computer #3 Radiated Emissions in GPS L5 Frequency Band.

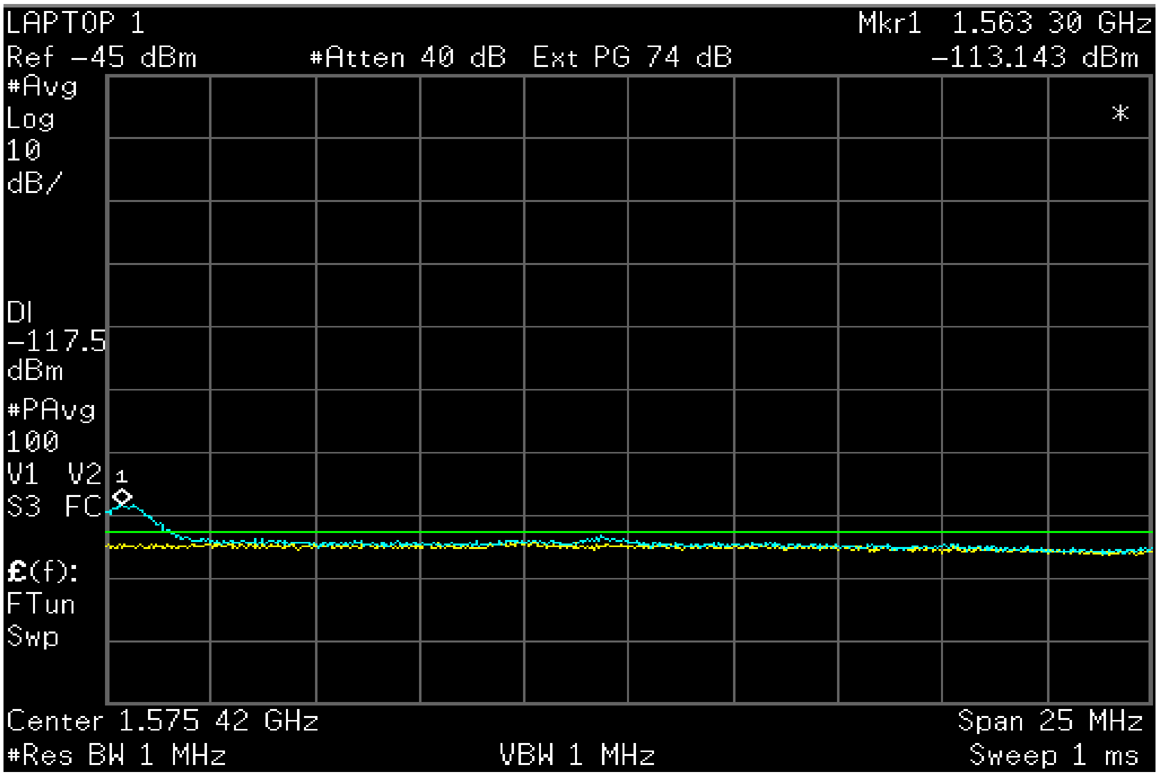


Figure E-128. Laptop Computer #1 Radiated Emissions in GPS L1 Frequency Band.

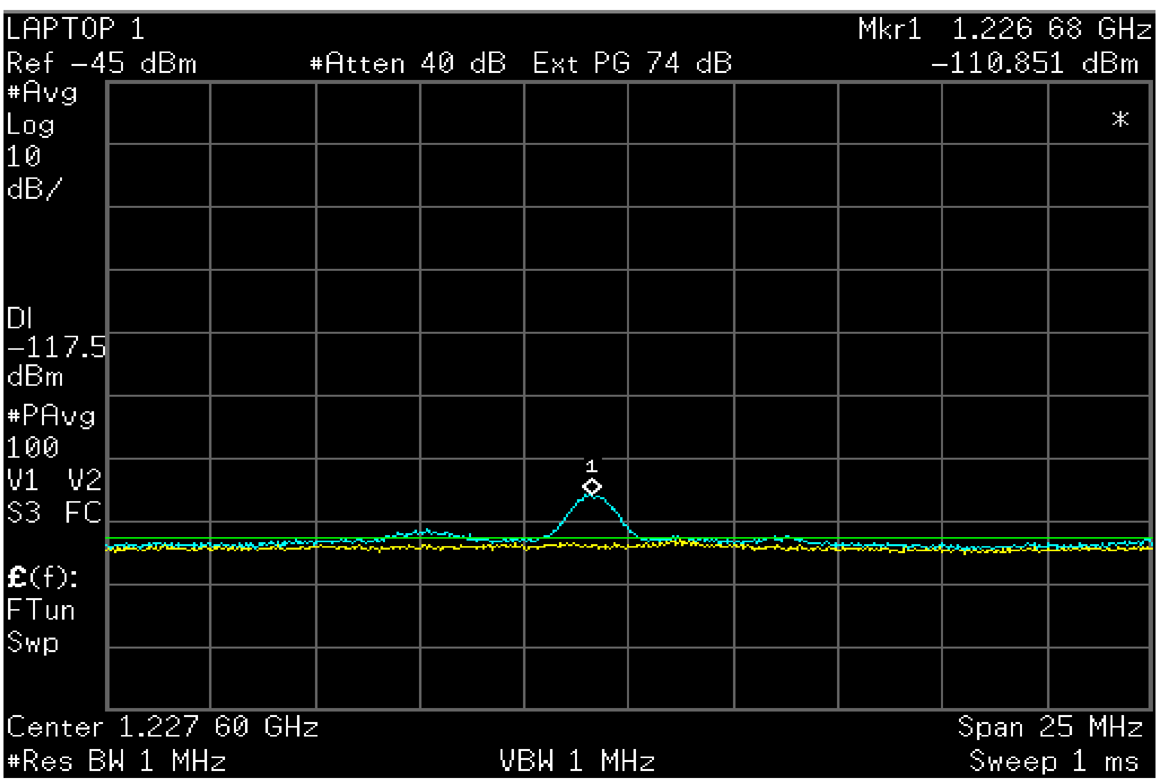


Figure E-129. Laptop Computer #1 Radiated Emissions in GPS L2 Frequency Band.

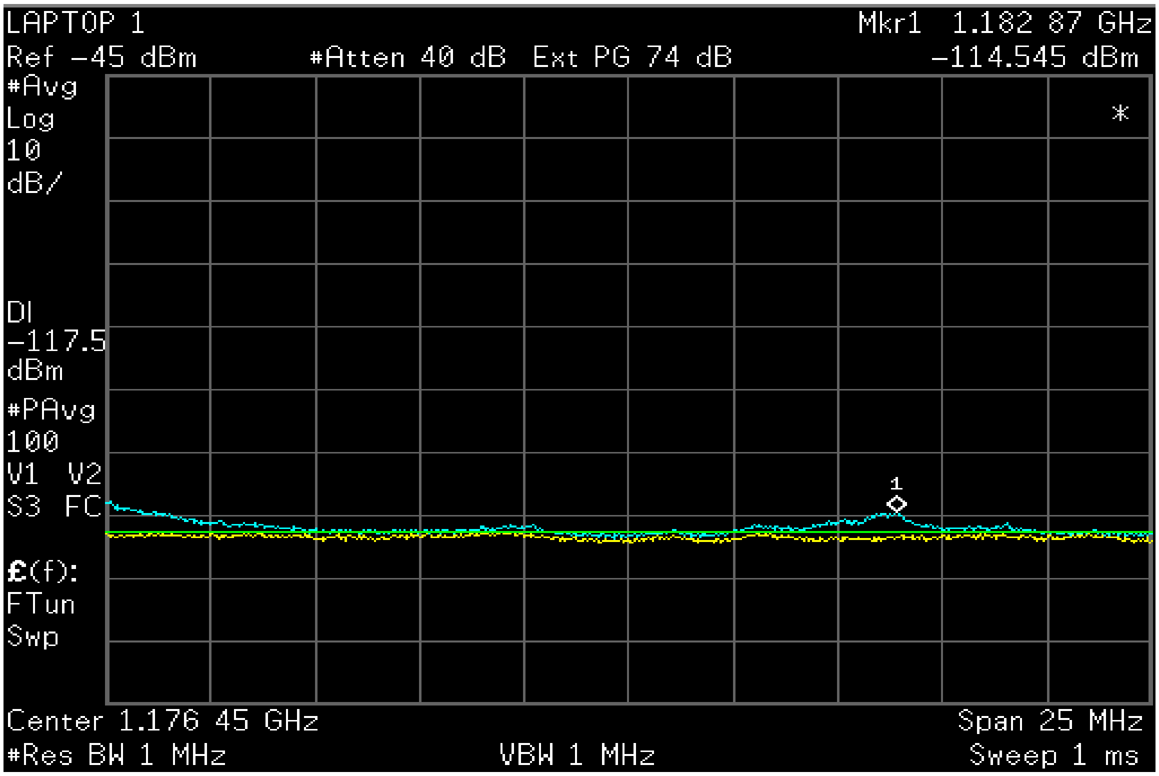


Figure E-130. Laptop Computer #1 Radiated Emissions in GPS L5 Frequency Band.

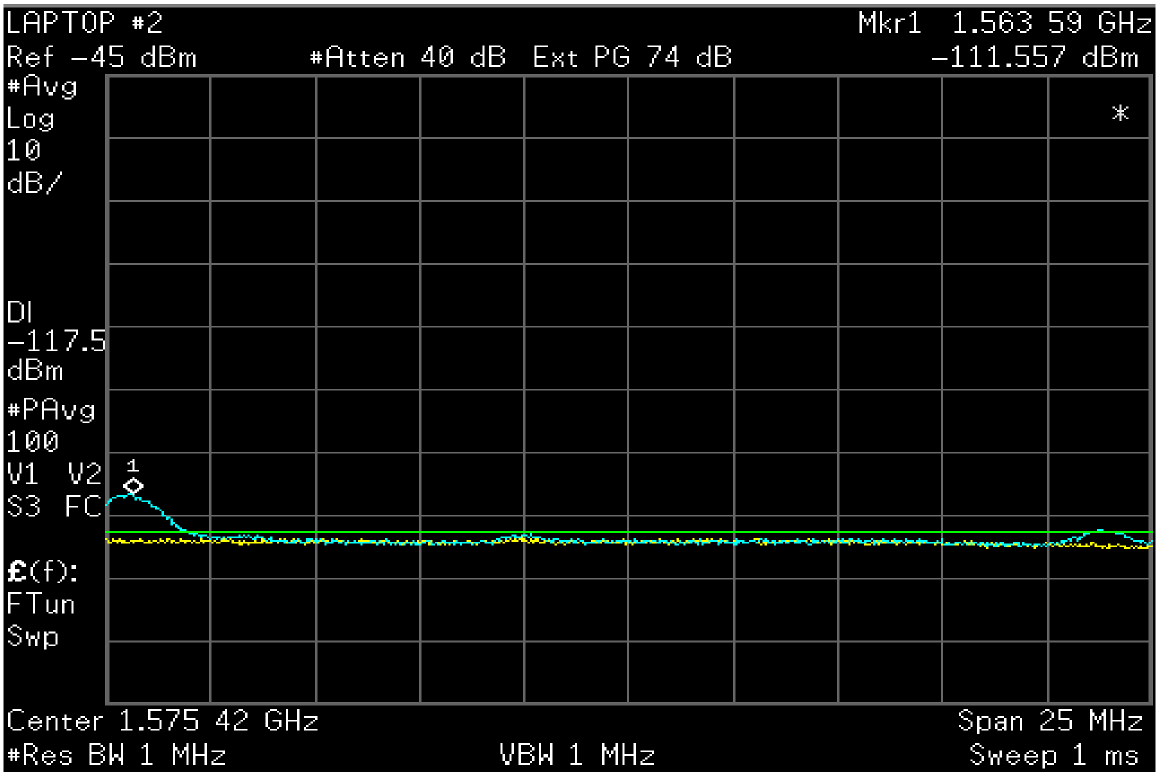


Figure E-131. Laptop Computer #2 Radiated Emissions in GPS L1 Frequency Band.

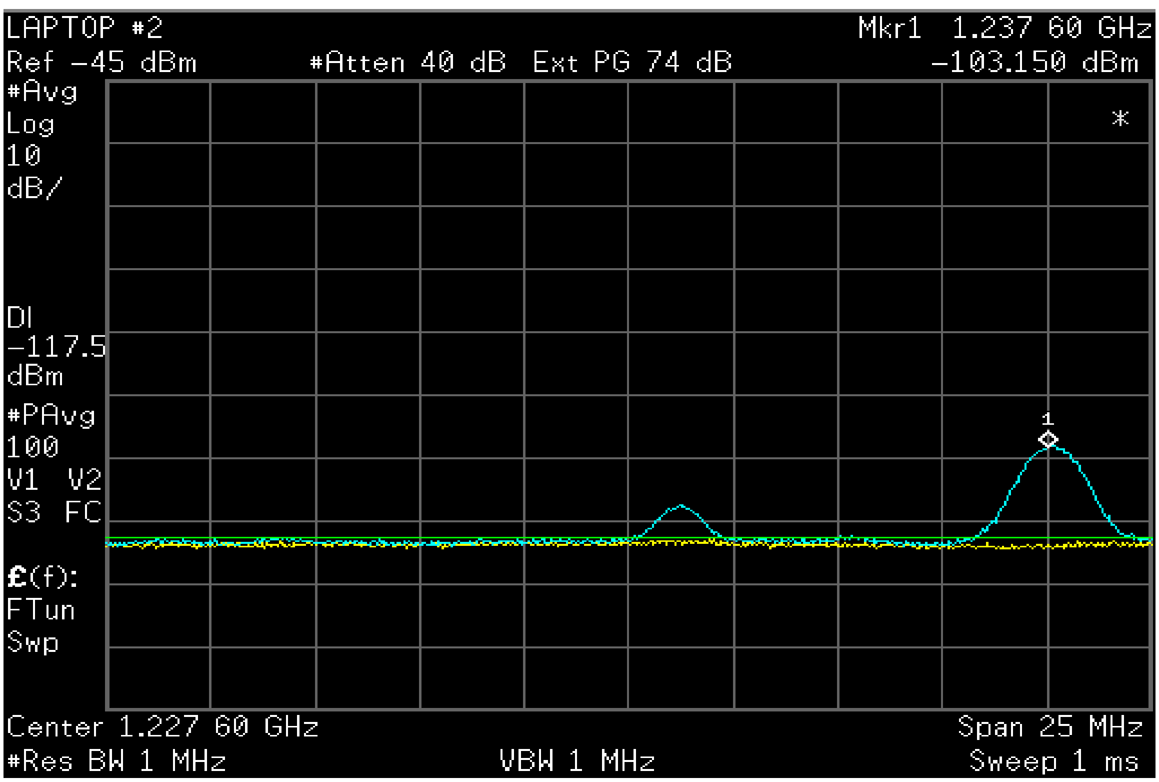


Figure E-132. Laptop Computer #2 Radiated Emissions in GPS L2 Frequency Band.

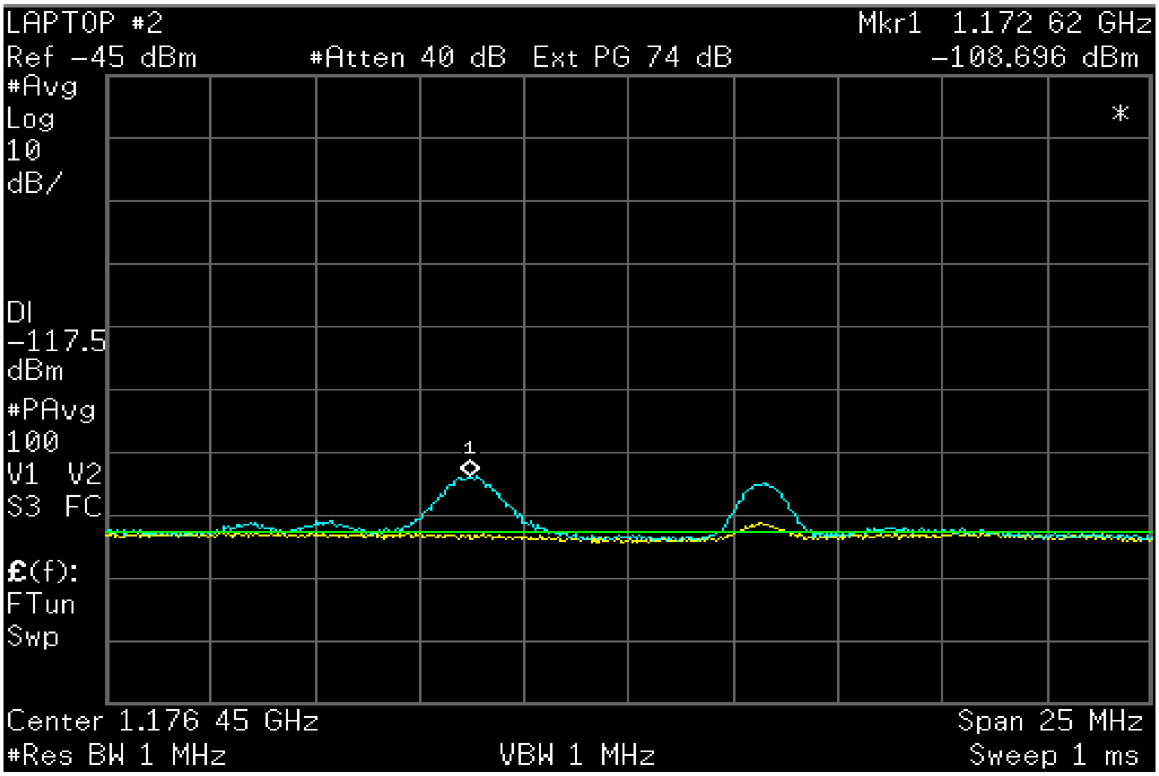


Figure E-133. Laptop Computer #2 Radiated Emissions in GPS L5 Frequency Band.

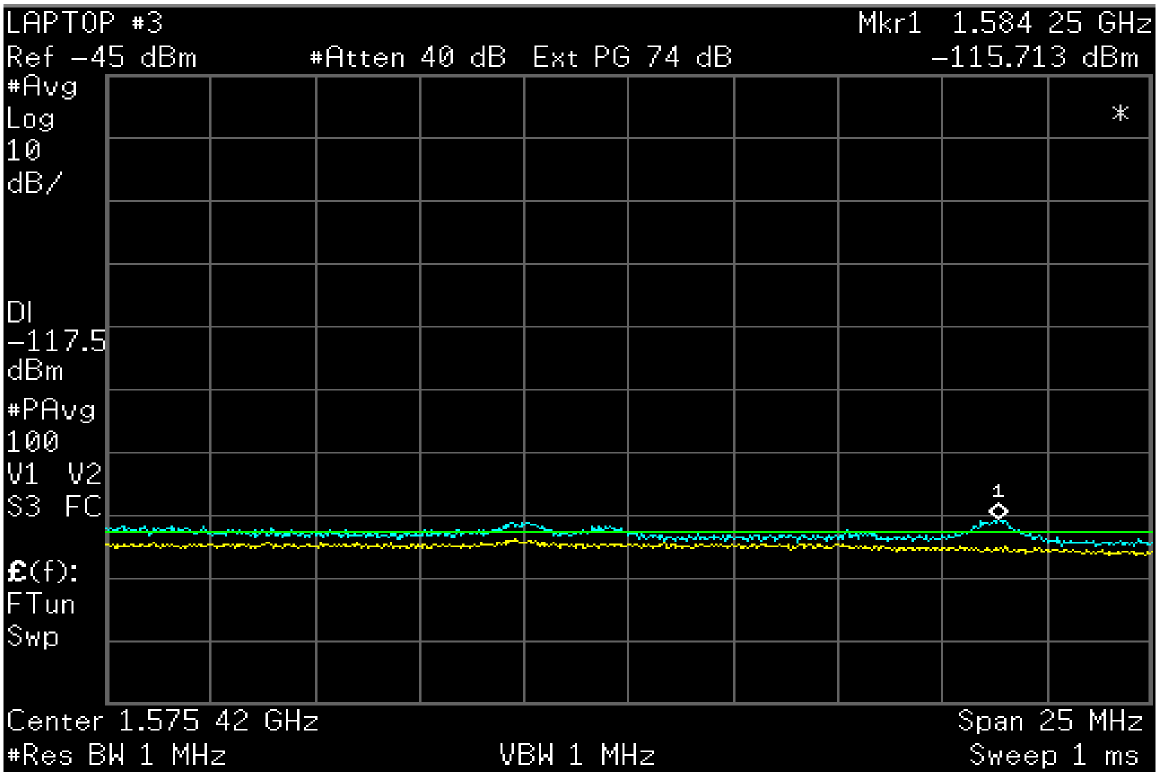


Figure E-134. Laptop Computer #3 Radiated Emissions in GPS L1 Frequency Band.

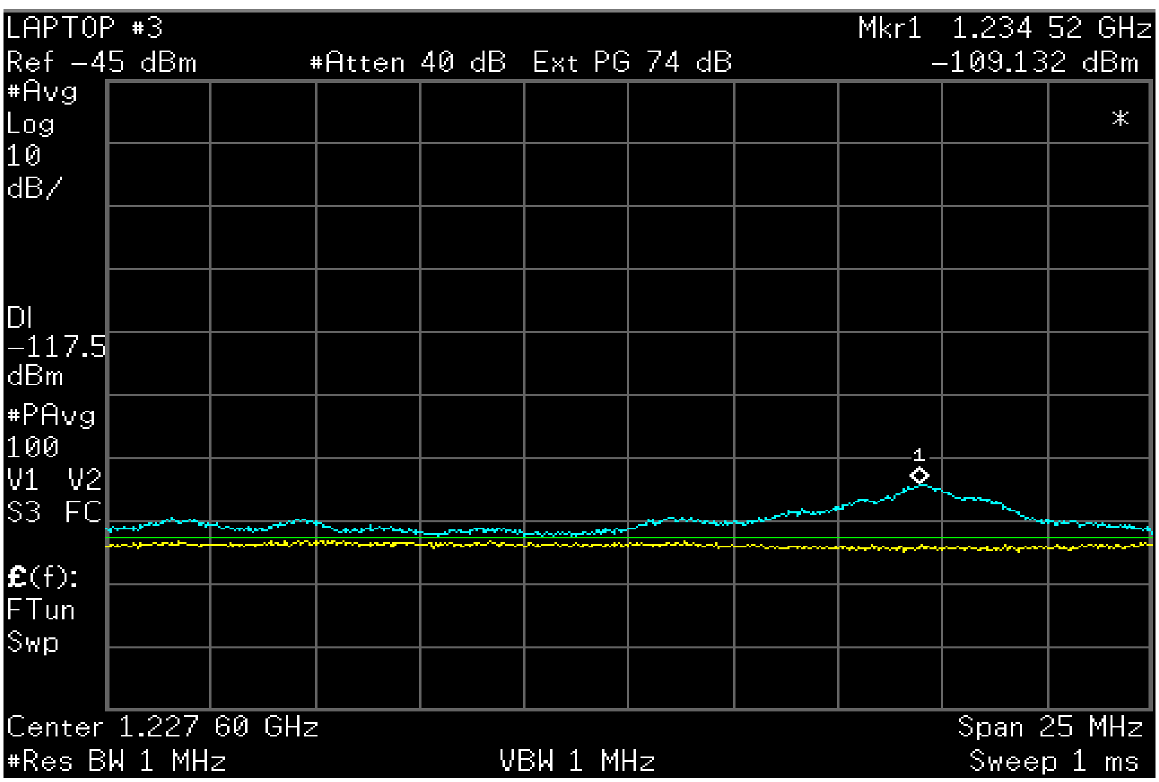


Figure E-135. Laptop Computer #3 Radiated Emissions in GPS L1 Frequency Band.

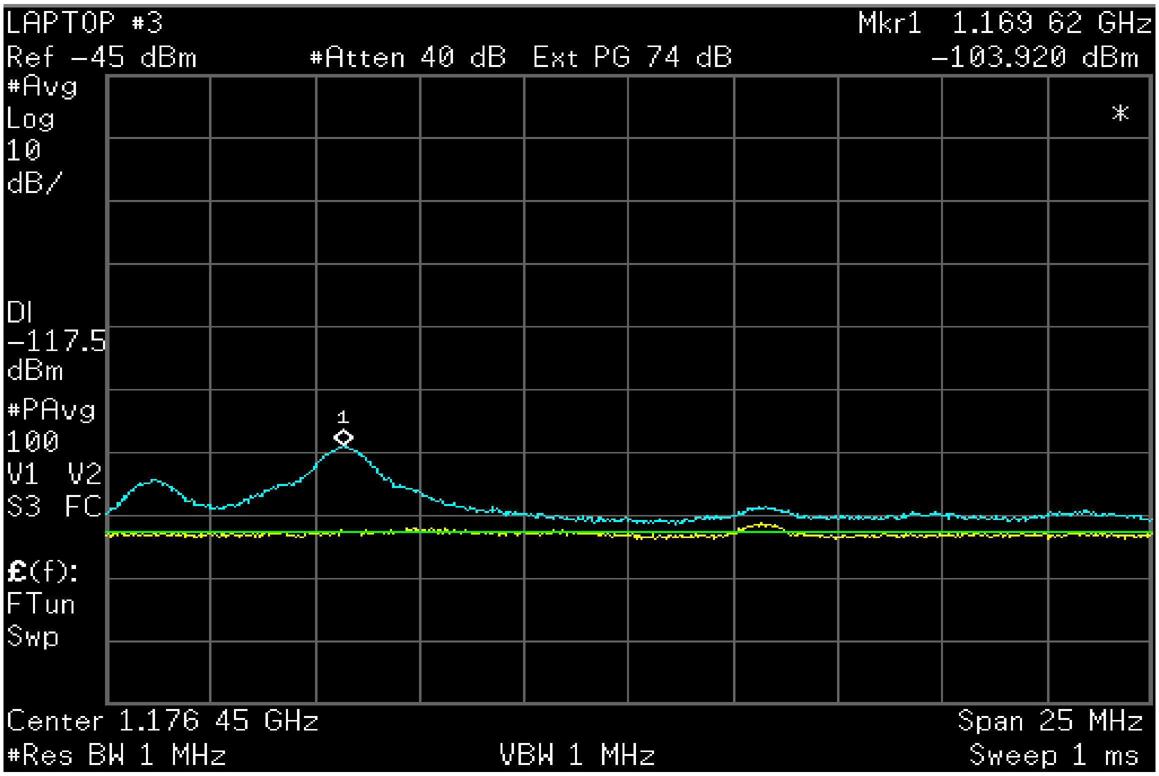


Figure E-136. Laptop Computer #3 Radiated Emissions in GPS L5 Frequency Band.

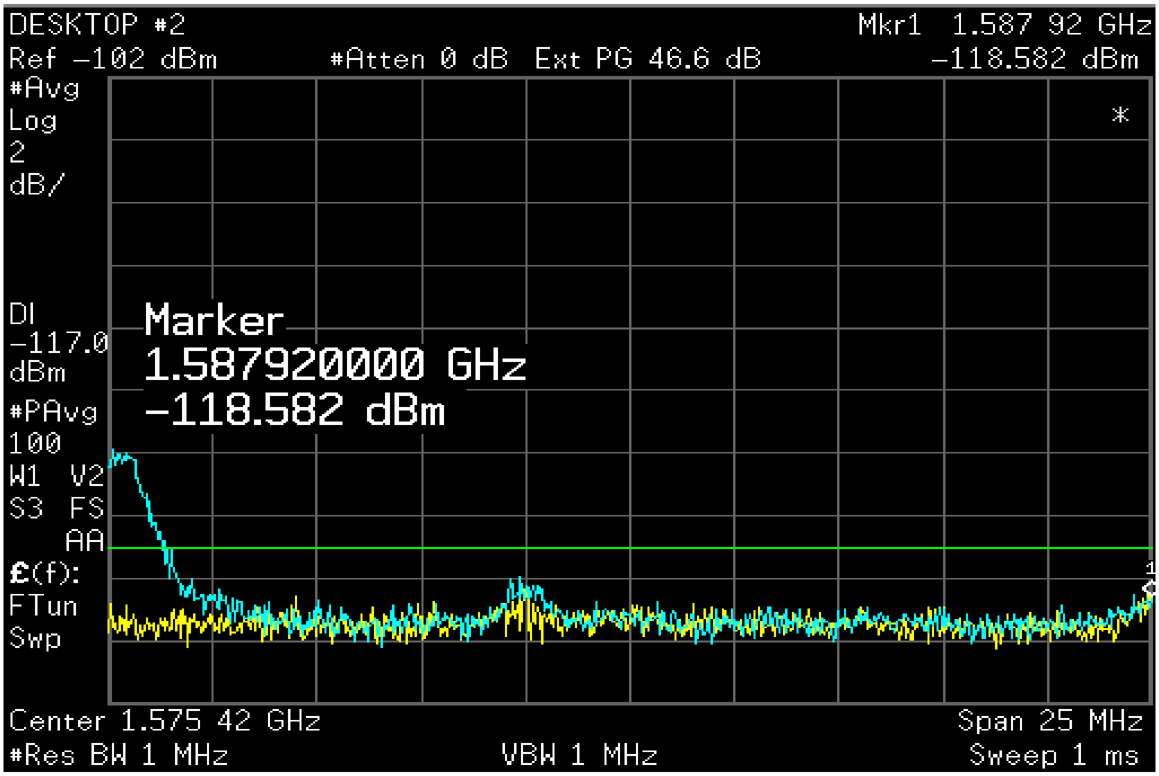


Figure E-137. Laptop Computer #4 Radiated Emissions in GPS L1 Frequency Band.

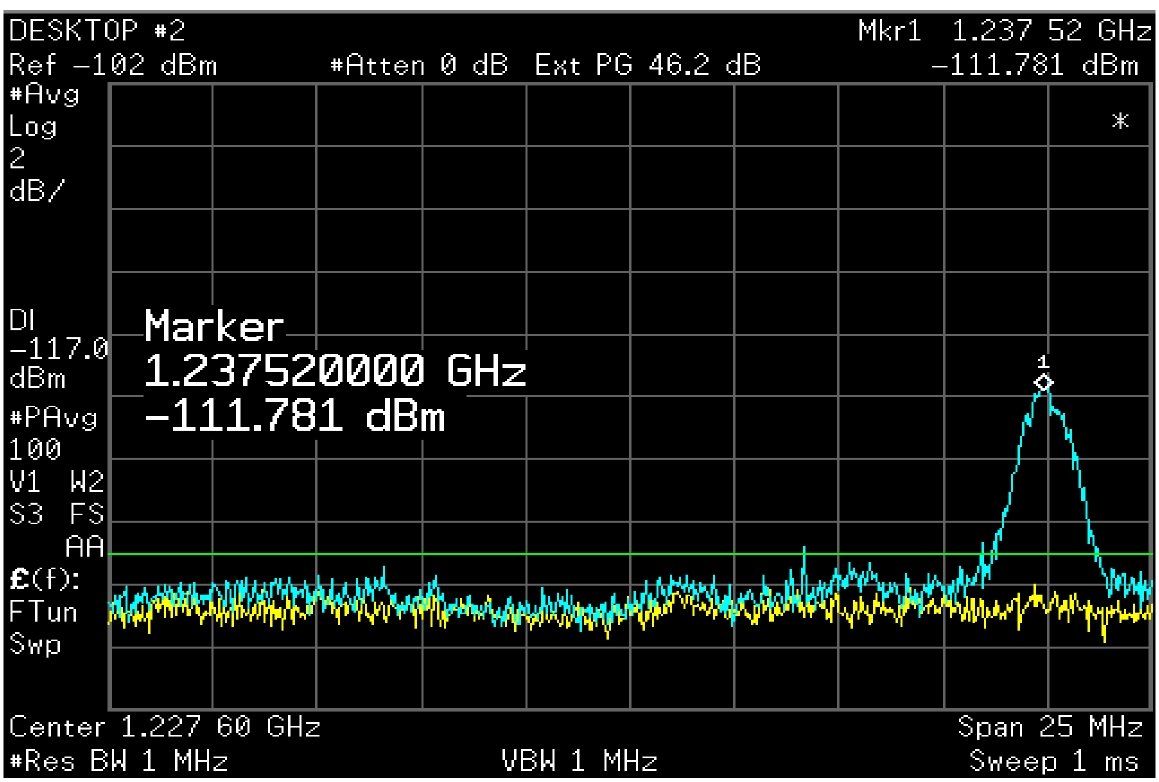


Figure E-138. Laptop Computer #4 Radiated Emissions in GPS L2 Frequency Band.

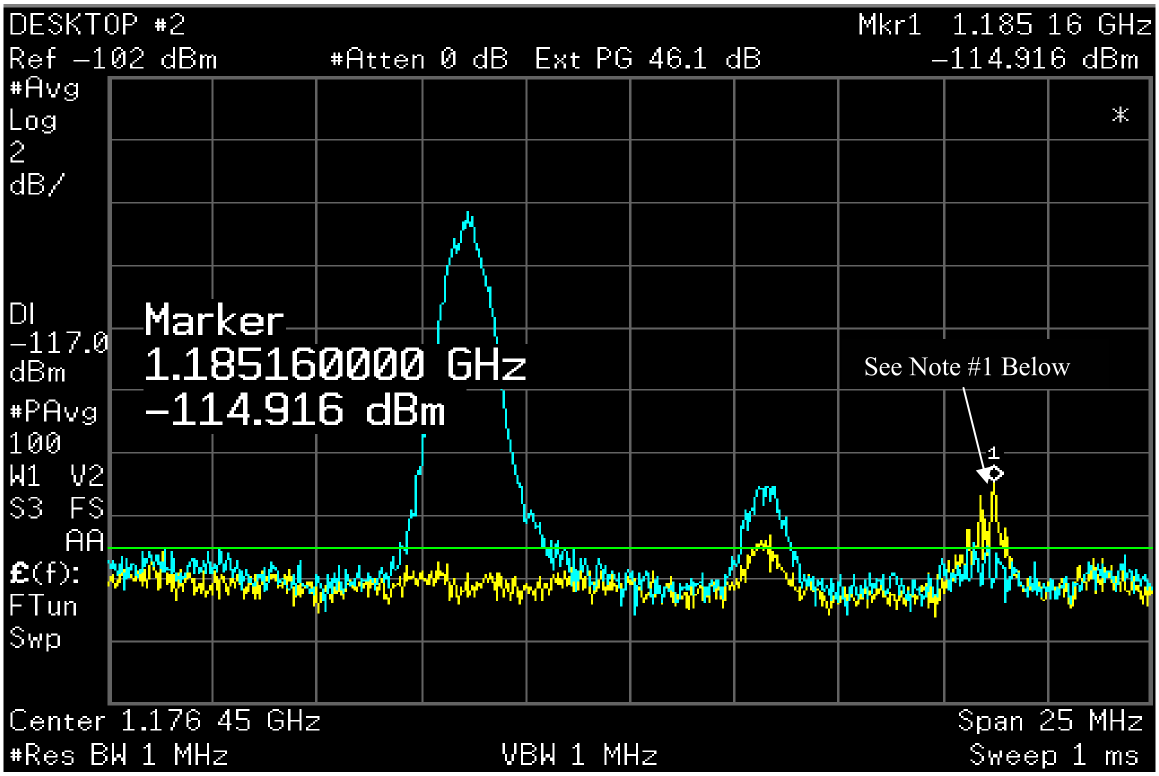


Figure E-139. Laptop Computer #4 Radiated Emissions in GPS L5 Frequency Band.

Note #1: In this spectral plot, the ambient or background emission level is shown as greater than the sum of the radiated emissions and the background emissions in the highlighted frequency range. Although this apparent inconsistency was not thoroughly examined, the most likely explanation is as follows: the background measurement and the radiated measurements were performed sequentially rather than simultaneously. The ambient emission was higher when the background measurement was performed than it was when the radiated measurement was made. This can be attributed to one or more of the following phenomena. An antenna rotation associated with the ambient transmitter (e.g., transmit antenna was pointed in the direction of the test facility when the background measurement was made, but pointed away during the radiated emissions measurement) or fading due to the occurrence of multi-path signal arrival at the measurement antenna.

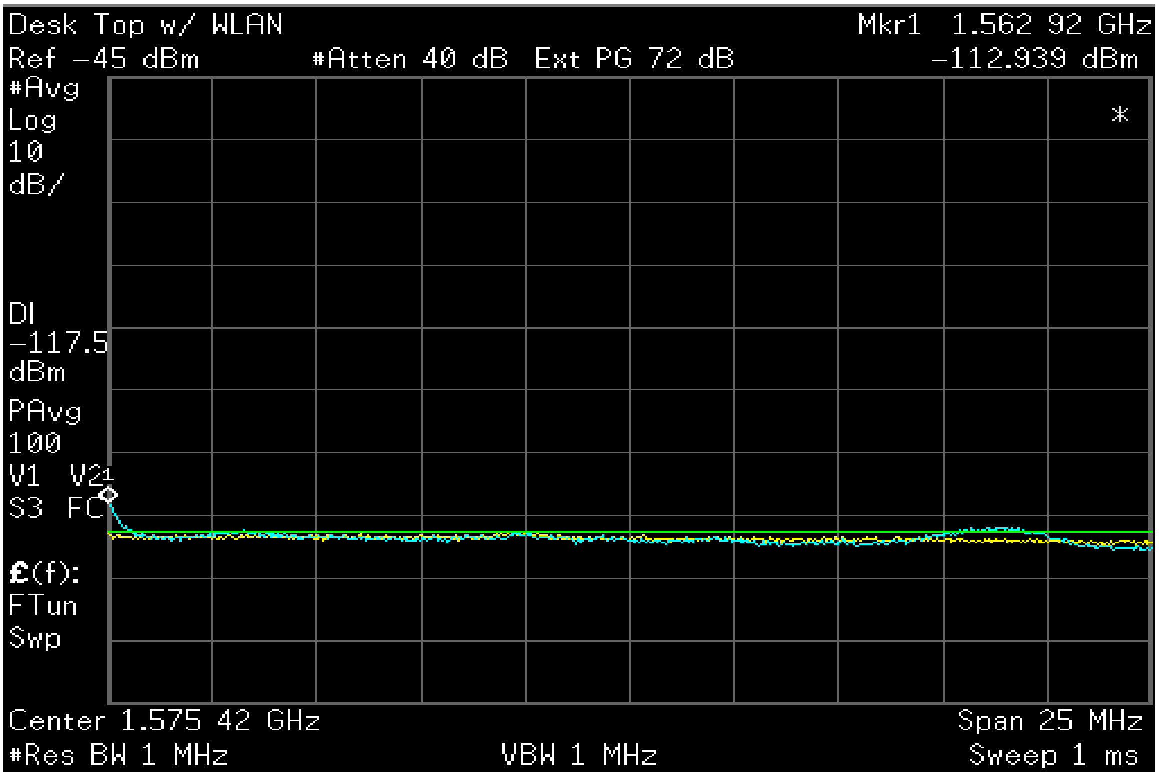


Figure E-140. Personal Digital Assistant (PDA) Radiated Emissions in GPS L1 Frequency Band.

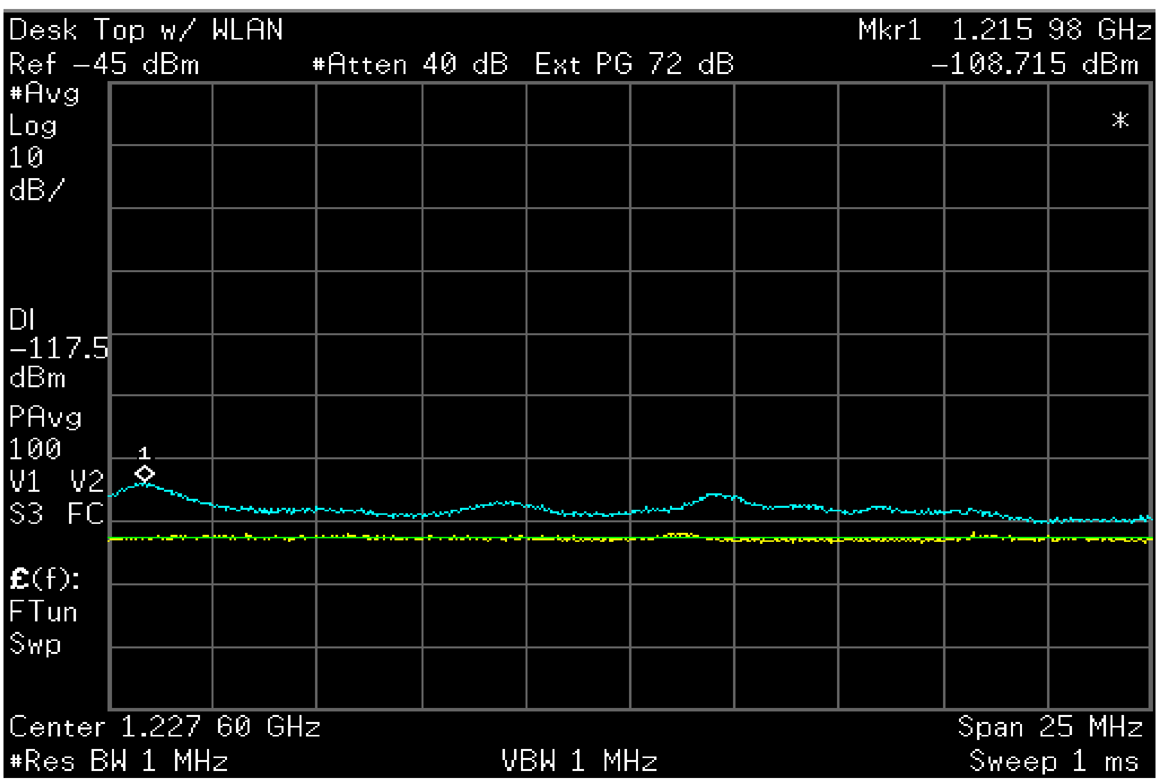


Figure E-141. Personal Digital Assistant (PDA) Radiated Emissions in GPS L2 Frequency Band.

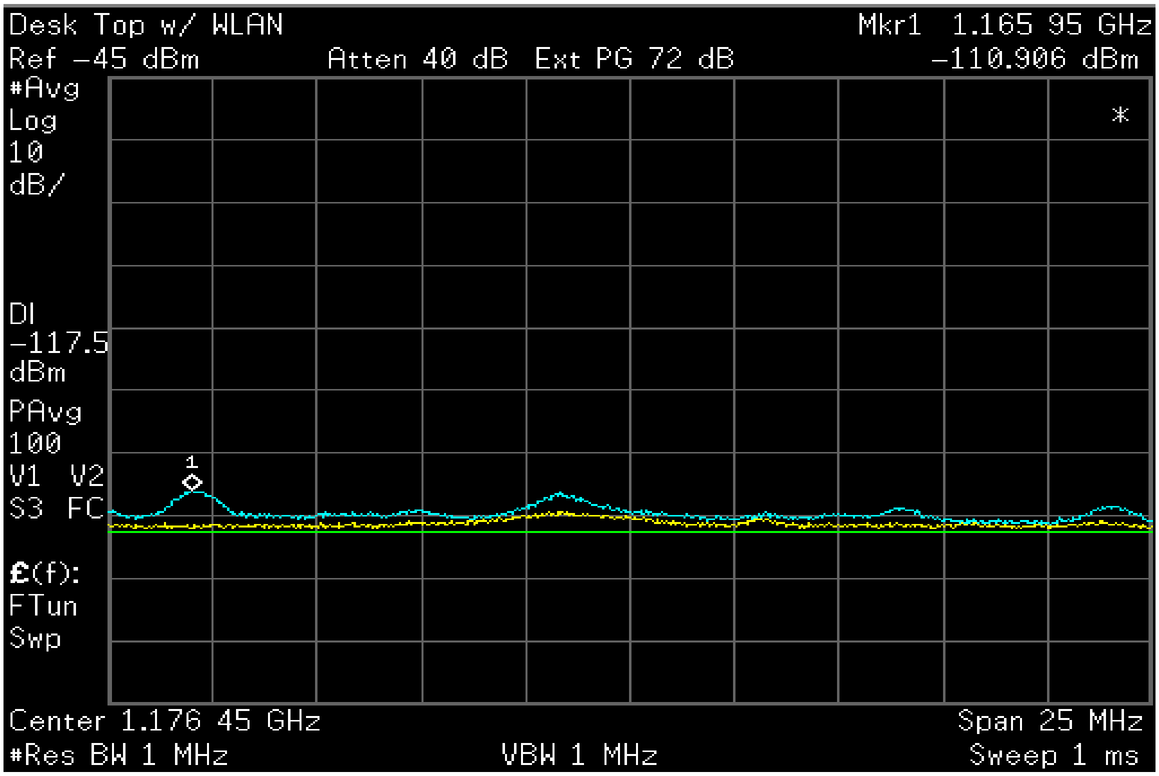


Figure E-142. Personal Digital Assistant (PDA) Radiated Emissions in GPS L5 Frequency Band.

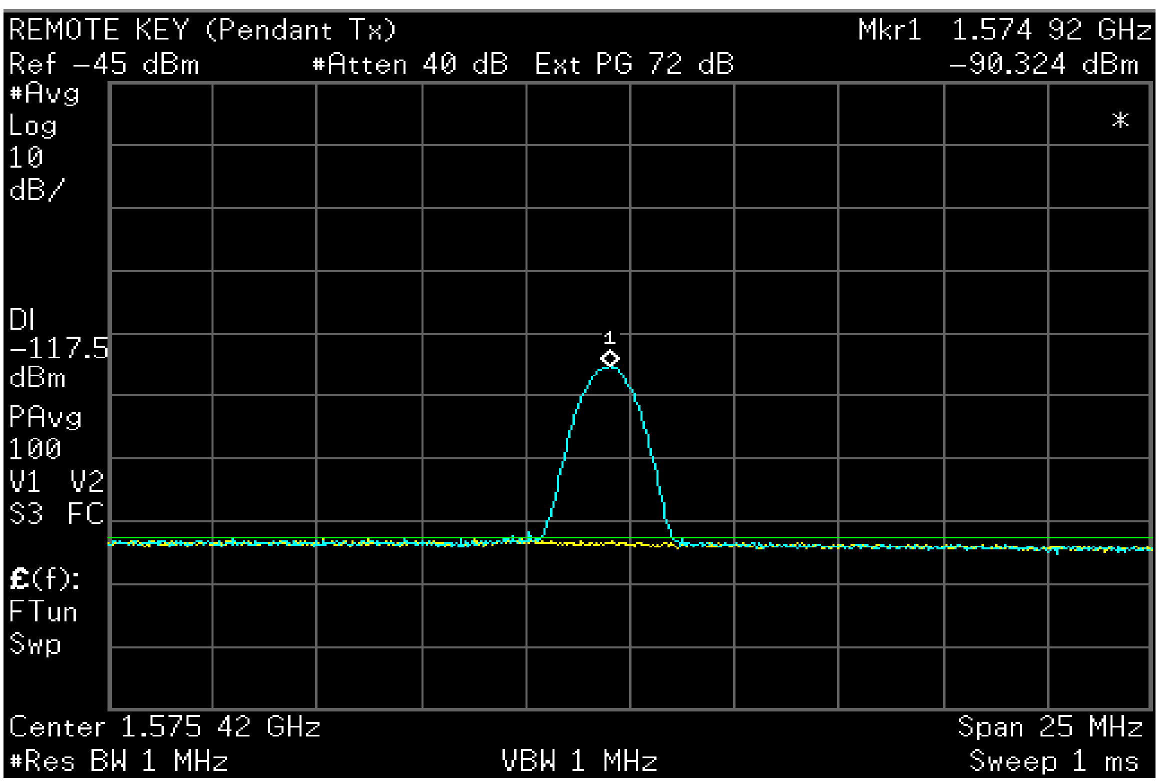


Figure E-143. Pendant Transmitter Radiated Emissions in GPS L1 Frequency Band.

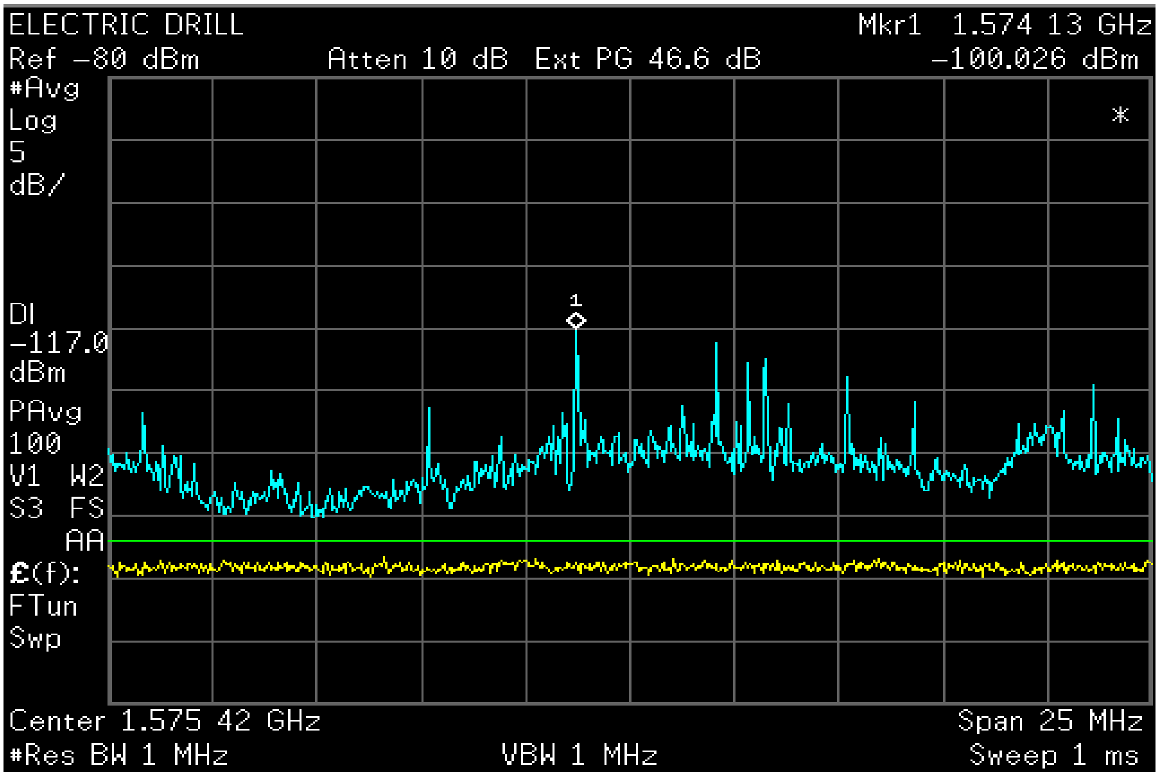


Figure E-144. Electric Drill #1 Radiated Emissions in GPS L1 Frequency Band.

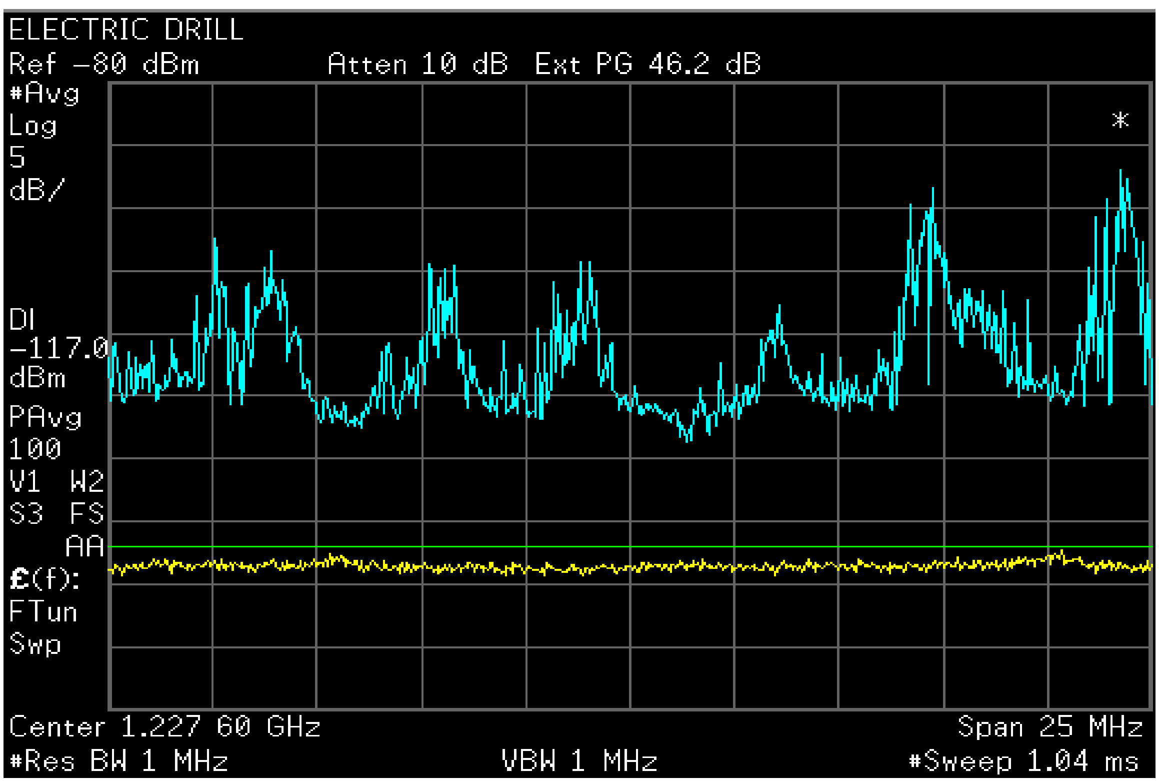


Figure E-145. Electric Drill #1 Radiated Emissions in GPS L2 Frequency Band.

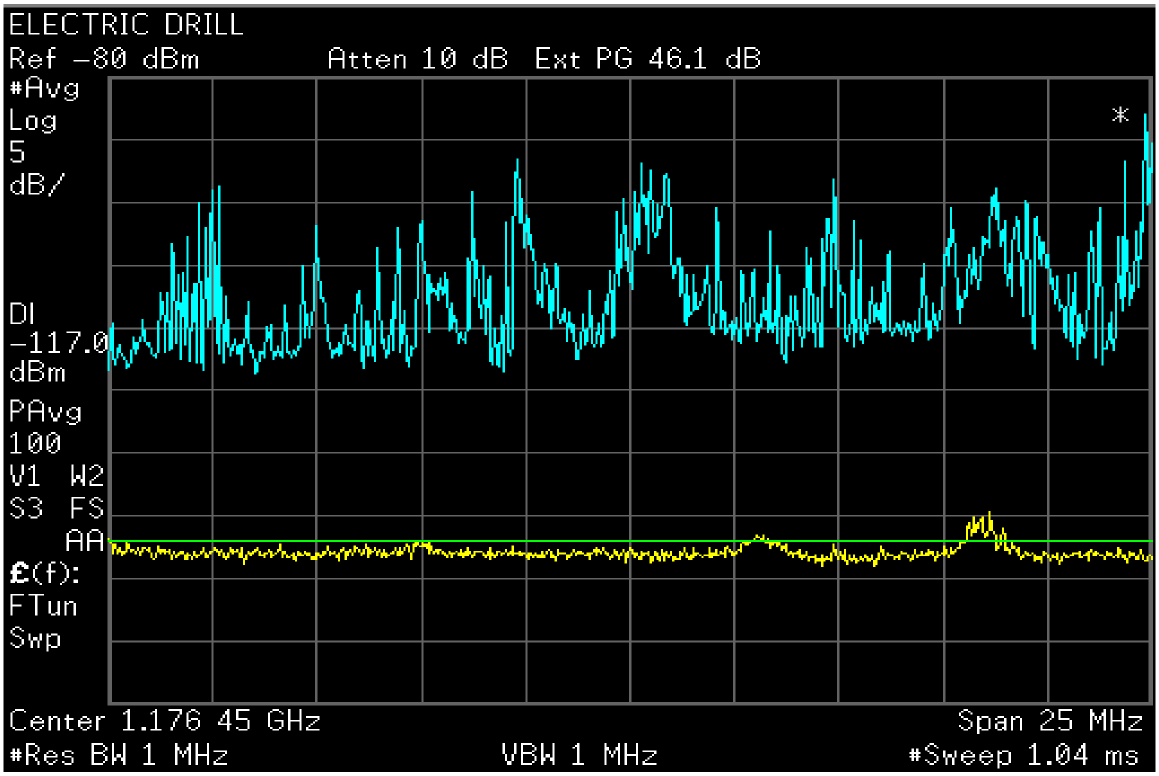


Figure E-146. Electric Drill #1 Radiated Emissions in GPS L5 Frequency Band.

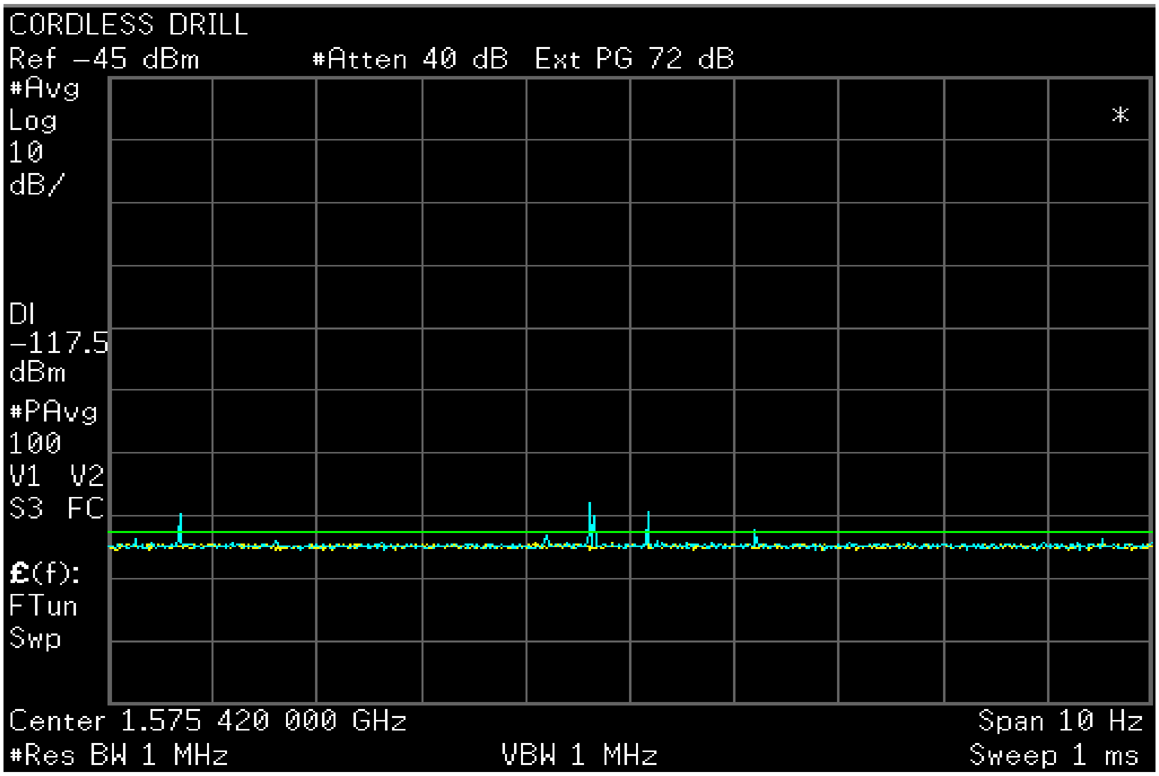


Figure E-147. Electric Drill #2 Radiated Emissions in GPS L1 Frequency Band.

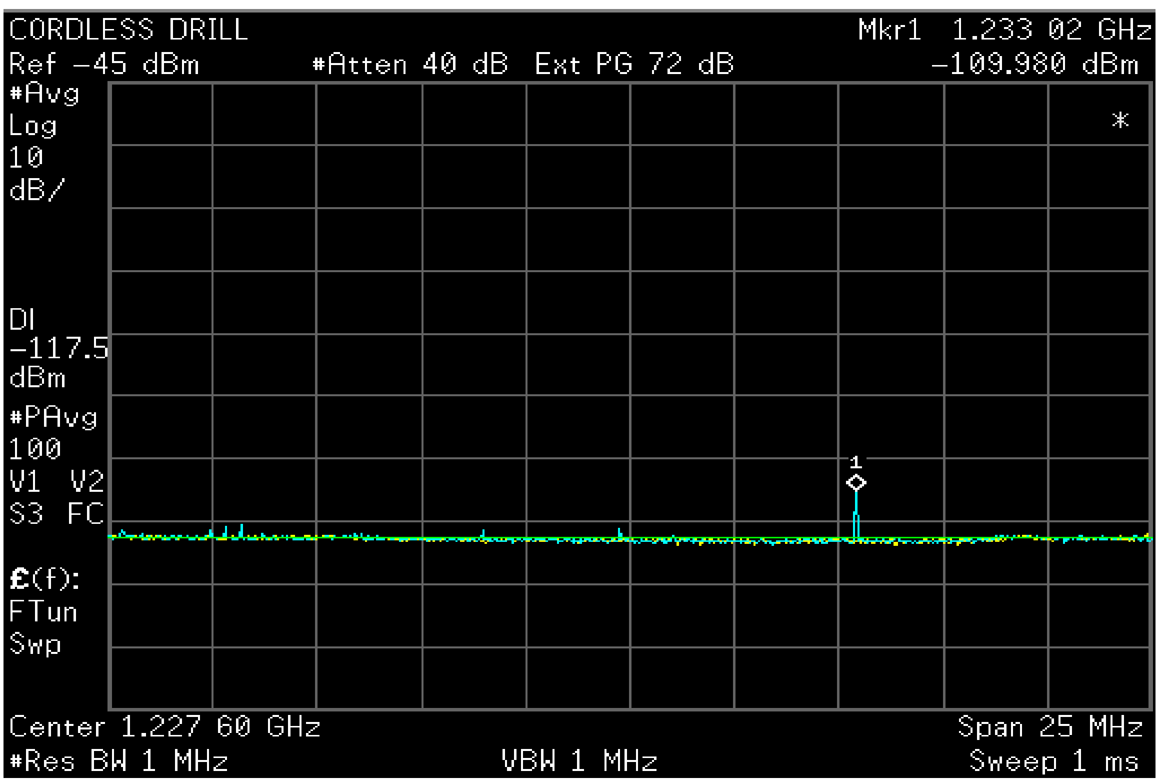


Figure E-148. Electric Drill #2 Radiated Emissions in GPS L2 Frequency Band.

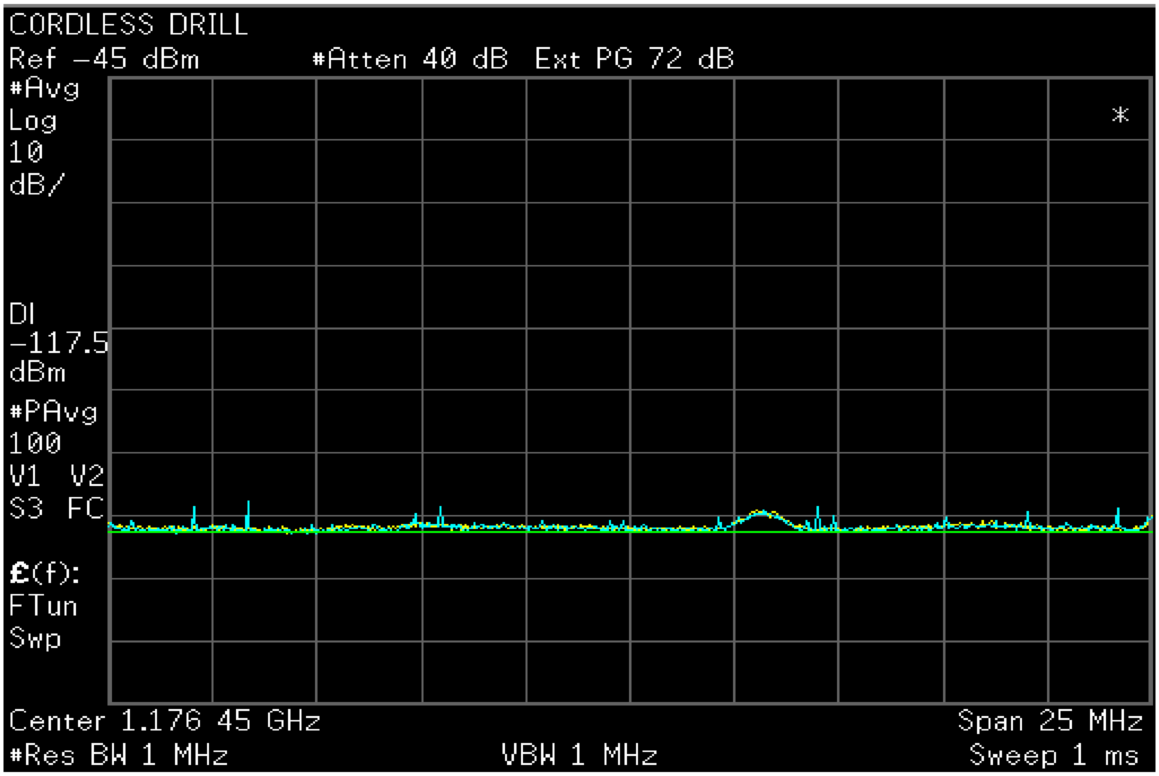


Figure E-149. Electric Drill #2 Radiated Emissions in GPS L5 Frequency Band.

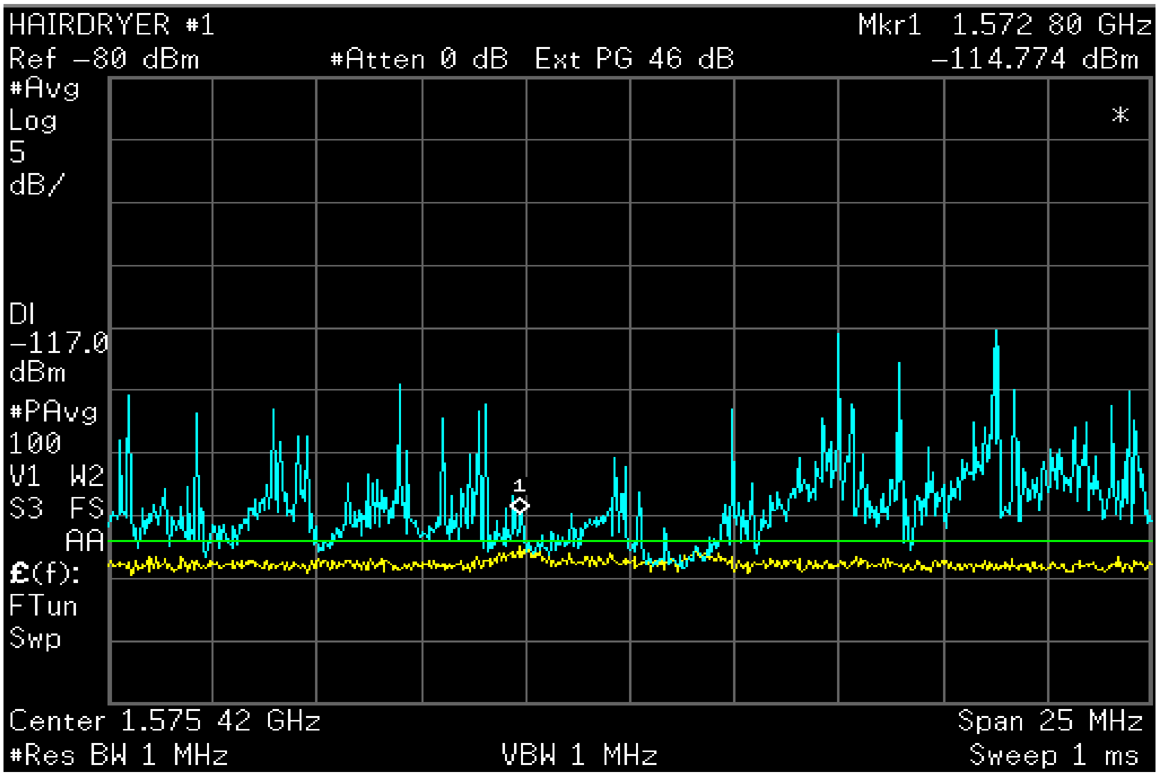


Figure E-150. Electric Hairdryer #1 Radiated Emissions in the GPS L1 Frequency Band.

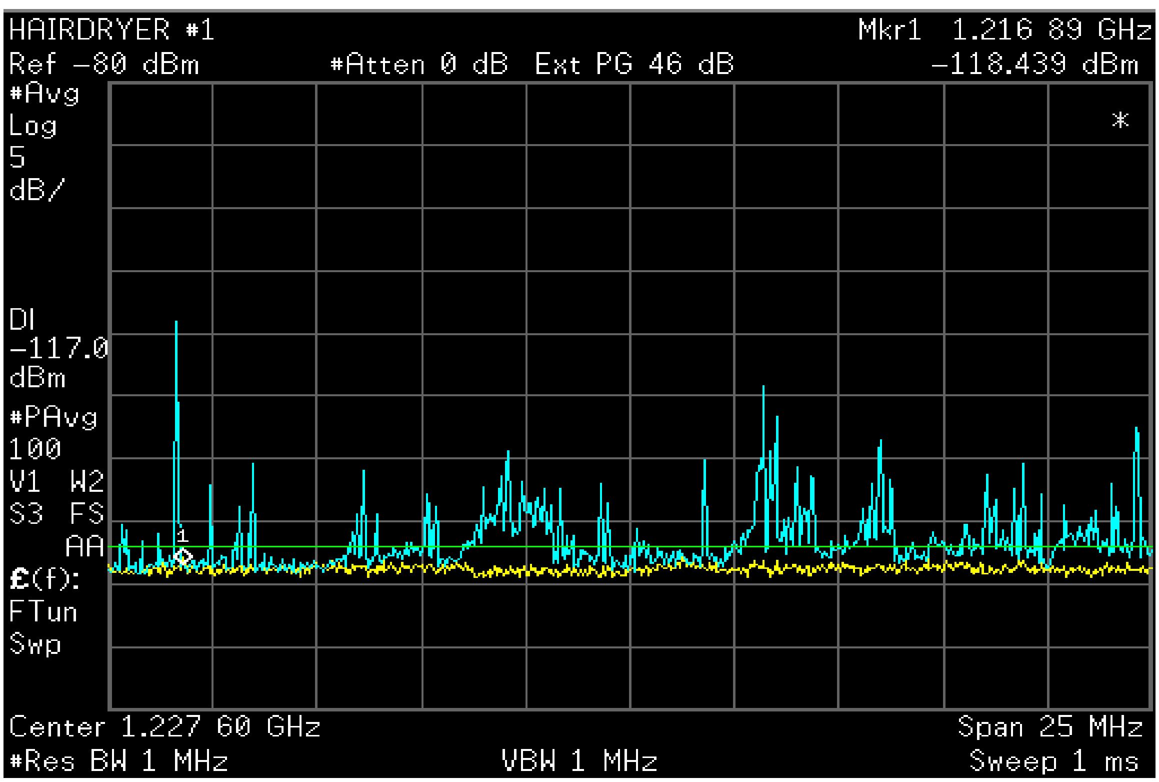


Figure E-151. Electric Hairdryer #1 Radiated Emissions in the GPS L2 Frequency Band.

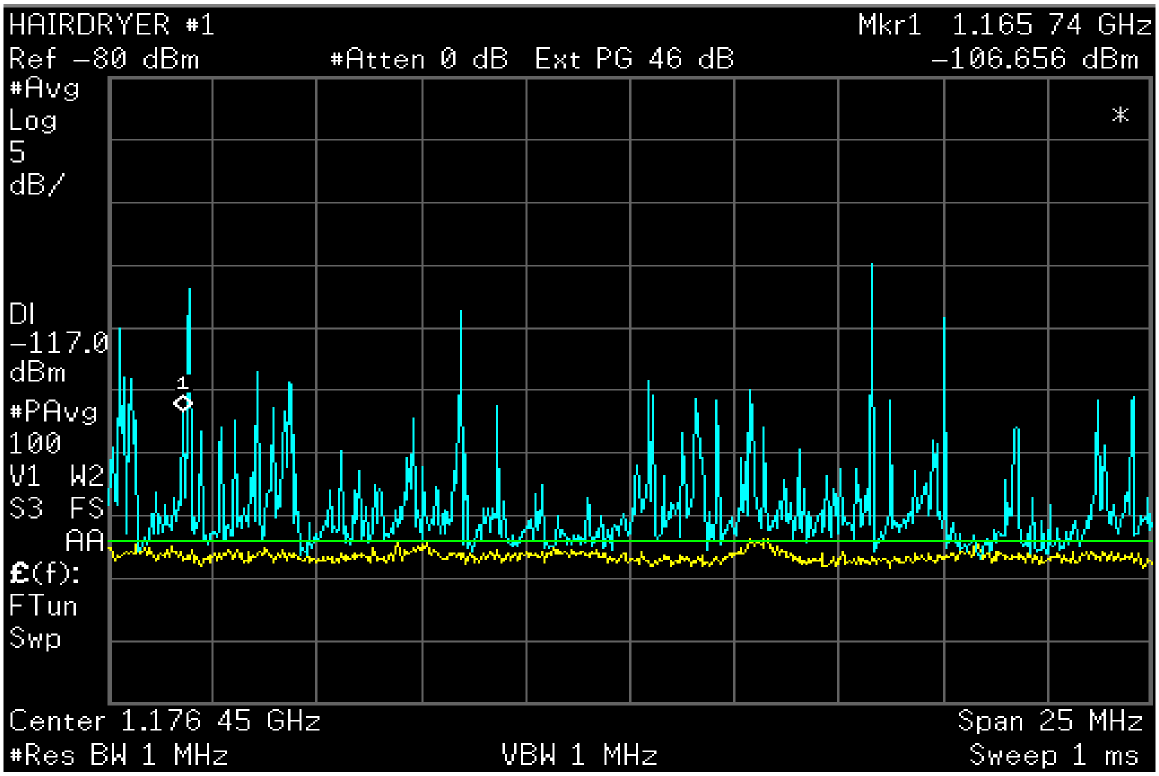


Figure E-152. Electric Hairdryer #1 Radiated Emissions in the GPS L5 Frequency Band.

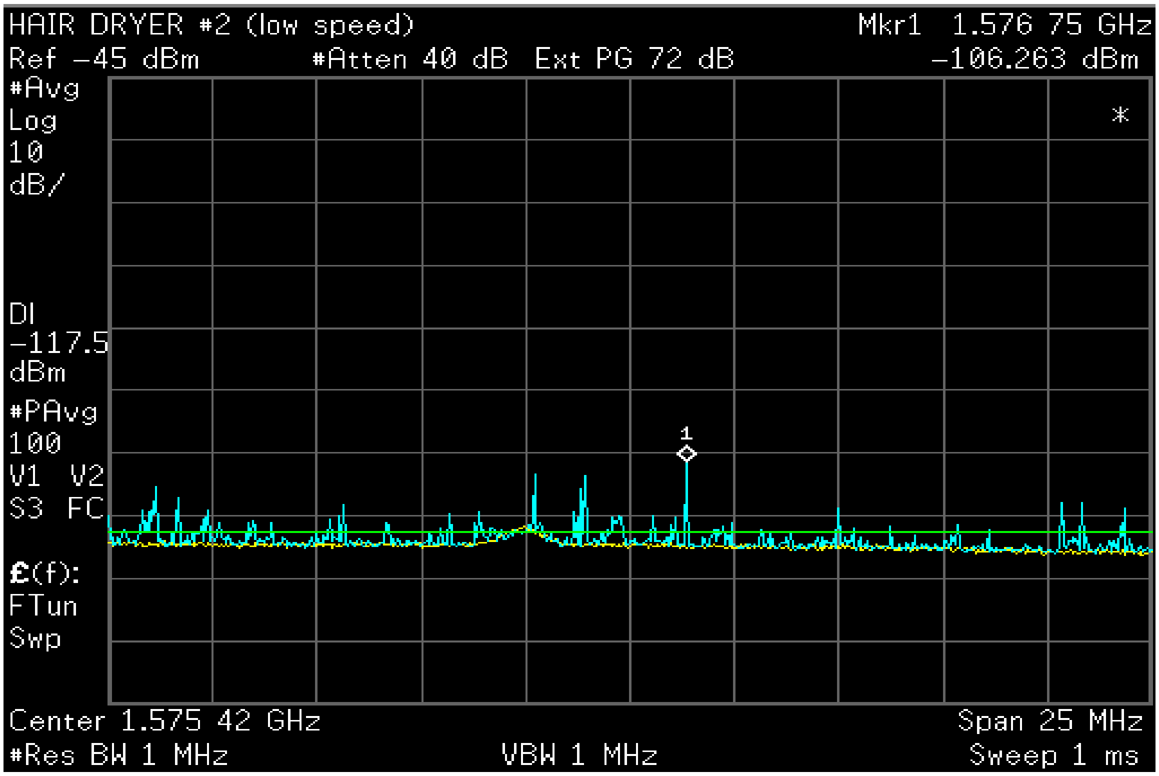


Figure E-153. Electric Hairdryer #2 Radiated Emissions in the GPS L1 Frequency Band.

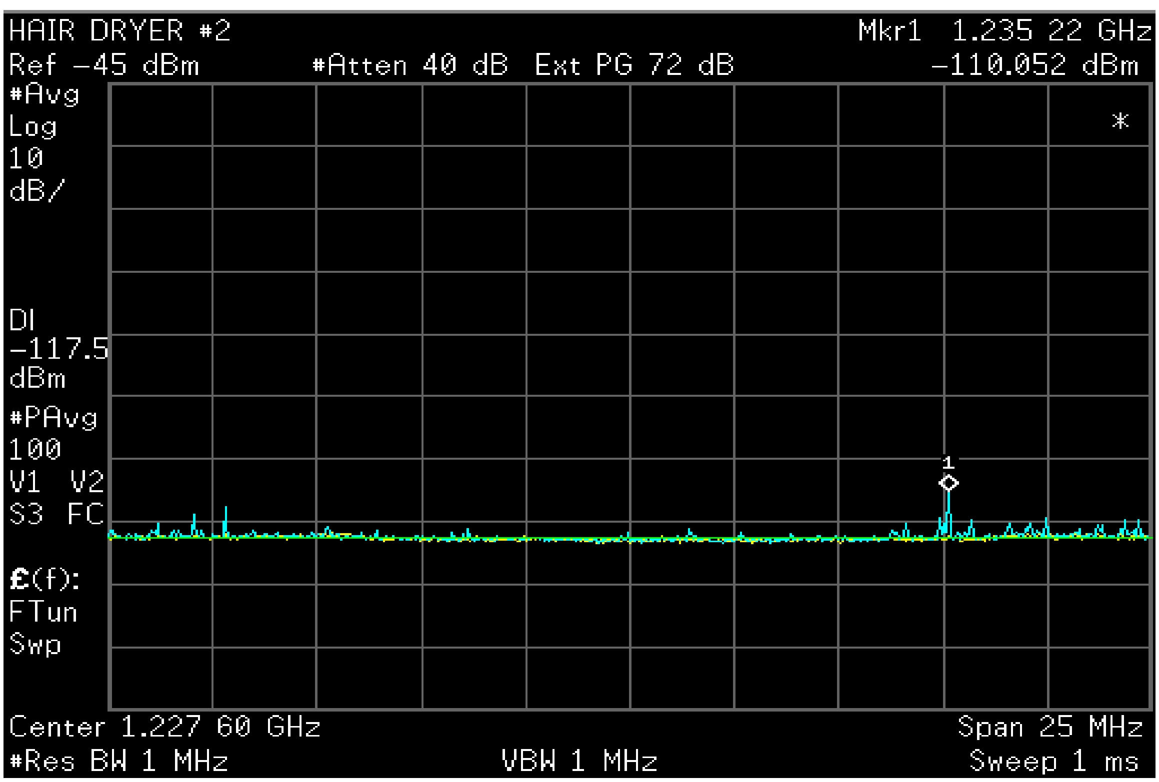


Figure E-154. Electric Hairdryer #2 Radiated Emissions in the GPS L2 Frequency Band.

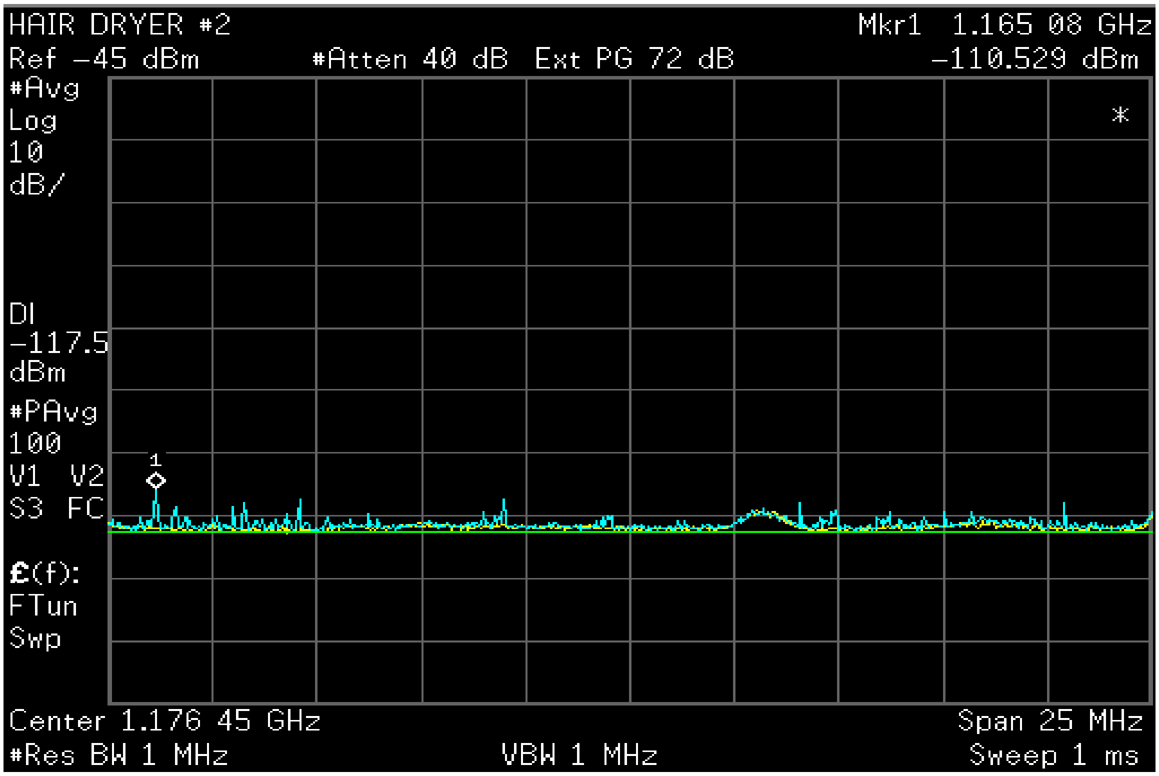


Figure E-155. Electric Hairdryer #2 Radiated Emissions in the GPS L5 Frequency Band.

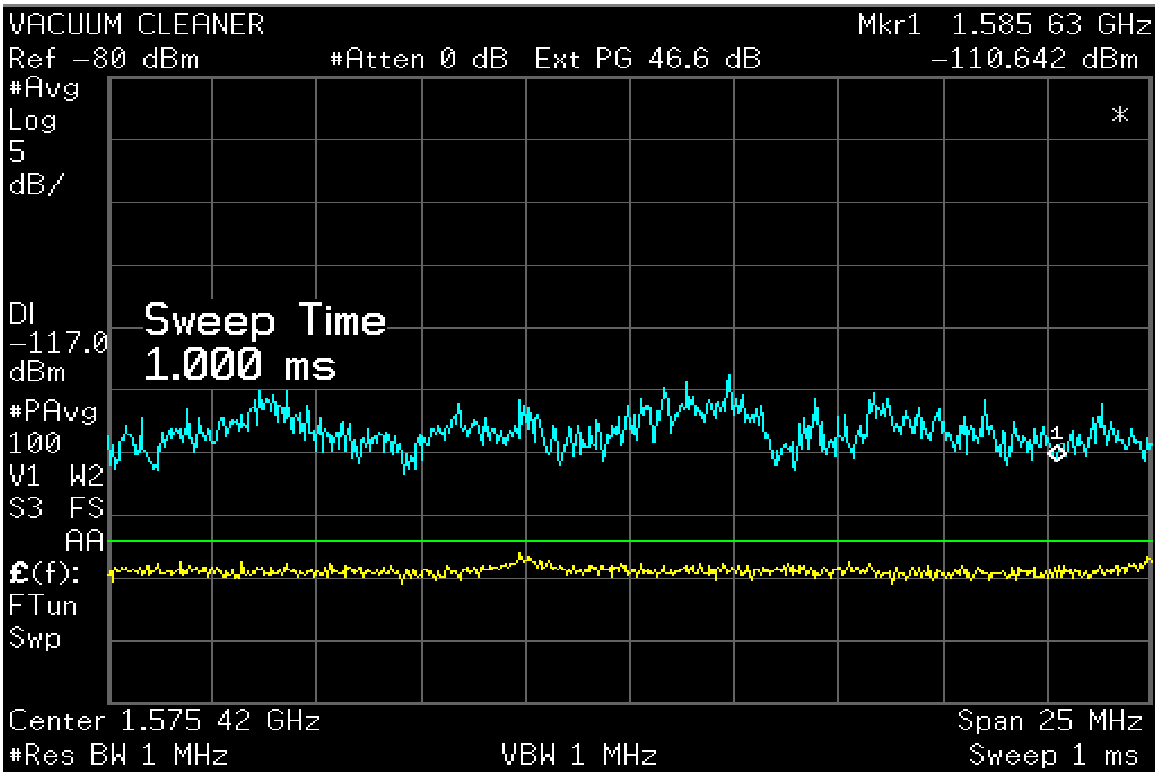


Figure E-156. Electric Vacuum Cleaner Radiated Emissions in the GPS L1 Frequency Band.

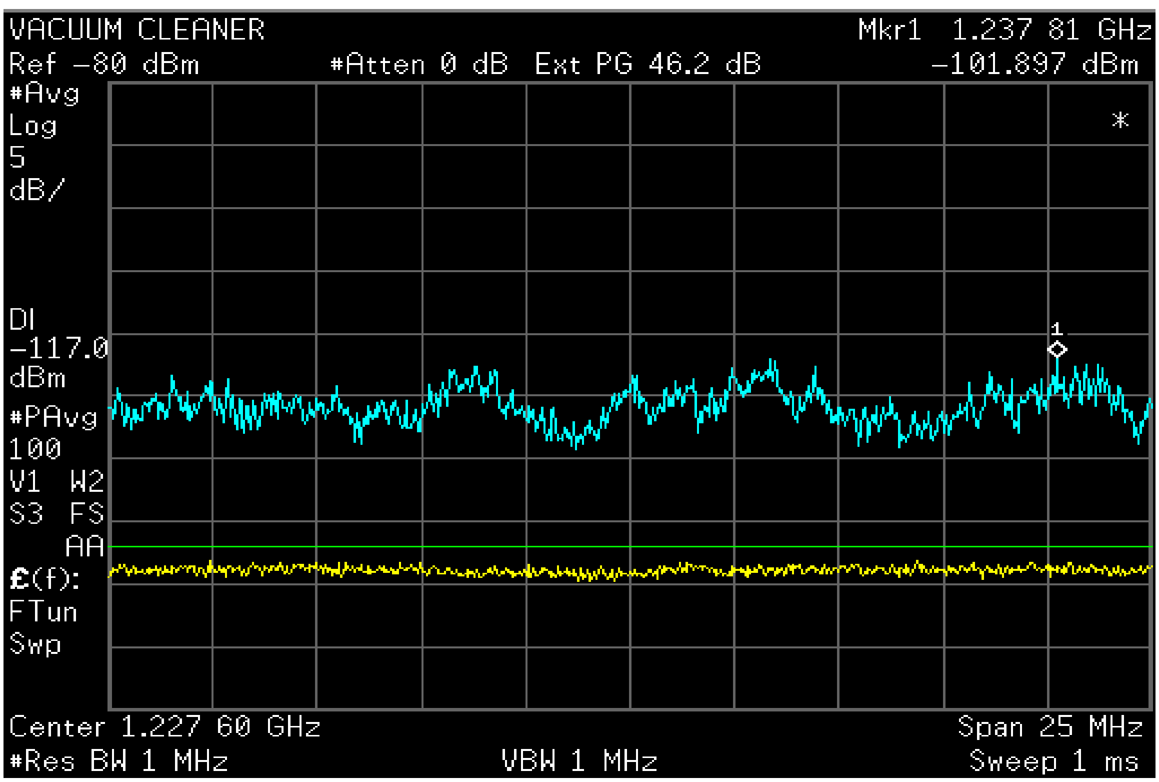


Figure E-157. Electric Vacuum Cleaner Radiated Emissions in the GPS L2 Frequency Band.

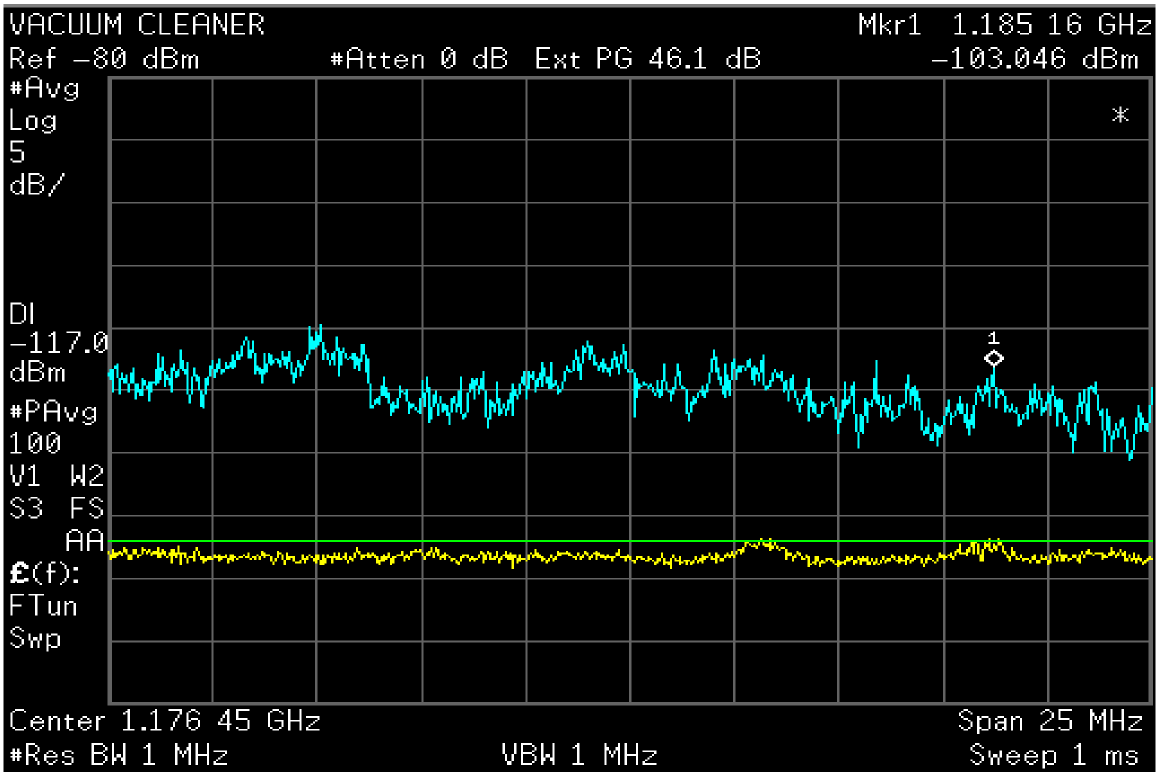


Figure E-158. Electric Vacuum Cleaner Radiated Emissions in the GPS L5 Frequency Band.