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Measured Radio Frequency Emissions
From

Caterpillar, Inc.
WiComm Model: 239-9955

Report No. 227
January 5, 2005

For:
Caterpillar, Inc.
8201 N. University St.
Peoria, IL 61615

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Summary
Tests for compliance with FCC Regulations, Part 15.247, and with Industry Canada Regulations, RSS-210, Section 6.2.2 (o), were performed on Caterpillar, Inc. spread spectrum RF Wireless Communication device. The DUT is subject to the Rules and Regulations as a Digital Spread Spectrum transmitter.

In testing completed on November 8, 2004, worst case radiated emissions in the restricted bands were met by 6.8 dB at a frequency of 2483.5 MHz (see p. 9). The DUT meets the FCC Class B digital emissions limits by greater than 20 dB. Power supply conducted emissions do not apply as the DUT is powered from a 12 VDC automotive system.

Introduction

Caterpillar, Inc. Model 239-9955 was tested for compliance with FCC Regulations, Part 15, adopted under Docket 87-389, April 18, 1989, and with Industry Canada RSS-210, Issue 5, November, 2001. The tests were performed at the University of Michigan Radiation Laboratory Willow Run Test Range following the procedures described in ANSI C63.4-1992 "Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz". The Site description and attenuation characteristics of the Open Site facility are on file with FCC Laboratory, Columbia, Maryland (FCC Reg. No: 91050) and with Industry Canada, Ottawa, ON (File Ref. No: IC 2057).

1. Test Procedure and Equipment Used

The test equipment commonly used in our facility is listed in Table 2.1 below. The HP 8593E spectrum analyzer is used for primary amplitude and frequency reference.

Table 2.1 Test Equipment

Test Instrument	Eqpt. Used	Manufacturer/Model
Spectrum Analyzer (0.1-1500 MHz)		Hewlett-Packard, 182T/8558B
Spectrum Analyzer (9kHz-22GHz)	X	Hewlett-Packard 8593A SN: 3107A01358
Spectrum Analyzer (9kHz-26GHz)	X	Hewlett-Packard 8593E, SN: 3412A01131
Spectrum Analyzer (9kHz-26GHz)		Hewlett-Packard 8563E, SN: 3310A01174
Spectrum Analyzer (9kHz-40GHz)		Hewlett-Packard 8564E, SN: 3745A01031
Power Meter	X	Hewlett-Packard, 432A
Power Meter		Anritsu, ML4803A/MP
Peak Power Meter	X	Pacific Instruments 1018B
Harmonic Mixer (26-40 GHz)		Hewlett-Packard 11970A, SN: 3003A08327
Harmonic Mixer (40-60 GHz)		Hewlett-Packard 11970U, SN: 2332A00500
Harmonic Mixer (75-110 GHz)		Hewlett-Packard 11970W, SN: 2521A00179
Harmonic Mixer (140-220 GHz)		Pacific Millimeter Prod., GMA, SN: 26
S-Band Std. Gain Horn	X	S/A, Model SGH-2.6
C-Band Std. Gain Horn	X	University of Michigan, NRL design
XN-Band Std. Gain Horn	X	University of Michigan, NRL design
X-Band Std. Gain Horn	X	S/A, Model 12-8.2
X-band horn (8.2- 12.4 GHz)	X	Narda 640
X-band horn (8.2- 12.4 GHz)		Scientific Atlanta , 12-8.2, SN: 730
K-band horn (18-26.5 GHz)	X	FXR, Inc., K638KF
Ka-band horn (26.5-40 GHz)	X	FXR, Inc., U638A
U-band horn (40-60 GHz)		Custom Microwave, HO19
W-band horn(75-110 GHz)		Custom Microwave, HO10
G-band horn (140-220 GHz)		Custom Microwave, HO5R
Bicone Antenna (30-250 MHz)	X	University of Michigan, RLBC-1
Bicone Antenna (200-1000 MHz)	X	University of Michigan, RLBC-2
Dipole Antenna Set (30-1000 MHz)	X	University of Michigan, RLDP-1,-2,-3
Dipole Antenna Set (30-1000 MHz)		EMCO 2131C, SN: 992
Active Rod Antenna (30 Hz-50 MHz)		EMCO 3301B, SN: 3223
Active Loop Antenna (30 Hz-50 MHz)		EMCO 6502, SN:2855
Ridge-horn Antenna (300-5000 MHz)	X	University of Michigan
Amplifier (5-1000 MHz)	X	Avantek, A11-1, A25-1S
Amplifier (5-4500 MHz)	X	Avantek
Amplifier (4.5-13 GHz)	X	Avantek, AFT-12665
Amplifier (6-16 GHz)	X	Trek
Amplifier (16-26 GHz)	X	Avantek
LISN Box		University of Michigan
Signal Generator		Hewlett-Packard 8657B

2. Configuration and Identification of Device Under Test

The DUT is a spread spectrum RF wireless link operating in 2400 - 2483.5 MHz band. The DUT consists of single WiComm unit with a monopole antenna connected to the device via an R-TNC connector. The system has been designed to operate with up to 11 channels from 2412 to 2462 MHz.

The DUT was designed and manufactured by Caterpillar, 8201 N. University St., Peoria, IL 61615. Figure 3.1 shows the block diagram of the basic system. It is identified as:

Caterpillar, Inc.
Model(s): 239-9955
SN(s): 3424B043LP
FCC ID: PQMWCA1
IC: 4071A-WCA1

With components evaluated:

Radio
DPAC Technologies
AIRBORNE WLN MODULE
Model: WLNB-AN-DP101

Cables
No cable was attached between the antenna and the DUT for radiated emission testing. The antenna was directly affixed to the DUT using an R-TNC connector.

A 0.3m coaxial cable with R-TNC adaptor used to conducted emissions testing. Loss accounted for in reported measurements.

Antennas

Table 3.2 Antennas

Antenna Model	Type	Construction	Gain (dBi)	Used in Testing
Monopole	OMNI	whip/monopole	1	X

2.1 EMI Relevant Modifications
No modifications were made to the DUT in the course of testing.

3. Emission Limits

3.1 Radiated Emission Limits
Since the DUT is a spread spectrum device (15.247, 2.4 GHz), the radiated emissions are subject to emissions in restricted bands (15.205). The applicable frequencies, through ten harmonics, are given below in Table 4.1. Emission limits from digital circuitry are specified in Table 4.2.

Table 4.1 Radiated Emission Limits (FCC:15.205; IC:RSS-210, 6.3) - Transmitter

Frequency	Fundamental Ave. E_{lim} (3m)		Spurious* Ave. E_{lim} (3m)	
(MHz)	(μV/m)	dB (μV/m)	(μV/m)	dB (μV/m)
2400-2483.5	---		---	
2310-2390 2483.5-2500 4500-5250	Restricted Bands Bands		500	54.0
7250-7750 14470-14500 17700-21400 22010-23120 23600-24000	Restricted Bands		500	54.0

* Measure up to tenth harmonic; 1 MHz res. BW, 100 Hz video BW (for average detection)

Table 4.2 Radiated Emission Limits (FCC:15.109;IC: RSS-210, 7.3) - Digital device.

Frequency	Class A ds = 10 m		Class B ds = 3 m	
(MHz)	(μV/m)	dB (μV/m)	(μV/m)	dB (μV/m)
30-88	90	39.0	100	40.0
88-216	150	43.5	150	43.5
219-960	210	46.4	200	46.0
960-	300	49.5	500	54.0

120 kHz BW up to 1 GHz, 1 MHz BW above 1 GHz

3.2 Conductive Emission Limits

Table 4.3 Conducted Emission Limits (FCC/CISPR:15.107; IC: RSS-210, 6.6).

Frequency MHz	Class A (dBμV)		Class B (dBμV)	
	Quasi-peak	Average	Quasi-peak	Average
.150 - 0.50	79	66	66 - 56*	56 - 46*
0.50 - 5	73	60	56	46
5 - 30	73	60	60	50

Notes:
1. The lower limit shall apply at the transition frequency
2. The limit decreases linearly with the logarithm of the frequency in the range 0.15-0.50 MHz:

*Class B Quasi-peak: dBμV = 50.25 - 19.12*log(f)
*Class B Average: dBμV = 40.25 - 19.12*log(f)

3. 9 kHz RBW

4. Radiated Emission Tests and Results

4.1 Anechoic Chamber Measurements
In our chamber, there is a set-up similar to that of an outdoor 3-meter site, with a turntable, an antenna mast, and a ground plane. Instrumentation includes spectrum analyzers and other equipment as needed. For these tests the receiver antennas were mounted on the antenna mast at about 1.2 m height, and the DUT on a turntable with foam blocks at 3 meter distance. Standard gain horn antennas were used for the measurements. At 2.4 GHz the horns were connected directly to a spectrum analyzer via RG-214 coaxial cable, and above 2.4 GHz a pre-amp was added. The cables and the pre-amplifier used were specially calibrated for these tests using a spectrum analyzer with built in sweep generator.

The DUT was rotated in all possible ways and the maximum emission recorded. Photographs in the *Test Setup Photos* exhibit demonstrate the measurement set-up.

Note: Digital Radiated emissions are exempt, as this is a vehicular device.

4.2 Outdoor Measurements
Measurements to verify that the DUT meets FCC Class B digital radiated emission limits, 30 to 1000 MHz were performed on an OATS. The DUT met the FCC Class B digital radiated emission limit by > 20 dB..

4.3 Computations and Results

To convert the dBm measured on the spectrum analyzer to dB(μV/m), we use expression

$$E_3(dB\mu V/m) = 107 + P_R + K_A - K_G + K_E$$

where P_R = power recorded on spectrum analyzer, dB, measured at 3m
K_A = antenna factor, dB/m
K_G = pre-amplifier gain, including cable loss, dB
K_E = pulse operation correction factor, dB

When presenting the data, the dominant measured emissions at each frequency, under all of the possible orientations, are given. Computations and results are given in Table 5.1. There we see that in the worst case the DUT meets the limit by 6.8 dB at 2483.5 MHz. Note, that besides the emission measurements, the table contains the frequency range of operation (in upper section of the table).

4.4 Duty Factor for Normal Operation

No Duty Factor was used during testing of this device, as it was programmed to transmit continuous.

5. Other Measurements and Computations

5.1 Peak-to-Average Ratio (15.35(b))

For the measurements presented here (for emissions in restricted bands), the DUT was programmed to transmit continuous, and such was verified with spectrum analyzer set to zero-span mode. The average measurements were made using 1 MHz RBW and 100 Hz VBW. The peak measurements were made using 1 MHz RBW and 3 MHz VBW.

Typically the difference between peak and average was 12 to 13 dB, and never exceeded the 20 dB limit.

5.2 Potential Health Hazard EM Radiation Level

The following table summarizes the minimum separation distance as calculated following FCC OET Bulletin 65.

To obtain the minimum separation distance, the antenna gain (dBi) listed in Table 3.2 must be added to the radio peak output power (dBm) listed in Table 6.2 (below), resulting in the total EIRP for a given system. This EIRP is then used to compute the power density at a distance of 20 cm.

S(mW/cm^2) = (20 mW * 1.26) / (4 π 20^2) = **0.005 mW/cm^2**

The following equations were used in calculating the operating distance (R).

$$EIRP(mW) = Po(mW) \cdot 10^{\frac{Gain(dB)}{10}}$$

and

$$S(mW/cm^2) = \frac{EIRP(mW)}{4 \cdot \Pi \cdot R^2}, \quad R = 20 \text{ cm}$$

5.3 Peak Output Power (15.247(b))

For this measurement, the DUT was set in a test mode for continuous data transmission. A direct comparison measurement was made between a known CW source and the DUT setup using calibrated attenuators, an HP 8472A Crystal Detector (with HP 54510A, 250 MHz digitizing oscilloscope) and an HP 432A average power meter. The known CW source power was first verified using the HP 432A and correlated with the DC output voltage from the HP 8472A Crystal Detector. Next, the DUT peak output power was recorded from the HP 8472A Crystal Detector's output waveform for the 802.11b radio at the channels indicated below. The maximum input rise/fall time of the 802.11b waveforms was measured to be >120 ns, which is sufficiently greater than the calibrated <10 ns rise/fall time of the HP 8472A Crystal Detector when properly loaded with the 50 Ω input of the HP 54510A oscilloscope.

Since the DUT transmits in continuous mode, there is no adjustment needed to the readings. Table 6.2, below, presents the results. The peak output power limit is 30dBm.

Table 6.2 Peak Output Power (Antenna Conducted)

Freq (MHz)	Peak P(dBm)	Comment(s)
2412	13.0	
2437	13.0	
2462	13.0	

5.4 Power Line Conducted Emissions (15.270)
Power line conducted emissions are not applicable. The DUT is powered from a vehicular 12 VDC system.

5.5 Bandwidth (15.247(a)(2))
For this test, the DUT was put in a test mode for continuous data transmission. The spectrum analyzer was connected where the antenna attaches to the DUT. The analyzer was set for RBW=100 kHz, VBW=300 kHz, SPAN=30 MHz. The 6-dB bandwidth was measured for lowest, middle, and highest channels for which the DUT operates. Plots are shown in Figure 6.1.

Frequency	6 dB Bandwidth
2.412 GHz	10.20 MHz
2.437 GHz	10.20 MHz
2.462 GHz	10.28 MHz

5.6 RF Antenna Conducted Spurious Emissions (15.247(c))
For this test, the DUT was put in a test mode for continuous data transmission. The spectrum analyzer was connected where the antenna attaches to the system. The analyzer was set for RBW=100 kHz, VBW=300 kHz, the frequency was swept from 0 to 25 GHz. See Figure 6.2. In all cases, the noise/spurious is at least 35 dB below the carrier. (Limit -20.0 dB below carrier). Figure 6.3 demonstrates band-edge compliance at lower and upper edges of the operating band.

5.7 Power Spectral Density and Line Spacing (15.247(d))
For this test, the DUT was put in a test mode for continuous data transmission. The spectrum analyzer was connected where the antenna attaches to the system. The spectrum was first scanned for the maximum spectrum peaks and then at these peaks the sweep was repeated with RBW=3 kHz, VBW=300 kHz, SPAN=300 kHz, and RBW=1 kHz, VBW=300 kHz, SPAN=100 kHz. Measured data is shown in Figures 6.4-6.6. The complete readings obtained are:

Frequency	Analyzer Reading	Line Spacing
2.41303 GHz	-6.20 dBm (Limit 8.0 dBm)	8.0 kHz
2.43802 GHz	-6.73 dBm (Limit 8.0 dBm)	8.0 kHz
2.46302 GHz	-6.25 dBm (Limit 8.0 dBm)	8.0 kHz

Table 5.1 Highest Emissions Measured - IEEE 802.11b

Radiated Emissions										CAT WiComm
#	Freq. MHz	Ant. Used	Ant. Pol.	Pr. (avg) dBm	Ka dB/m	Kg dB	E3 dBμV/m	E3lim dBμV/m	Pass dB	Comments
1	2412.0									Low channel
2	2437.0									Mid channel
3	2462.0									High channel
4										
5	2390.0	Horn S	H/V	-83.7	21.5	- 0.6	45.4	54.0	8.6	Low
6	2390.0	Horn S	H/V	-86.8	21.5	- 0.6	42.3	54.0	11.7	Mid
7	2390.0	Horn S	H/V	-87.4	21.5	- 0.6	41.7	54.0	12.3	High
8	2483.5	Horn S	H/V	-87.2	21.5	- 0.6	41.9	54.0	12.1	Low
9	2483.5	Horn S	H/V	-87.2	21.5	- 0.6	41.9	54.0	12.1	Mid
10	2483.5	Horn S	H/V	-81.9	21.5	- 0.6	47.2	54.0	**6.8**	High
11	4824.0	Horn C	H/V	-48.3	25.5	37.0	47.2	54.0	**6.8**	Low
12	4874.0	Horn C	H/V	-48.9	25.5	37.0	46.6	54.0	7.4	Mid
13	4924.0	Horn C	H/V	-49.5	25.5	37.0	46.0	54.0	8.0	High
14	7236.0	Horn XN	H/V	-72.3	25.5	36.0	24.2	N/A	-	Low
15	7311.0	Horn XN	H/V	-72.4	25.5	36.0	24.1	54.0	29.9	Mid
16	7386.0	Horn XN	H/V	-72.9	25.5	36.0	23.6	54.0	30.4	High
17	9648.0	Horn X	H/V		25.5	34.0	-	N/A	-	Low
18	9748.0	Horn X	H/V		25.5	34.0	-	N/A	-	Mid
19	9848.0	Horn X	H/V		25.5	34.0	-	N/A	-	High
20	12060.0	Horn X	H/V	-73.1	25.5	34.0	25.4	54.0	28.6	Low, noise
21	12185.0	Horn X	H/V	-72.9	25.5	34.0	25.6	54.0	28.4	Mid, noise
22	12310.0	Horn X	H/V	-73.0	25.5	34.0	25.5	54.0	28.5	High, noise
23	14472.0	Horn Ku	H/V	-70.5	25.5	17.3	44.7	54.0	9.3	Low, noise
24	14622.0	Horn Ku	H/V		25.5	17.3	-	N/A	-	Mid
25	14772.0	Horn Ku	H/V		25.5	17.3	-	N/A	-	High
26	16884.0	Horn Ku	H/V		32.3	34.0	-	N/A	-	Low
27	17059.0	Horn Ku	H/V		32.3	34.0	-	N/A	-	Mid
28	17234.0	Horn Ku	H/V		32.3	34.0	-	N/A	-	High
29	19296.0	Horn K	H/V	-71.6	32.3	32.0	35.7	54.0	18.3	Low, noise
30	19496.0	Horn K	H/V	-71.7	32.3	32.0	35.6	54.0	18.4	Mid, noise
31	19696.0	Horn K	H/V	-71.7	32.3	32.0	35.6	54.0	18.4	High, noise
32	21708.0	Horn K	H/V		32.3	32.0	-	N/A	-	Low
33	21933.0	Horn K	H/V		32.3	32.0	-	N/A	-	Mid
34	22158.0	Horn K	H/V	-69.0	32.3	32.0	38.3	54.0	15.7	High, noise
35	24120.0	Horn Ka	H/V		32.3	32.0	-	N/A	-	Low
36	24370.0	Horn Ka	H/V		32.3	32.0	-	N/A	-	Mid
37	24620.0	Horn Ka	H/V		32.3	32.0	-	N/A	-	High
38										
39	* Ave: measured with 1 MHz RBW and 100 Hz VBW									
40										
41										
42										

U. of Mich; Meas. 11/8/2004

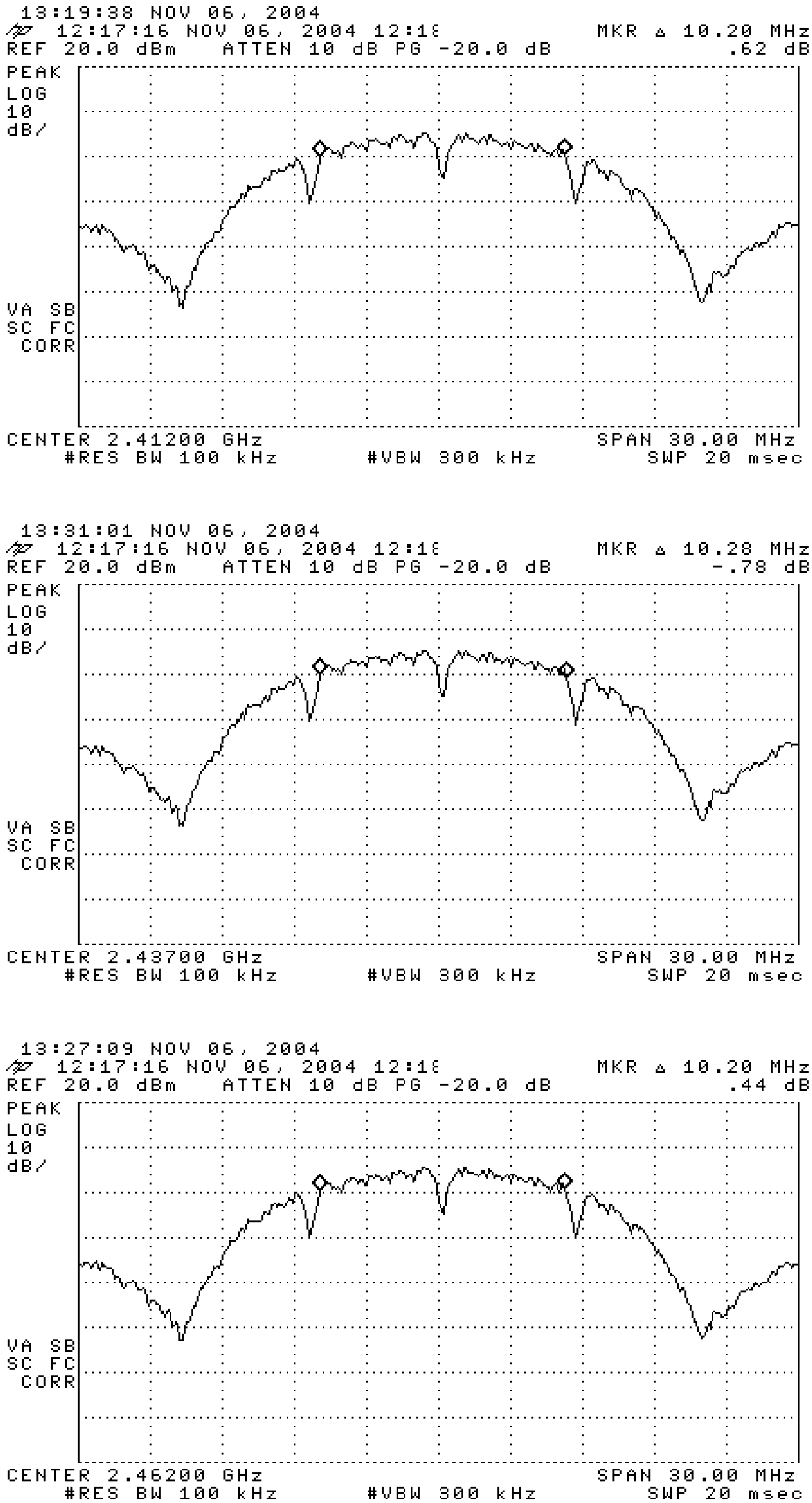

Figure 6.1 6 dB-point bandwidth measurements; low, mid, and high channels.

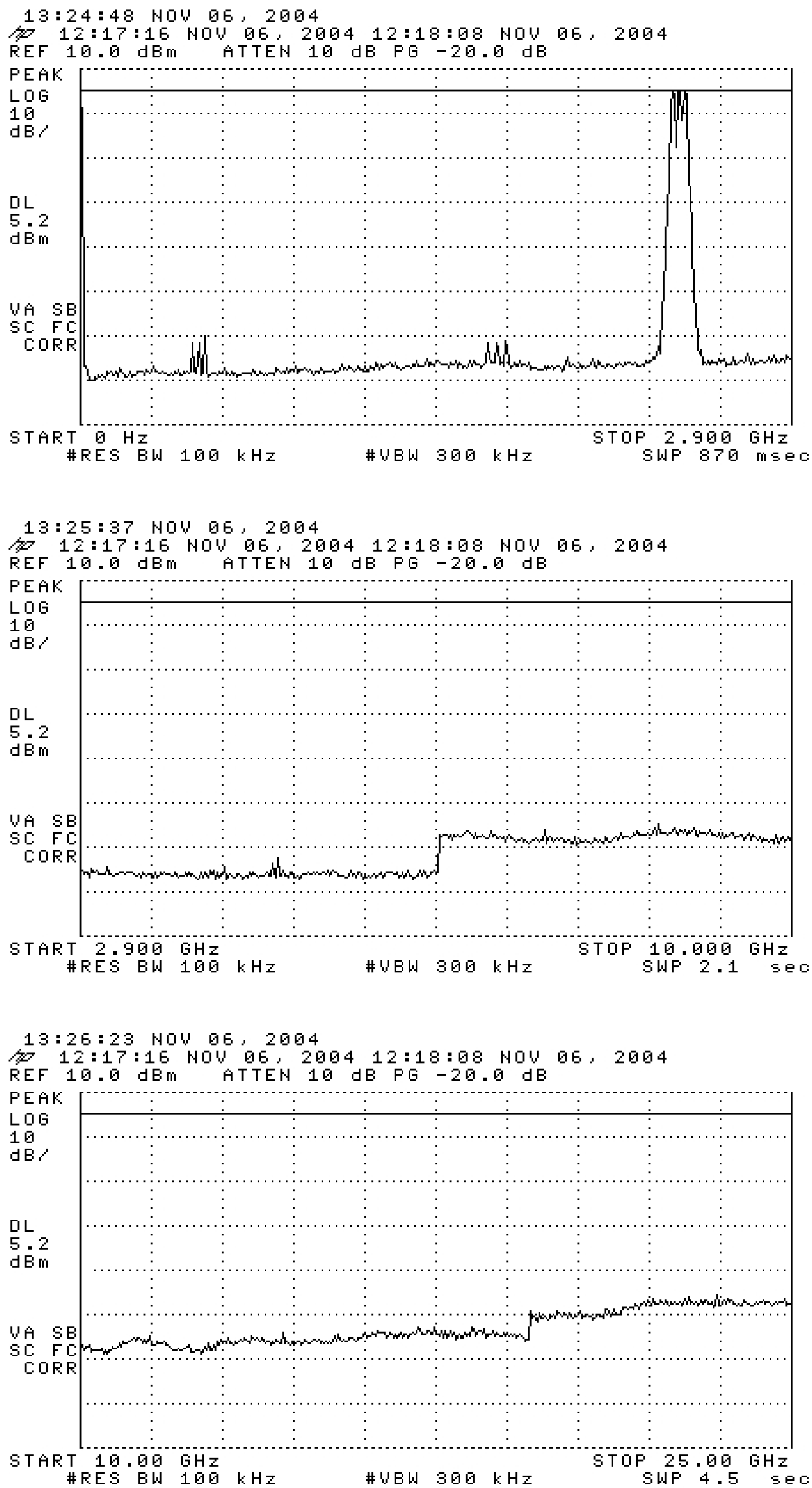

Figure 6.2 Antenna conducted spurious emissions, low, mid, and high channels.

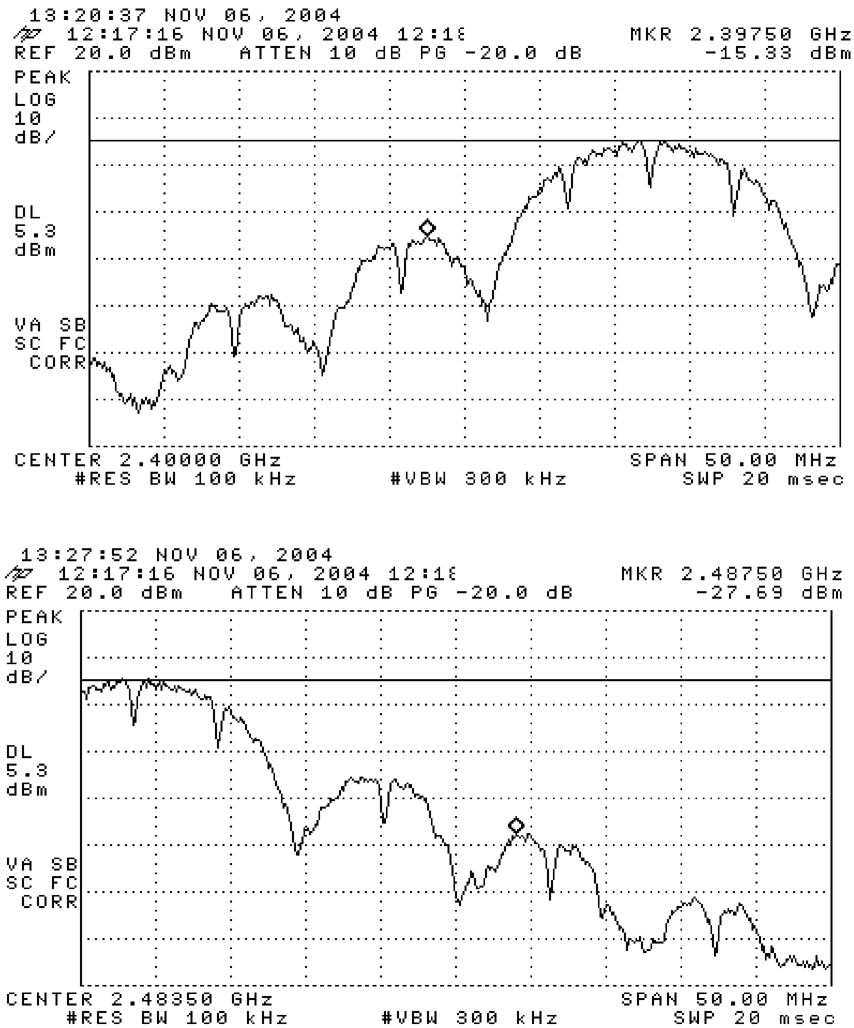

Figure 6.3 Band-edge behavior at low end and high end of the band.

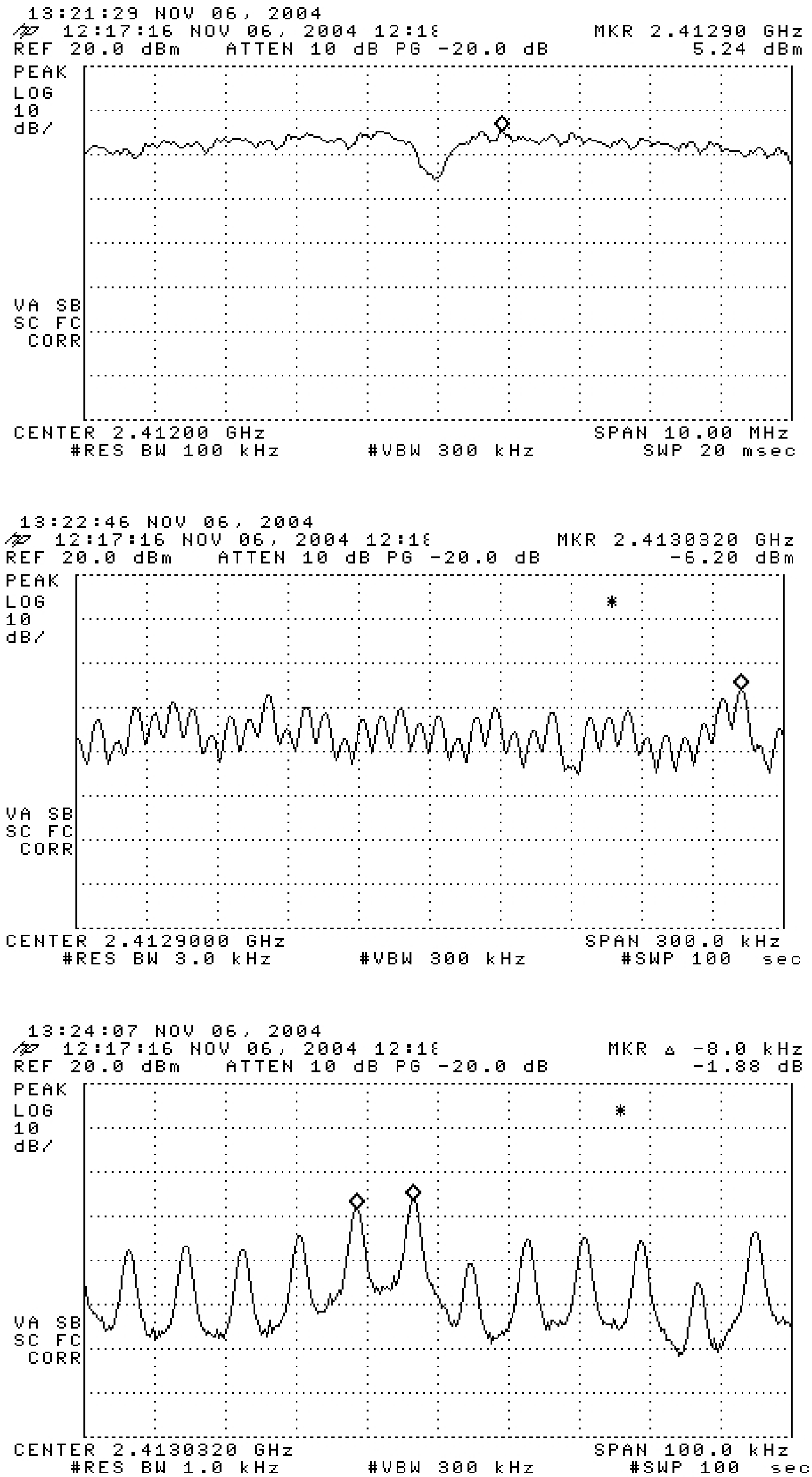

Figure 6.4 Spectral Density (low channel);
(top) Spectrum Scan, (mid) Spectral Density, (bottom) Line Spacing.

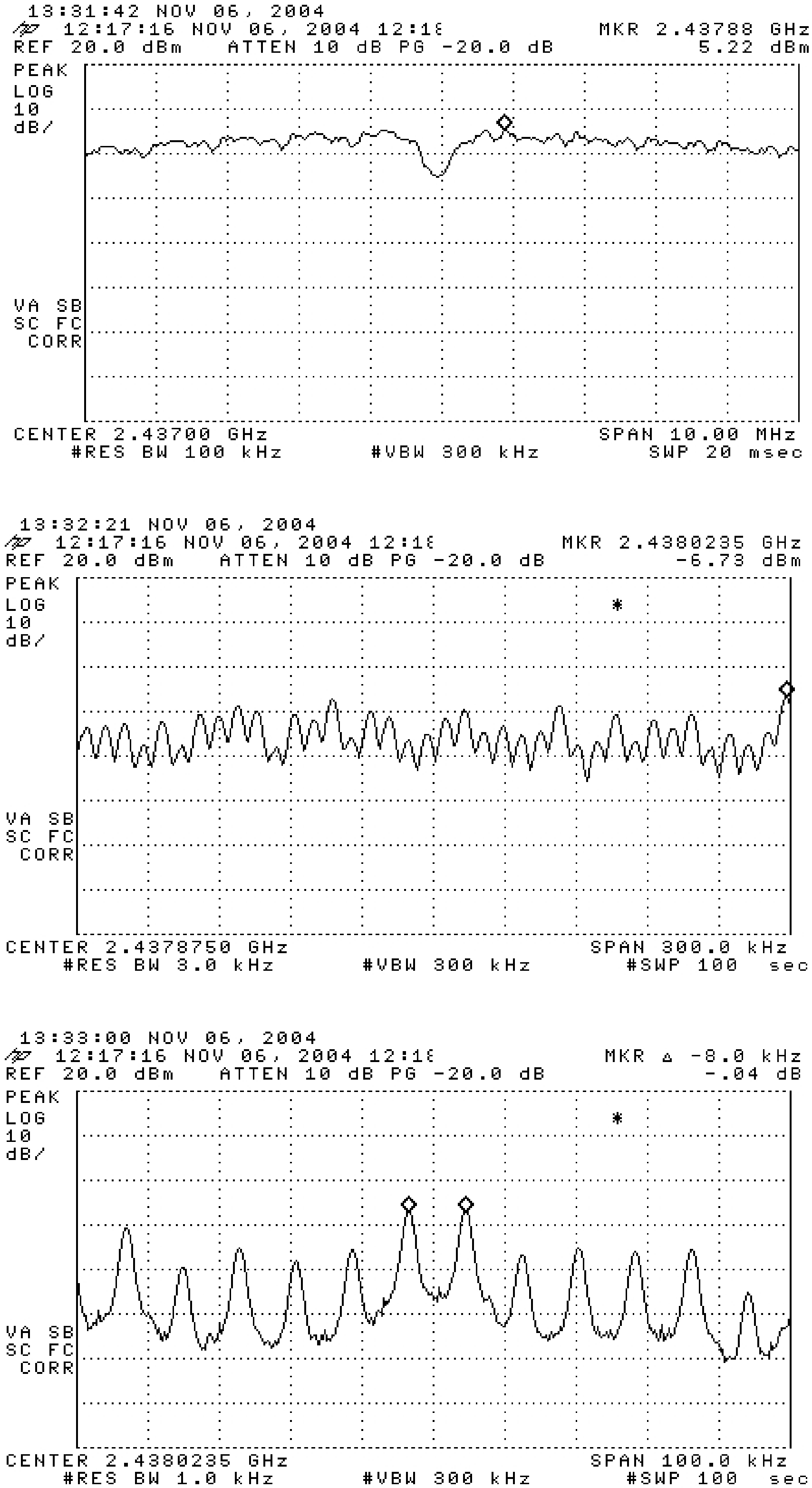

Figure 6.5 Spectral Density (mid channel);
(top) Spectrum Scan, (mid) Spectral Density, (bottom) Line Spacing.

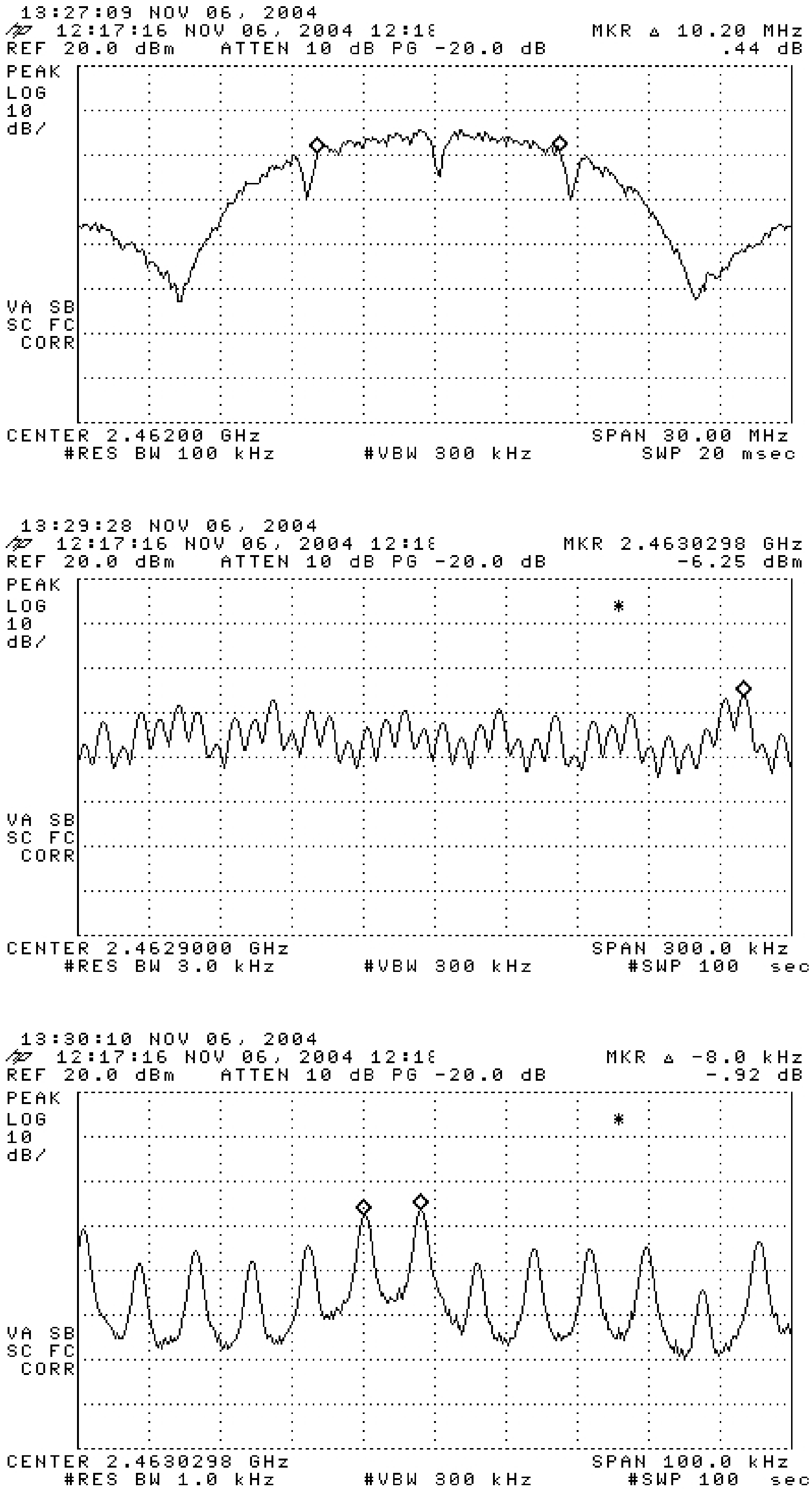

Figure 6.6 Spectral Density (high channel);
(top) Spectrum Scan, (mid) Spectral Density, (bottom) Line Spacing.