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Measured Radio Frequency Emissions
From

Raven IEEE 802.15.4 Hopping Transceiver
FCC ID: KSME1005300
IC: 2004A- E1005300

Report No. 415031-454
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For:
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Summary
Tests for compliance with FCC Regulations, Part 15.249, and with Industry Canada (IC) Regulations, RSS-210 (A8.1) and RSS-GEN, were performed on Raven model(s) KSME1005300 frequency hopping spread spectrum (FHSS) transceiver. The DUT is subject to the Rules and Regulations as a transceiver.

In testing competed on September 6, 2008, transmitter fundamental radiated emissions by 20.5 dB, restricted band emissions are met by 11.4 dB (p. 8). Receiver and digital emissions meet the Class B limit by more than 8.0 dB (p. 9). AC line conducted emissions tests do not apply, since the device is powered from a four 1.5 VDC AAA batteries.

1. Introduction

Raven model(s) KSME1005300 was(were) tested for compliance with FCC Regulations, Part 15, Subpart C, adopted under Docket 87-389, April 18, 1989, and with Industry Canada RSS-210, Issue 7, June, 2007. The tests were performed at the University of Michigan Radiation Laboratory Willow Run Test Range following the procedures described in ANSI C63.4-2003 "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 2057A-1).

2. Test Equipment Used

The pertinent test equipment commonly used in our facility for measurements is listed in Table 2.1 below. The middle column identifies the specific equipment used in these tests. The quality system employed at the University of Michigan Radiation Laboratory Willow Run Test Range has been established to ensure all equipment has a clearly identifiable classification, calibration expiry date, and that all calibrations are traceable to national standards.

Table 2.1 Test Equipment.

Test Instrument	Used	Manufacturer/Model	Q Number
Spectrum Analyzer (9kHz-26GHz)	X	Hewlett-Packard 8593E, SN: 3412A01131	HP8593E1
Spectrum Analyzer (9kHz-6.5GHz)	X	Hewlett-Packard 8595E, SN: 3543A01546	JDB8595E
Power Meter		Hewlett-Packard, 432A	HP432A1
Harmonic Mixer (26-40 GHz)		Hewlett-Packard 11970A, SN: 3003A08327	HP11970A1
Harmonic Mixer (40-60 GHz)		Hewlett-Packard 11970U, SN: 2332A00500	HP11970U1
Harmonic Mixer (75-110 GHz)		Hewlett-Packard 11970W, SN: 2521A00179	HP11970W1
Harmonic Mixer (140-220 GHz)		Pacific Millimeter Prod., GMA, SN: 26	PMPGMA1
S-Band Std. Gain Horn		S/A, Model SGH-2.6	SBAND1
C-Band Std. Gain Horn		University of Michigan, NRL design	CBAND1
XN-Band Std. Gain Horn		University of Michigan, NRL design	XNBAND1
X-Band Std. Gain Horn		S/A, Model 12-8.2	XBAND1
X-band horn (8.2- 12.4 GHz)		Narda 640	XBAND2
X-band horn (8.2- 12.4 GHz)		Scientific Atlanta , 12-8.2, SN: 730	XBAND3
K-band horn (18-26.5 GHz)		FXR, Inc., K638KF	KBAND1
Ka-band horn (26.5-40 GHz)		FXR, Inc., U638A	KABAND1
U-band horn (40-60 GHz)		Custom Microwave, HO19	UBAND1
W-band horn(75-110 GHz)		Custom Microwave, HO10	WBAND1
G-band horn (140-220 GHz)		Custom Microwave, HO5R	GBAND1
Bicone Antenna (30-250 MHz)	X	University of Michigan, RLBC-1	LBBIC1
Bicone Antenna (200-1000 MHz)	X	University of Michigan, RLBC-2	HBBIC1
Dipole Antenna Set (30-1000 MHz)	X	University of Michigan, RLDP-1,-2,-3	UMDIP1
Dipole Antenna Set (30-1000 MHz)		EMCO 3121C, SN: 992 (Ref. Antennas)	EMDIP1
Active Rod Antenna (30 Hz-50 MHz)		EMCO 3301B, SN: 3223	EMROD1
Active Loop Antenna (30 Hz-50 MHz)		EMCO 6502, SN:2855	EMLOOP1
Ridge-horn Antenna (300-5000 MHz)	X	University of Michigan	UMRH1
Amplifier (5-1000 MHz)	X	Avantek, A11-1, A25-1S	AVAMP1
Amplifier (5-4500 MHz)	X	Avantek	AVAMP2
Amplifier (4.5-13 GHz)		Avantek, AFT-12665	AVAMP3
Amplifier (6-16 GHz)		Trek	TRAMP1
Amplifier (16-26 GHz)		Avantek	AVAMP4
LISN Box		University of Michigan	UMLISN1
Signal Generator		Hewlett-Packard 8657B	HPSG1

3. Device Under Test

3.1 Identification

The DUT is a frequency hopping IEEE 802.15.4 transceiver operating in the 2400 - 2483.5 MHz band. The DUT measures 2.25 x 7.25 x 1.0 inches. The system is a fully compliant IEEE 802.15.4 transceiver supporting 250 kbps O-QPSK data in each of its 16, 5.0 MHz wide channels from 2405-2480 MHz. The DUT was designed and manufactured by Raven Industries, 4372 Green Ash Drive, Earth City, MO 63045. It is identified as:

Raven IEEE 802.15.4 Transceiver
Model(s): KSME1005300
FCC ID: KSME1005300
IC: 2004A- E1005300

3.2 Variants

There is only a single version of this module. In addition to a standard unit, a modified unit was provided which had the internal antenna disabled and an SMA connector attached for conducted antenna measurement purposes. The DUT has only one antenna built into the PCB and has been setup with test software to control channel selection and to enable/disable hopping for testing purposes.

3.3 Modes of Operation

This device only operates in a single mode, data transmission. The operating mode of this hopping IEEE 802.15.4 transceiver does not influence peak output power. There is only one transmitter which is driven by identical input parameters.

3.4 EMI Relevant Modifications

No modifications were made to the DUT by this laboratory during testing.

4. Emission Limits

4.1 Radiated Emission Limits

The DUT tested is a 2405-2480 MHz Transmitter, subject to FCC 15.249 and IC RSS-210e A2.9, and all other sections referred to therein. The applicable critical testing frequencies with corresponding emission limits are given in Tables 4.1 and 4.2.

Table 4.1. Radiated Emission Limits (Ref: FCC: 15.249; IC: RSS-210e A2.9)

Frequency (MHz)	Field Strength of Fundamental (mV/m)	Field Strength of Harmonics (μV/m)
902.0 – 928.0	50	500
2400 - 2483.5	50	500
5725.0 – 5875.0	50	500
24000.0 – 24250.0	250	2500

1) Field strength limits are specified at a distance of 3 meters.
2) Emissions radiated outside of the specified frequency bands, except for harmonics, shall be attenuated by at least 50 dB below the level of the fundamental or to the general radiated emission limits in Section 15.209 (Class B), whichever is the lesser attenuation.
3) Peak field strength of any emission above 1GHz shall not exceed the maximum permitted average limits specified above by more than 20 dB under any condition of modulation. (15.35)

Table 4.2 Radiated Emission Limits (FCC:15.109;IC: RSS-210, Table 2) – Receiver/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

4.2 Conducted Emission Limits

Conducted emissions do not apply as the device is powered by four 1.5 VDC batteries.

5. Test Procedure and Computations

5.1 Test Procedure: General

Prior to any measurements, all active components of the test setup were allowed a warm-up for a period of approximately one hour, or as recommended by their manufacturers.

5.2 Semi-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 (horn) antennas were placed on a Styrofoam block or antenna mast, at about 1.2 m height, and the DUT on a turntable at 3 meter distance.

Standard gain horn antennas are used for the measurements. Up to 4.5 GHz, horn antennas are connected directly to a spectrum analyzer via RG-214 coaxial cable. Above 4.5 GHz a pre-amp is added. The cables and the pre-amplifier used are specially calibrated for these tests using a network analyzer. The DUT antenna was rotated in all possible ways and the maximum emission recorded. A photograph in the Test Setup portion of this submittal shows the measurement set-up. DUT is tested on 3-axes.

5.3 Open Area Test Site (OATS) Measurements

After the chamber measurements, the emissions were re-measured on the outdoor 3-meter site at fundamental and harmonics up to 1 GHz using tuned dipoles and/or the high frequency Bicone. Photographs included in this filing show the DUT on the Open Area Test Site (OATS).

5.4 Computations and Results

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

5.5 Supply Voltage Variation

For intentional radiators, measurements of the variation of the input power or the radiated signal level of the fundamental frequency component of the emission, as appropriate, shall be performed with the supply voltage varied between 85% and 115% of the nominal rated supply voltage. For battery operated equipment, the equipment tests shall be performed using a new battery. Worst case emissions are reported employing a new battery.

6. Other Measurements and Computations

6.1 Radiated Emissions
Table 5.1 and Table 5.2.

6.2 Peak to Average Ratio
Figure 6.1. Peak to Average Ratio. For the DUT in normal operating mode the peak to average ratio is greater than 20 dB. Only one 0.85 ms pulse exists in any given 100 ms window. See Figure 6.1.

K_E = 0.85 ms / 100 ms = 0.0085 < 20 dB

6.3 Emission Bandwidth
For this test, the DUT was put in a test mode for continuous data transmission (hopping disabled). The DUT was placed in front of the horn antenna oriented for maximum radiation. The analyzer was set for RBW = 100 kHz ≤ VBW, SPAN= 10 MHz. The 20-dB bandwidth bandwidths were measured for low, mid, and high channels used by the DUT. The resulting measured data is below, and plots are shown in Figure 6.2.

Channel	Frequency	20 dB BW
1	2.405 GHz	2.65 MHz
9	2.445 GHz	2.68 MHz
16	2.480 GHz	2.65 MHz

6.4 Number of Channels
For this test, the DUT was put in normal operating mode (hopping enabled). The DUT was placed in front of the horn antenna at the location of maximum radiation. The analyzer was set for RBW = 100 kHz ≤ VBW, SPAN as needed. The number of channels employed is 16. Plots are shown in Figure 6.3.

6.5 Peak Output Power & Health Hazard EM Radiation Level
For this test, the DUT was put in a test mode for data transmission (hopping disabled). Peak power measurements were made using 3 MHz RBW and 5 MHz VBW on the Spectrum Analyzer. The power was measured from the RF port of DUT (a modified module was provided for this purpose; the antenna is not generally removable). Table 5.1(b) presents the results.

The following table summarizes the power density at a distance of 20 cm from the device as calculated from FCC OET Bulletin 65.

Table 6.3 Potential Health Hazard Radiation Level

Ant.	Ant.Gain (dBi)	Po (mW)	EIRP (mW)	S (mW/cm^2)
PCB	1.0	1.81	1.02	0.00406

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

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

and

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

6.6 AC Power Line Conducted Emissions (15.270)
No power line conducted emissions were measured as this device operates from four 1.5 VDC, AAA batteries.

6.7 Effect of Supply Voltage Variation

The DUT has been designed to operate from 12 VDC power. Using a spectrum analyzer, relative radiated emissions were recorded at the center channel as voltage was varied from 4.0 to 8.0 VDC. Figure 6.4 shows the emission variation.

Batteries:	before testing	Voc = 6.3 V
	after testing	Voc = 6.0 V
Ave. current from batteries		I = 65 mA (non-hopping)

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Table 5.1(a) Highest Emissions Measured

Restricted Band Radiated Emissions											RAVEN Remote; FCC/IC
#	Freq. MHz	Ant. Used	Ant. Pol.	Pr dBm	Det.* Used	Ka dB/m	Kg dB	E3** dBµV/m	E3lim dBµV/m	Pass dB	Comments
1	2405.0	R-Horn	H/V	-10.5	Pk	23.5	26.5	73.5	94.0	**20.5**	Low Channel, 2405 MHz
2	2445.0	R-Horn	H/V	-12.3	Pk	23.7	26.4	71.9	94.0	22.1	9th Channel, 2445 MHz
3	2480.0	R-Horn	H/V	-13.6	Pk	23.8	26.4	70.8	94.0	23.2	High Channel, 2480 MHz
4	4810.0	Horn C	H/V	-47.7	Pk	24.6	38.0	25.9	54.0	28.1	Low
5	4890.0	Horn C	H/V	-47.0	Pk	24.6	38.0	26.6	54.0	27.4	Mid
6	4960.0	Horn C	H/V	-45.6	Pk	24.6	38.0	28.0	54.0	26.0	High
7	7215.0	Horn XN	H/V	-	Pk	25.1	36.8	-	N/A	-	Low
8	7335.0	Horn XN	H/V	-54.9	Pk	25.2	36.8	20.5	54.0	33.5	Mid
9	7440.0	Horn XN	H/V	-51.4	Pk	25.3	36.8	24.1	54.0	29.9	High
10	9620.0	Horn X	H/V	-	Pk	27.8	36.8	-	N/A	-	Low
11	9780.0	Horn X	H/V	-	Pk	27.9	36.8	-	N/A	-	Mid
12	9920.0	Horn X	H/V	-	Pk	28.0	36.8	-	N/A	-	High
13	12025.0	Horn X	H/V	-56.0	Pk	31.7	35.7	27.0	54.0	27.0	Low, noise
14	12225.0	Horn X	H/V	-56.1	Pk	31.8	34.0	28.8	54.0	25.2	Mid, noise
15	12400.0	Horn X	H/V	-57.5	Pk	32.0	32.4	29.0	54.0	25.0	High, noise
16	14430.0	Horn Ku	H/V	-	Pk	33.2	17.3	-	N/A	-	Low
17	14670.0	Horn Ku	H/V	-	Pk	33.3	17.3	-	N/A	-	Mid
18	14880.0	Horn Ku	H/V	-	Pk	33.4	17.3	-	N/A	-	High
19	16835.0	Horn Ku	H/V	-	Pk	34.6	34.0	-	N/A	-	Low
20	17115.0	Horn Ku	H/V	-	Pk	34.8	34.0	-	N/A	-	Mid
21	17360.0	Horn Ku	H/V	-	Pk	35.0	34.0	-	N/A	-	High
22	19240.0	Horn K	H/V	-56.9	Pk	32.2	32.0	30.3	54.0	23.7	Low, noise
23	19560.0	Horn K	H/V	-57.1	Pk	32.3	32.0	30.2	54.0	23.8	Mid, noise
24	19840.0	Horn K	H/V	-56.8	Pk	32.3	32.0	30.5	54.0	23.5	High, noise
25	21645.0	Horn K	H/V	-	Pk	32.7	32.0	-	N/A	-	Low
26	22005.0	Horn K	H/V	-	Pk	32.8	32.0	-	N/A	-	Mid
27	22320.0	Horn K	H/V	-52.9	Pk	32.8	32.0	34.9	54.0	**19.1**	High, noise
28	24050.0	Horn Ka	H/V	-	Pk	33.2	32.0	-	N/A	-	Low
29	24450.0	Horn Ka	H/V	-	Pk	33.3	32.0	-	N/A	-	Mid
30	24800.0	Horn Ka	H/V	-	Pk	33.3	32.0	-	N/A	-	High
31											
32											
33	*Measured with 3 MHz RBW and 5 MHz VBW, Avg. more than 20 dB below Peak.										
34	** 20 dB maximum permissible duty cycle applied.										
35											
36											
37											

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Table 5.1(b) Highest Emissions Measured

Radiated Band Edge Emissions											RAVEN Remote; FCC/IC
#	Freq. MHz	Ant. Used	Ant. Pol.	Pr dBm	Det.* Used	Ka dB/m	Kg dB	E3** dBµV/m	E3lim dBµV/m	Pass dB	Comments
1	2390.0	Horn S	H/V	-70.9	Pk	21.5	- 1.5	39.1	54.0	14.9	Low Channel, 2405 MHz
2	2390.0	Horn S	H/V	-71.2	Pk	21.5	- 1.5	38.8	54.0	15.2	9th Channel, 2445 MHz
3	2390.0	Horn S	H/V	-70.9	Pk	21.5	- 1.5	39.1	54.0	14.9	High Channel, 2480 MHz
4	2483.5	Horn S	H/V	-72.3	Pk	21.5	- 1.5	37.7	54.0	16.3	Low, noise
5	2483.5	Horn S	H/V	-71.8	Pk	21.5	- 1.5	38.2	54.0	15.8	Mid
6	2483.5	Horn S	H/V	-67.4	Pk	21.5	- 1.5	42.6	54.0	**11.4**	High
7	* Band edge Peak measured with 1 MHz RBW, 3 MHz VBW, 20 dB duty cycle applied										
8											
Conducted Peak Output Power											
#	Freq. MHz	Ant. Used	Ant. Pol.	Pcond dBm	Det.* Used	Pr mW	DUT Ant Gain (dB)	DUT EIRP mW	Pclim dBm	Pass dB	Comments
9	2405.0	Cond	H/V	-1.1	Pk	0.78	1.0	0.98			Lowest channel, conducted
10	2445.0	Cond	H/V	-1.4	Pk	0.72	1.0	0.91			Middle channel, conducted
11	2480.0	Cond	H/V	-0.9	Pk	0.81	1.0	1.02			Highest channel, conducted
12	* Peak measured with 3 MHz RBW and 5 MHz VBW										
13											
14											
Receiver Spurious Emissions											
#	Freq. MHz	Ant. Used	Ant. Pol.	Pr* dBm	Det.* Used	Ka dB/m	Kg dB	E3** dBµV/m	E3lim dBµV/m	Pass dB	Comments
15	2470.0	R-Horn	H/V	-61.2	Pk	23.7	26.4	43.1	54.0	10.9	noise
16	2510.0	R-Horn	H/V	-62.0	Pk	23.8	26.3	42.5	54.0	11.5	noise
17	2545.0	R-Horn	H/V	-61.0	Pk	23.9	26.2	43.7	54.0	10.3	noise
18	5090.0	C-Horn	H/V	-59.8	Pk	24.7	38.0	33.9	54.0	20.1	max all channels, noise
19	7635.0	Xn-Horn	H/V	-56.3	Pk	25.5	36.8	39.4	54.0	14.6	max all channels, noise
20	10180.0	X-Horn	H/V	-59.0	Pk	28.1	36.8	39.3	54.0	14.7	max all channels, noise
21	12725.0	Ku-Horn	H/V	-54.3	Pk	29.3	36.0	46.0	54.0	**8.0**	max all channels, noise
22											
23	* Note: Rx LO is fc+65 MHz.										
Digital Radiated Emissions*											
#	Freq. kHz	Ant. Used	Ant. Pol.	Pr dBm	Det. Used	Ka dB/m	Kg dB	E3 dBµV/m	E3lim dBµV/m	Pass dB	Comments
24											
25	* Digital Emissions > 20 dB Below FCC/IC Class B Limit										
26											
27											
28											

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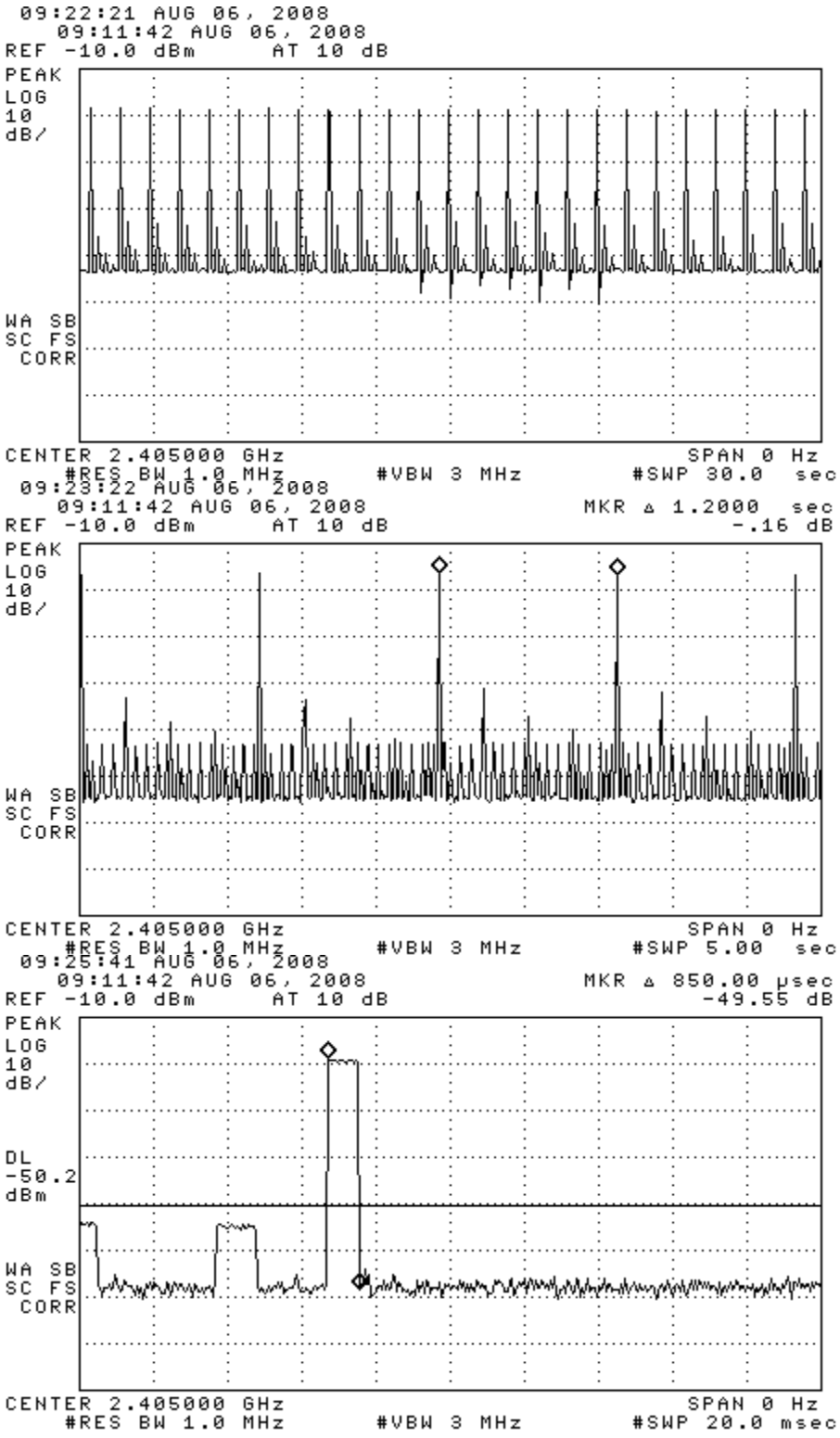


Figure 6.1 Single Channel Emissions. (top) complete transmission on a single channel, (middle) One packet every 1.2 seconds, (bottom) packet width
(Same for all 16 channels)

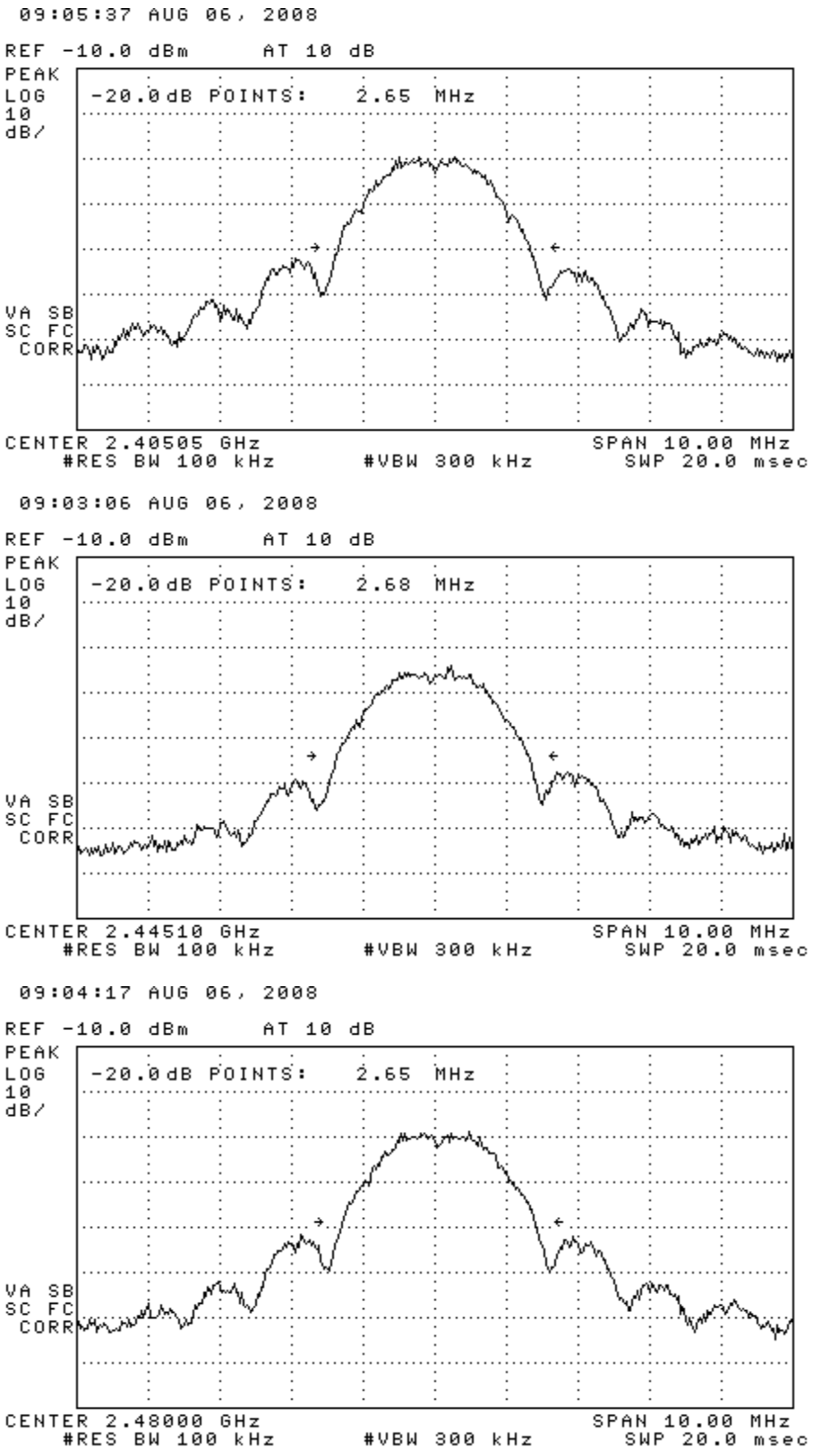


Figure 6.2 Measurement of channel bandwidth.
(top) Low Channel, (middle) Middle Channel, (bottom) High Channel

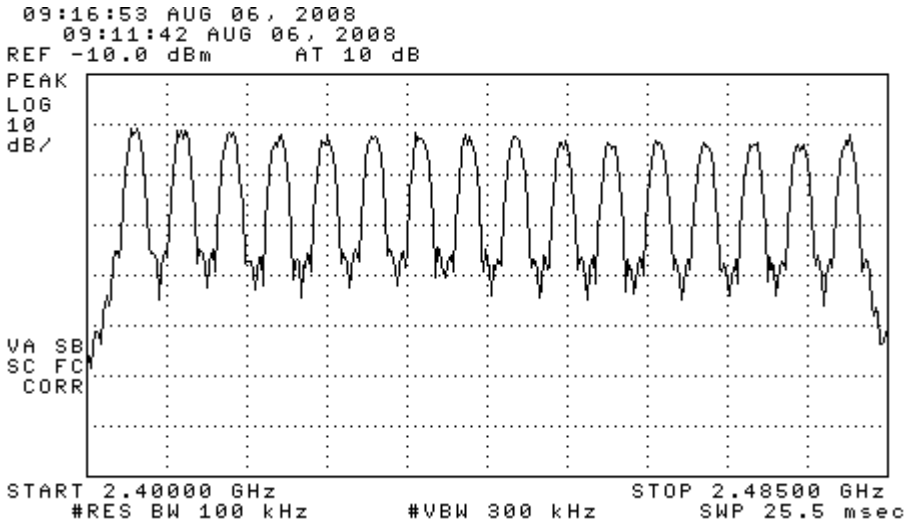


Figure 6.3 Number of Hopping Frequencies.

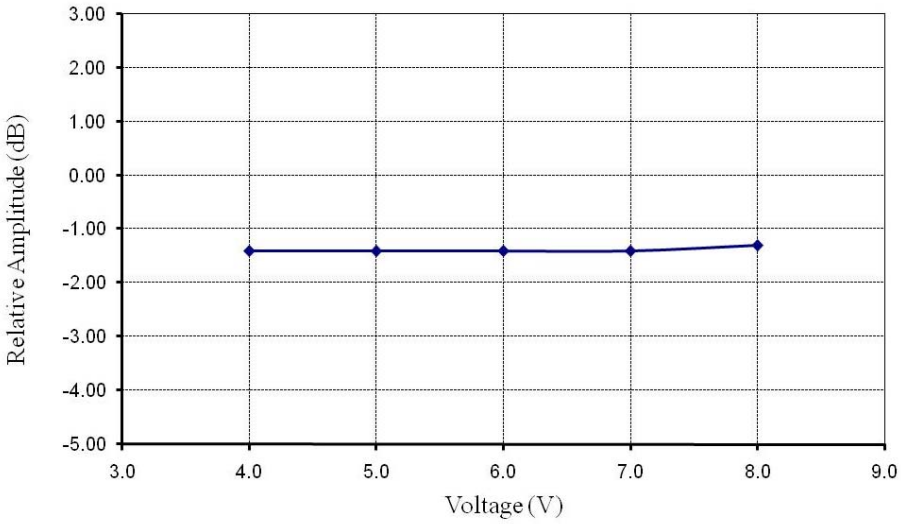
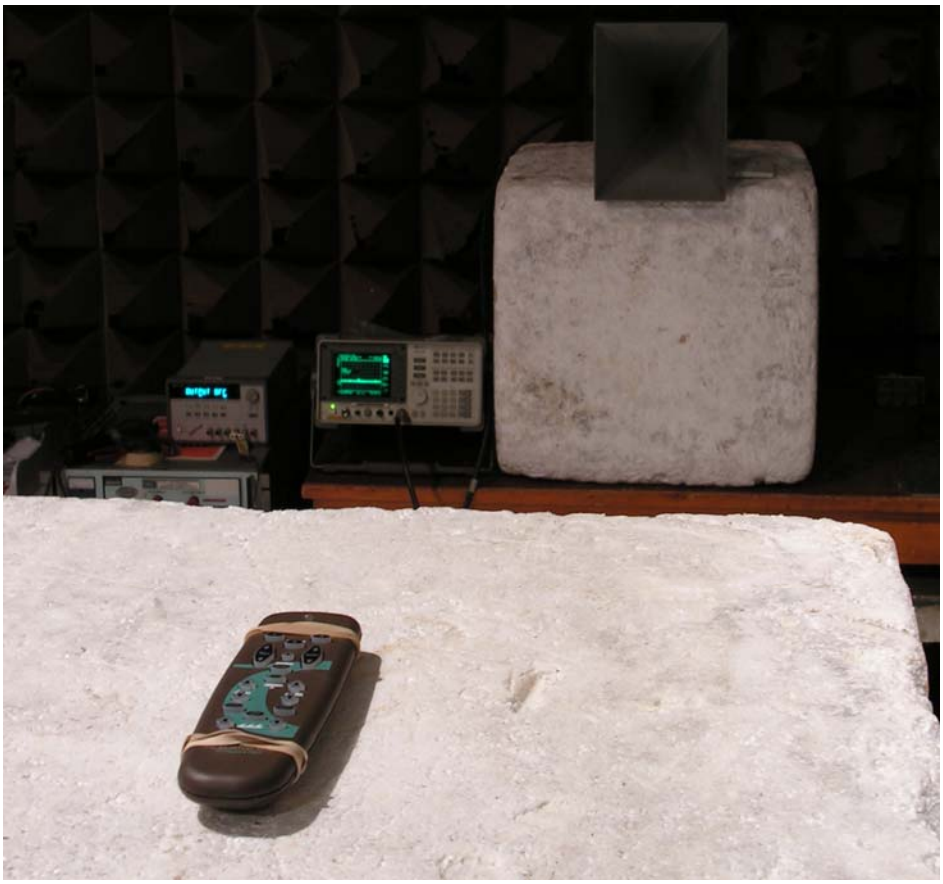


Figure 6.4 Relative emission vs. supply voltage, center channel.



Test Setup (Radiated Emissions) – one of three axes tested

DUT on OATS (close-up) – one of three axes tested