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Measured Radio Frequency Emissions
From

Johnson Controls
Model: CB2UCON2

Report No. 203
March 22, 2004

For:
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Summary
Tests for compliance with FCC Regulations, Part 15.247, and with Industry Canada (IC) Regulations, RSS-210, Part 6.2.2, were performed on Johnson Controls model CB2UCON2 frequency hopping spread spectrum (FHSS) transmitter. The DUT is subject to the Rules and Regulations as a transmitter.

In testing competed on March 11, 2004, the radiated emissions in restricted bands were met by 12.1 dB. The AC line conducted emissions tests do not apply, since the device is powered from a 12 VDC system. The DUT is exempt as a digital device since it is used in a transportation vehicle. All other testing indicates that the Johnson Controls model CB2UCON2 meets the limitations set forth by the FCC and IC for a 2.4 GHz FHSS transmitter.

1. Introduction

Johnson Controls model CB2UCON2 was 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 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).

2. Test Procedure and 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.

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		Hewlett-Packard, 432A
Power Meter		Anritsu, ML4803A/MP
Peak Power Meter		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	Avantak, A11-1, A25-1S
Amplifier (5-4500 MHz)	X	Avantak
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

3. Configuration and Identification of Device Under Test

The DUT is a frequency hopping spread spectrum (FHSS) transmitter operating in 2400 - 2483.5 MHz band. The DUT is 5 x 1.5 x 3.5 inches, and connects to a peripheral laptop computer via a serial interface card for testing purposes. The system has been designed to operate with 79 channels spaced 1 MHz apart, between 2402 MHz and 2480 MHz. The DUT has only one antenna built into the PCB. Three parts have been tested. All contain identical RF sections and differ only in the communications bus (CAN, J1850 General, J1850 Differential).

The DUT was designed and manufactured by Johnson Controls Interiors L.L.C., One Prince Center, Holland, MI 49423. It is identified as:

Johnson Controls Bluetooth Module
Model: CB2UCON2
SN: D2C00GDA, BZC00APA, FZC0023A
FCC ID: CB2UCON2
IC: 279B-UCON2

Peripheral Equipment:

Laptop Computer	
Toshiba Satellite	SN: X3058741H
Model: A10-S1291	PN: PSA10U-0ZH6M3
Serial/USB Adaptor	SN: Proto1

In addition to a standard unit, a modified unit was provided by the manufacturer which had the internal antenna disabled and a SMA connector attached for conducted antenna measurement purposes.

3.1 EMI Relevant Modifications

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

4. Emission Limits

4.1 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

4.2 Conducted Emission Limits

Table 4.3 Conducted Emission Limits (FCC:15.107(CISPR); 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

5. Radiated Emission Tests and Results

5.1 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 (horn) antennas were placed on a Styrofoam block, at about 1.2 m height, and the DUT on a turntable at 3 meter distance (moved to 1 m distance if needed).

Standard gain horn antennas were used for the measurements. Up to 7 GHz the horns were connected to a spectrum analyzer via RG-214 coaxial cable, and above 7 GHz a pre-amp was added. The cables and the pre-amplifier used were 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.

5.2 Outdoor Measurements

None made.

5.3 Computations and Results

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

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

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 12.1 dB at 4804 MHz.

Note, that besides the emission measurements, each table contains the frequency range of operation (in upper section of the table).

5.4 Duty Factor for Normal Operation

No duty factor is used.

6. Other Measurements and Computations

6.1 20 dB Bandwidth (15.247(a)(1)(ii))

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=10 kHz, VBW=10 kHz, SPAN= 2 MHz. The 20-dB bandwidth was measured for low, mid, and high channels used by the DUT. The maximum limit for 20dB bandwidth of a single channel is 1 MHz. The resulting measured data is below, and plots are shown in Figure 6.1.

Channel	Frequency	20 dB BW	Limit (max)
1	2.402 GHz	625 kHz	1 MHz
39	2.441 GHz	720 kHz	1 MHz
79	2.480 GHz	720 kHz	1 MHz

6.2 Carrier Frequency Separation (15.247(a)(1))

For this test, the DUT was put in a test mode for data transmission (hopping enabled). The DUT was placed in front of the horn antenna at the location of maximum radiation. The analyzer was set for RBW=10 kHz, VBW= 30 kHz, SPAN= 1.8 MHz. The Carrier Frequency Separation was measured for low, mid, and high channels used by the DUT. A minimum carrier separation of 25 kHz, or the 20 dB bandwidth of the hopping channel, whichever is larger, is required. The resulting measured data is below, and plots are shown in Figure 6.2.

Channel	Frequency	Separation	Limit (min)
1	2.402 GHz		
2	2.403 GHz	1.010 MHz	625 kHz
38	2.440 GHz		
39	2.441 GHz	1.010 MHz	720 kHz
78	2.479 GHz		
79	2.480 GHz	1.010 MHz	720 kHz

Note: The different operating modes (data-mode, acquisition-mode) of a Bluetooth device do not influence the channel spacing. There is only one transmitter which is driven by identical input parameters concerning this parameter.

6.3 Number of Hopping Frequencies (15.247(a)(1)(ii))

For this test, the DUT was put in a test mode for data transmission (hopping enabled). The DUT was placed in front of the horn antenna at the location of maximum radiation. The analyzer was set for RBW=30 kHz, VBW=30 kHz, SPAN as needed. The total number of hopping channels must be 75 or greater. The number of measured channels is below, and plots are shown in Figure 6.3.

Frequency Range	Number of Channels	Total	Limit
2402.0 – 2428.5	27		
2430.0 – 2454.5	26	79	>75
2455.0 – 2483.5	26		

6.4 Single-Channel Dwell Time (15.247(a)(1)(ii))

For this test, the DUT was put in a test mode for data transmission (hopping enabled). The DUT was placed in front of the horn antenna at the location of maximum radiation. The analyzer was set for RBW= 1 MHz, VBW= 3 MHz, SPAN= 0 Hz. The limit for total average dwell time in a single channel must be less than 0.4 sec in a 30 sec period. The dwell time was measured at low, mid, and high channels and the results are listed below. Plots are shown in Figure 6.4.

Channel	Frequency	Num. Pulses	Active Time	Total	Limit (max)
1	2.402 GHz	54	2.938ms	0.1587 sec	0.4 sec
39	2.441 GHz	87	2.938ms	0.2556 sec	0.4 sec
79	2.480 GHz	66	2.938ms	0.1939 sec	0.4 sec

Note: The measured dwell time above may not indicate the actual single channel dwell time of the DUT. A dwell time of 0.3797 seconds within a 30 second period in data mode is independent from the packet type (packet length) for all Bluetooth devices. Therefore, all Bluetooth devices comply with the FCC dwell time requirement in the data mode.

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

The measured difference between peak and average is always greater than 20 dB for a Bluetooth device. As demonstrated below, measurements made at 2441 MHz comparing relative peak emissions (1 MHz RBW and 3 MHz VBW) and average emissions (1 MHz RBW and 100 Hz VBW) demonstrate that the DUT has a 37.7 dB Peak-to-Average Ratio in the mode used for testing radiated emissions. Therefore, peak power radiated emissions are measured, and peak limits (average limit + 20 dB) are applied.

Measured Peak emission (relative):	-30.6 dB
Measured Avg. emission (relative):	-68.3 dB
Peak-to-Average Ratio:	37.7 dB

6.6 Peak and Average Output Power (15.247(b))

For this test, the DUT was put in a test mode for data transmission (hopping disabled). Peak power measurements were made using 1 MHz RBW and 3 MHz VBW on the Spectrum Analyzer. The power was measured from the RF port of DUT (a modified module was provided from the manufacturer for this purpose; the antenna is not generally removable). Table 6.2 presents the results. The maximum peak output power limit is 30dBm (1 Watt).

Table 6.2 Peak Output Power (Antenna Conducted)

Freq (MHz)	Peak P(dBm)	Peak Limit (dBm)
2402	4.44	30
2441	3.81	30
2480	3.00	30

Note: The different operating modes (data-mode, acquisition-mode) of a Bluetooth device do not influence the output power. There is only one transmitter which is driven by identical input parameters concerning this parameter.

6.7 Potential Health Hazard EM Radiation Level

It has been determined that the DUT output power is less than 10 mW (10 dBm), and given the low gain of the PCB antenna (~1 dBi) , no health hazard exists beyond the physical dimensions of the DUT. The following table summarizes the minimum operating distance for this device as calculated from FCC OET Bulletin 65.

Table 6.3 Potential Health Hazard Radiation Level

Ant.	Ant.Gain (dB)	Po (mW)	EIRP (mW)	R (cm)
PCB	1	2.78	3.50	0.53

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

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

and

$$R = \sqrt{\frac{EIRP(mW)}{4 \cdot \Pi \cdot S(mW/cm^2)}}, \quad S = 1mW/cm^2$$

6.8 Power Line Conducted Emissions (15.270)

No power line conducted emissions were measured as this device operates from a 12 VDC system.

6.9 RF Antenna Spurious Emissions (15.247(c))

For this test, the DUT was put in a test mode for data transmission (hopping disabled). 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. The DUT was measured for 3 channels used in the system. See Figure 6.5. In all cases, the noise is at least 30 dB below the carrier. (Limit -20.0 dB below carrier).

6.10 Band Edge Emissions (15.247(c))

For this test, the DUT was put in a test both hopping and non-hopping test modes. The spectrum analyzer was connected where the antenna attaches to the system. The analyzer was set for RBW=100 kHz, VBW=300 kHz, with the SPAN=5 MHz. The DUT was measured for low and high channels used in the system. Figures 6.6 and 6.7 show the band edge emissions, as summarized below.

Not Hopping

Channel	Frequency	Band Edge	Attenuation	Limit(max)
1	2402.0 MHz	2400.0 MHz	-45.3 dB	-20 dB
79	2480.0 MHz	2483.5 MHz	-46.9 dB	-20 dB

Hopping

Channel	Frequency	Band Edge	Attenuation	Limit(max)
1	2402.0 MHz	2400.0 MHz	-42.8 dB	-20 dB
79	2480.0 MHz	2483.5 MHz	-47.2 dB	-20 dB

Table 5.1 Highest Emissions Measured

	Radiated Emissions									CI CB2UCON2; FCC/IC
#	Freq. MHz	Ant. Used	Ant. Pol.	Peak dBm	Ka dB/m	Kg dB	E3 (Pk) dBμV/m	E3lim (Pk) dBμV/m	Pass dB	Comments
1	2402.0									Low channel
2	2441.0									Mid channel
3	2480.0									High channel
4	Module: J1850 Diff									
5	2390.0	Horn S	H/V	-71.9	21.5	- 0.6	57.2	74.0	16.8	Low, noise
6	2390.0	Horn S	H/V	-72.2	21.5	- 0.6	56.9	74.0	17.1	Mid, noise
7	2390.0	Horn S	H/V	-72.5	21.5	- 0.6	56.6	74.0	17.4	High, noise
8	2483.5	Horn S	H/V	-70.2	21.5	- 0.6	58.9	74.0	15.1	Low, noise
9	2483.5	Horn S	H/V	-70.0	21.5	- 0.6	59.1	74.0	14.9	Mid
10	2483.5	Horn S	H/V	-66.8	21.5	- 0.6	62.3	74.0	11.7	High
11	4804.0	Horn C	H/V	-36.7	25.5	37.0	58.9	74.0	15.2	Low
12	4882.0	Horn C	H/V	-36.1	25.5	37.0	59.5	74.0	**14.6**	Mid
13	4960.0	Horn C	H/V	-37.0	25.5	37.0	58.5	74.0	15.5	High
14	7206.0	Horn XN	H/V	-	25.5	36.0	-	N/A	-	Low
15	7323.0	Horn XN	H/V	-42.5	25.5	36.0	54.0	74.0	20.0	Mid
16	7440.0	Horn XN	H/V	-42.8	25.5	36.0	53.7	74.0	20.3	High
17	12010.0	Horn X	H/V	-54.2	25.5	34.0	44.3	74.0	29.7	Low
18	12205.0	Horn X	H/V	-57.8	25.5	34.0	40.7	74.0	33.3	Mid
19	12400.0	Horn X	H/V	-60.0	25.5	34.0	38.5	74.0	35.5	High, noise
20	14412.0	Horn Ku	H/V	-	32.3	32.0	-	N/A	-	Low
21	14472.0	Horn Ku	H/V	-61.5	32.3	32.0	45.8	74.0	28.2	Mid, noise
22	14880.0	Horn Ku	H/V	-	32.3	32.0	-	N/A	-	High
23	19216.0	Horn K	H/V	-61.7	32.3	32.0	45.6	74.0	28.4	Low, noise
24	19528.0	Horn K	H/V	-59.3	32.3	32.0	48.0	74.0	26.0	Mid, noise
25	19840.0	Horn K	H/V	-59.1	32.3	32.0	48.2	74.0	25.8	High, noise
26	21618.0	Horn K	H/V	-	32.3	32.0	-	N/A	-	Low
27	21969.0	Horn K	H/V	-	32.3	32.0	-	N/A	-	Mid
28	22320.0	Horn K	H/V	-56.0	32.3	32.0	51.3	74.0	22.7	High, noise
29										
30	Worst Case Emissions From other Models/Modules									
31	Module: J1850 Gen									
32	4804.0	Horn C	H/V	-37.9	25.5	37.0	57.6	74.0	16.4	Low
33	4882.0	Horn C	H/V	-36.3	25.5	37.0	59.2	74.0	**14.8**	Mid
34	4960.0	Horn C	H/V	-36.5	25.5	37.0	59.0	74.0	15.0	High
35	Module: CAN									
36	4804.0	Horn C	H/V	-33.6	25.5	37.0	61.9	74.0	**12.1**	Low
37	4882.0	Horn C	H/V	-34.8	25.5	37.0	60.7	74.0	13.3	Mid
38	4960.0	Horn C	H/V	-36.2	25.5	37.0	59.3	74.0	14.7	High
39	* Peak: measured with 1 MHz RBW and 3 MHz VBW									
40	* Average measurements were not made, as the Pk to Avg ratio is greater than 20 dB (FCC 15.35)									
41	Note: Digital emissions were more than 20 dB below FCC/IC Class B Limit.									
42										

U. of Mich; Meas. 3/11/2004

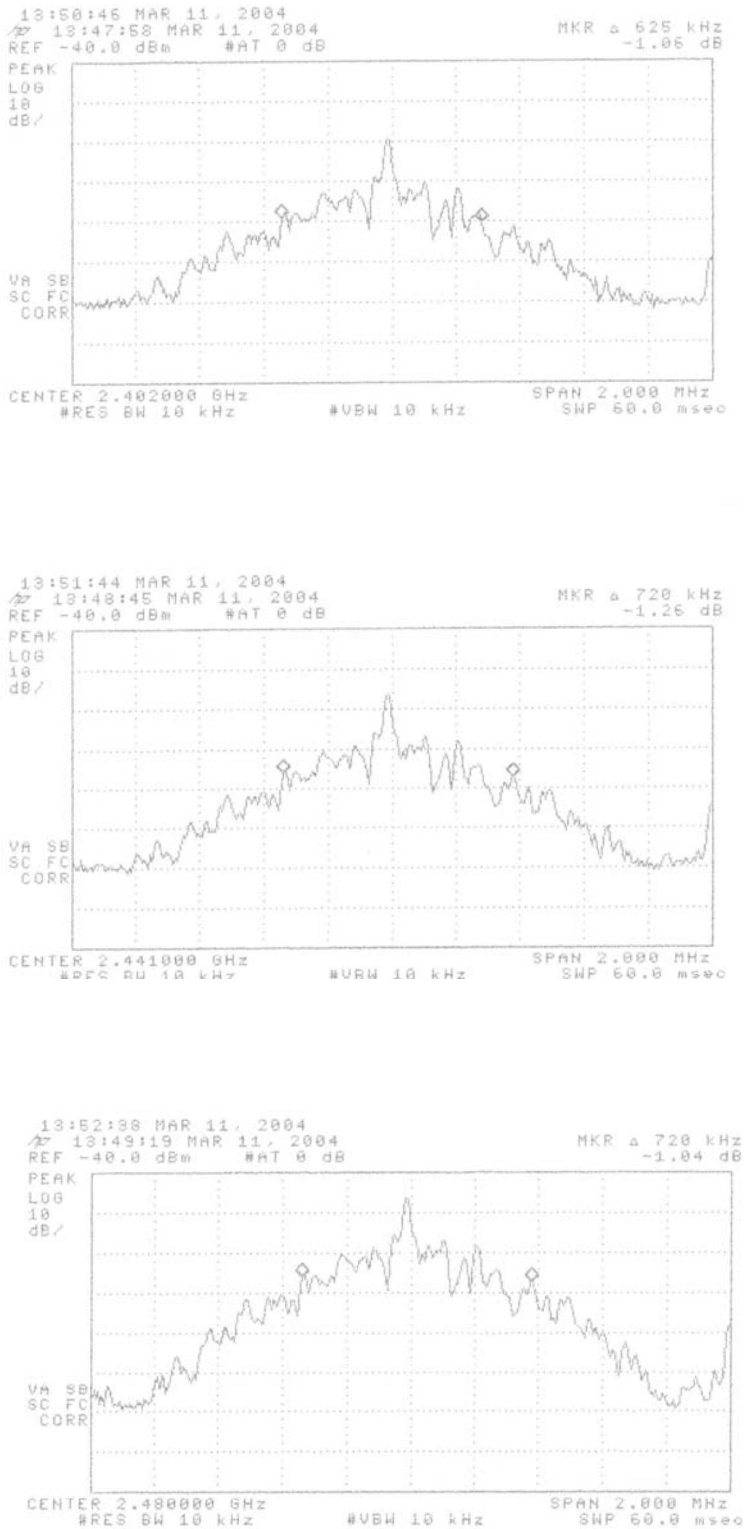


Figure 6.1 Measurement of channel 20 dB bandwidth.
(top) Low Channel, (middle) Middle Channel, (bottom) High Channel

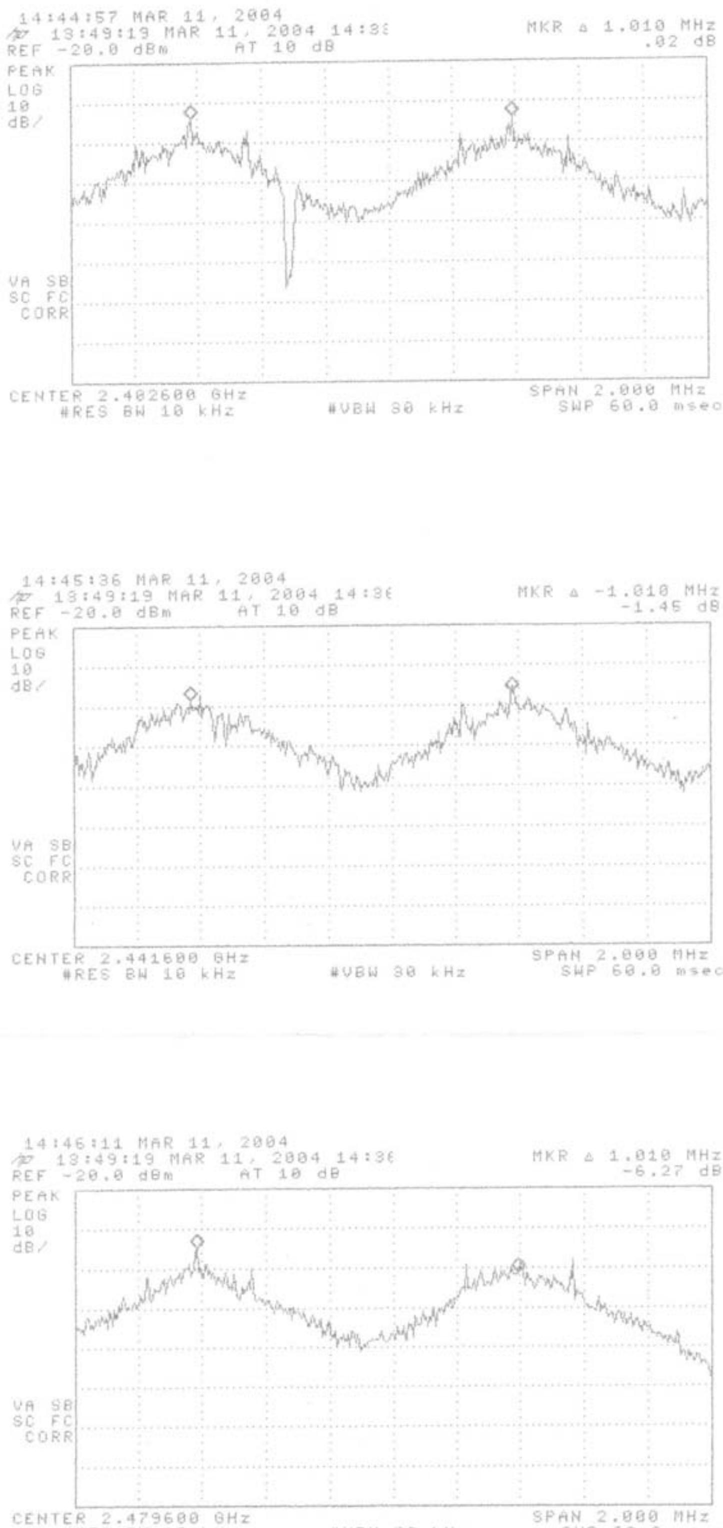


Figure 6.2 Carrier Frequency Separation.
(top) Low Channel, (middle) Middle Channel, (bottom) High Channel

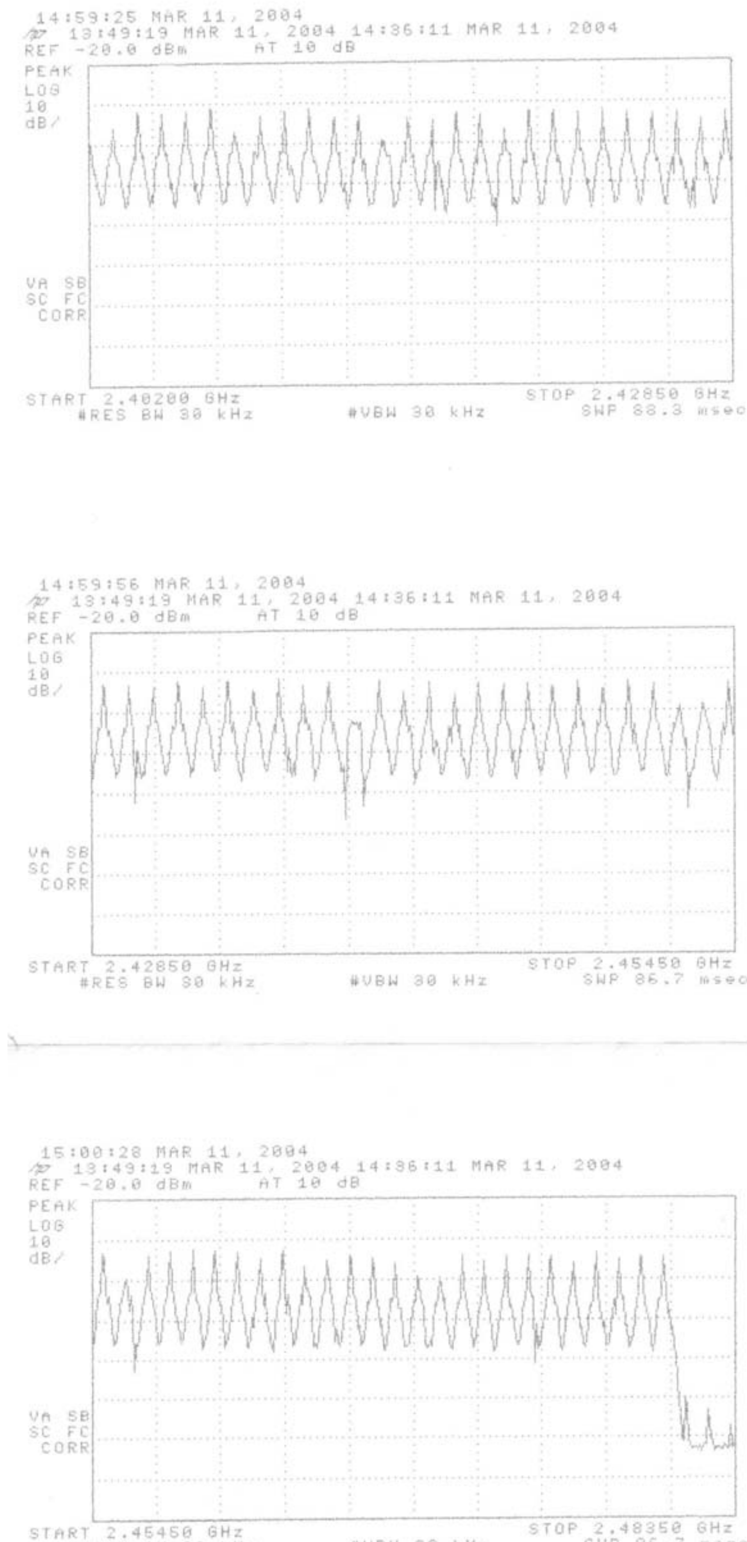
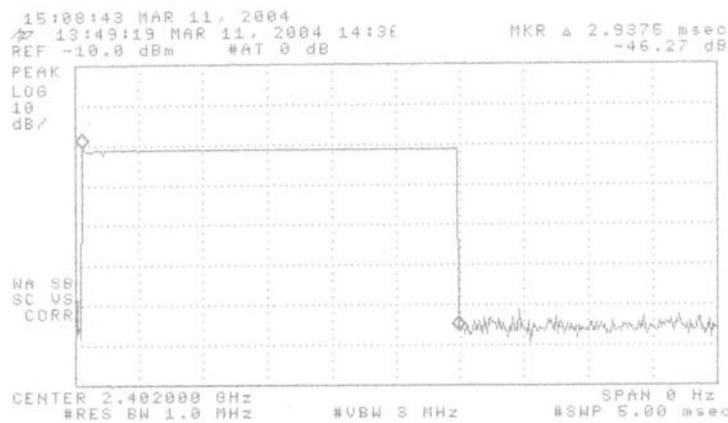


Figure 6.2 Number of Hopping Frequencies.
(top) low, (middle) middle, (bottom) high portion of band



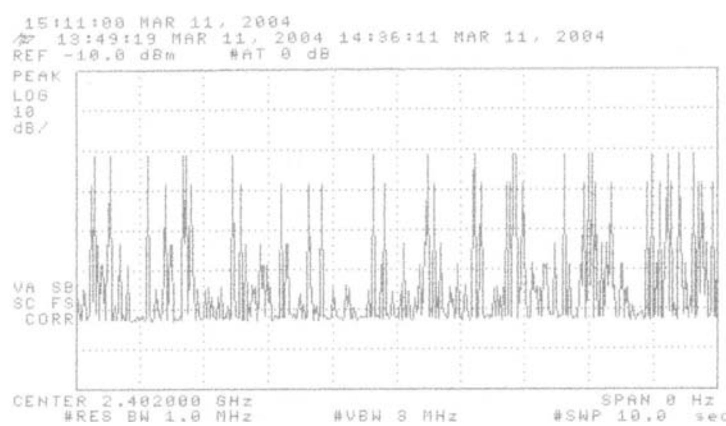
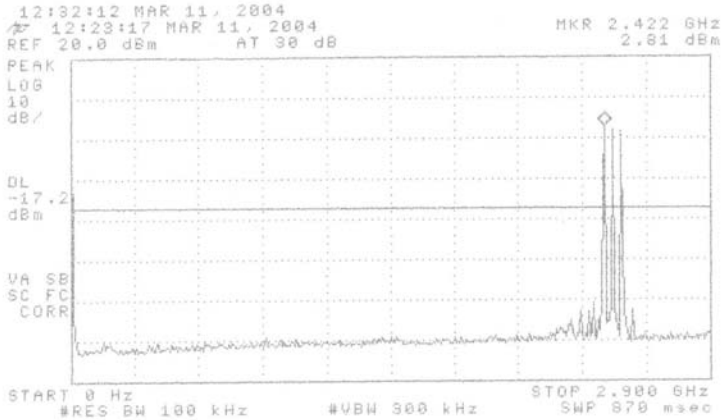
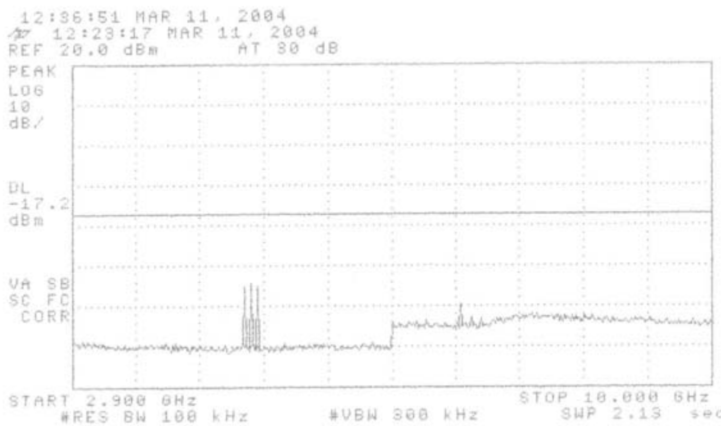


Figure 6.4 Single Channel Dwell Time.
(only Low Channel shown)





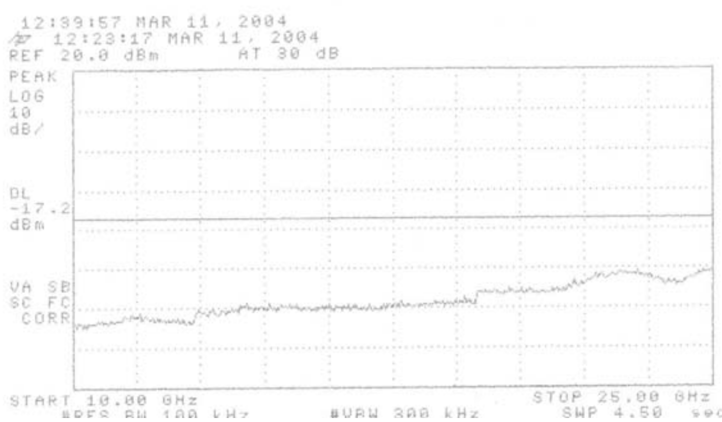


Figure 6.5 Antenna Conducted Spurrious Emissions.
(all channels)

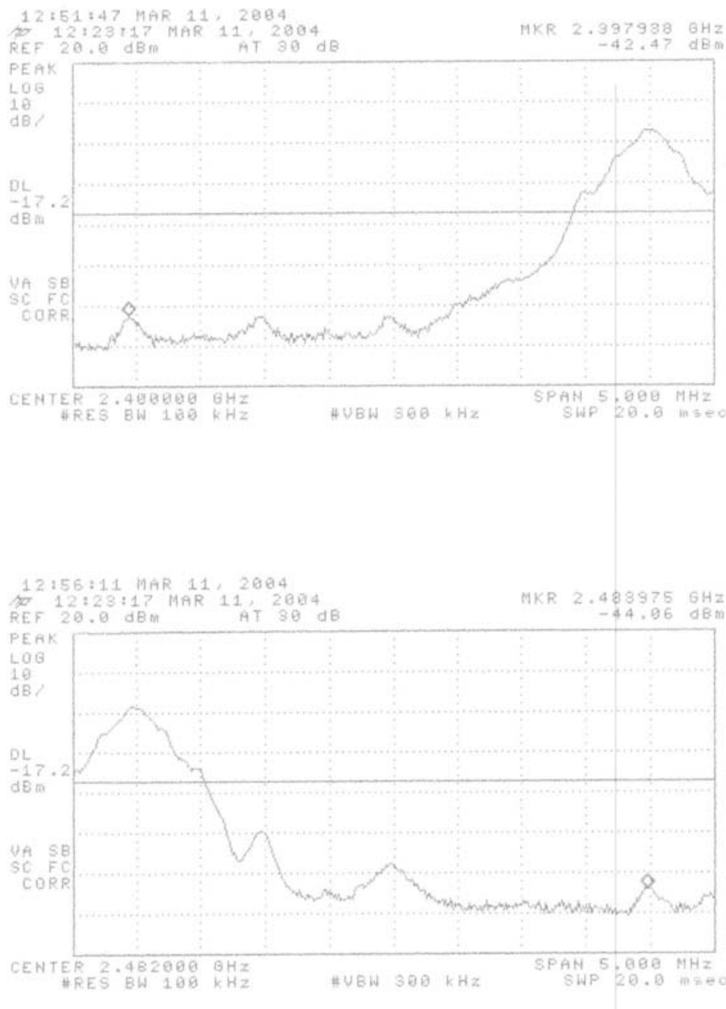
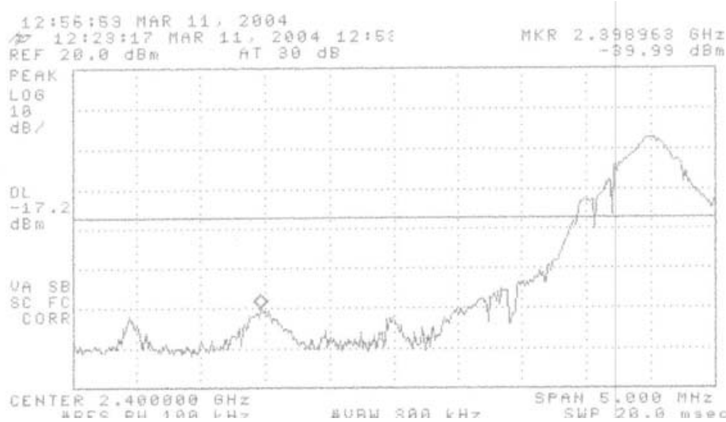


Figure 6.6 Band edge emissions – NOT HOPPING.
(top) Low Channel, (bottom) High Channel



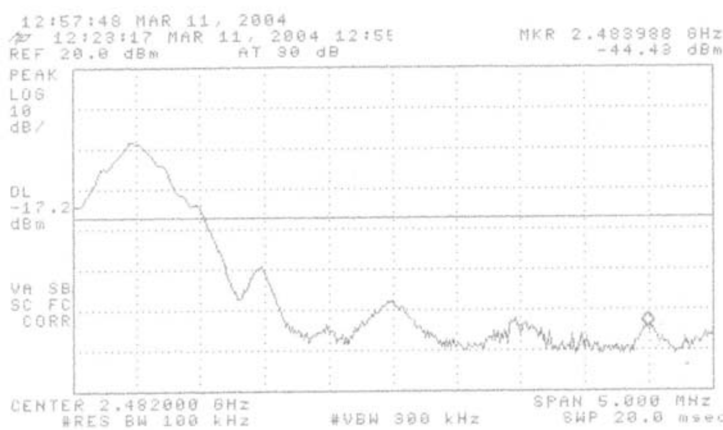


Figure 6.7 Band edge emissions - HOPPING.
(top) Low Channel, (bottom) High Channel