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Measured Radio Frequency Emissions
From

Johnson Controls
Model: U-connect

Report No. 137
October 19, 2002

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 U-connect frequency hopping spread spectrum (FHSS) Bluetooth transmitter. The DUT is subject to the Rules and Regulations as a transmitter.

In testing competed on 17-Oct-02, the radiated emissions in restricted bands were met by 11.8 dB. The AC line conducted emissions tests do not apply, since the device is powered from a 12 VDC automotive 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 U-connect meets the limitations set forth by the FCC and IC for a 2.4 GHz FHSS transmitter.

1. Introduction

Johnson Controls model U-connect 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	X	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 one antenna built into the PCB.

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: U-connect
SN: Proto1
FCC ID: CB2UCONN
IC: 279B-UCONN

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.

Peripheral Equipment:

Laptop Computer	
Compaq Presario	SN: V745BQD22994
Model: Series 2940	FCC ID: CNTTAI-24639-TT-E
Serial Interface Card	SN: Proto1

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 only (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; IC: RSS-210, 6.6).

Frequency	Class A		Class B	
(MHz)	μV	dBμV	μV	dBμV
0.45-1.705	1000	60.0	250	48.0
1.705-30.0	3000	69.6	250	48.0

Note: Quasi-Peak readings apply here (9 kHz BW)

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-amplifiers 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 Photos* 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

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

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 losses, 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 11.8 dB at 4882 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	800 kHz	1 MHz
39	2.441 GHz	800 kHz	1 MHz
79	2.480 GHz	800 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	1.0 MHz	800 kHz
38	2.440 GHz		
39	2.441 GHz	1.0 MHz	800 kHz
78	2.479 GHz		
79	2.480 GHz	1.0 MHz	800 kHz

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 0.4sec in a 30sec 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	900	135us	0.122 sec	0.4 sec
39	2.441 GHz	900	135us	0.122 sec	0.4 sec
79	2.480 GHz	900	135us	0.122 sec	0.4 sec

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

For the measurements presented here for emissions in restricted bands, the DUT was put in a test mode for data transmission (hopping disabled). The worst case on time is 135 μs in a period of 30 ms. See Figure 6.4. Thus, the duty factor is

$$K_E = 135us / 30\ ms = 0.0041 \text{ or } -47.0\ dB.$$

The measured difference between peak and average is greater than 30 dB across the band of operation, which exceeds the 20 dB limit. Therefore, peak power radiated emissions are measured, and peak limits (average limit + 20 dB) are applied. See Attestations exhibit for Duty Factor of alternate hopping modes.

6.6 Peak Output Power (15.247(b))

For this test, the DUT was put in a test mode for data transmission (hopping disabled). Average power measurements were made using 1 MHz RBW and 100 Hz VBW and 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	4.6	30
2441	4.5	30
2480	4.7	30

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.

6.8 Power Line Conducted Emissions (15.270)

No power line conducted emissions were measured as this device operates from a 12 VDC automotive 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	-50.0 dB	-20 dB
79	2480.0 MHz	2483.5 MHz	-53.0 dB	-20 dB

Hopping

Channel	Frequency	Band Edge	Attenuation	Limit(max)
1	2402.0 MHz	2400.0 MHz	-52.0 dB	-20 dB
79	2480.0 MHz	2483.5 MHz	-57.0 dB	-20 dB

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Table 5.1 Highest Emissions Measured

Radiated Emissions										JCI BlueConnect
#	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										
5	2390.0	Horn S	H/V	-72.4	21.5	- 0.6	56.7	74.0	17.3	Low, noise
6	2390.0	Horn S	H/V	-75.1	21.5	- 0.6	54.0	74.0	20.0	Mid, noise
7	2390.0	Horn S	H/V	-74.9	21.5	- 0.6	54.2	74.0	19.8	High, noise
8	2483.5	Horn S	H/V	-75.2	21.5	- 0.6	53.9	74.0	20.1	Low, noise
9	2483.5	Horn S	H/V	-75.4	21.5	- 0.6	53.7	74.0	20.3	Mid, noise
10	2483.5	Horn S	H/V	-70.9	21.5	- 0.6	58.2	74.0	15.8	High
11	4804.0	Horn C	H/V	-33.8	25.5	37.0	61.7	74.0	12.3	Low
12	4882.0	Horn C	H/V	-33.3	25.5	37.0	62.2	74.0	**11.8**	Mid, worst case
13	4960.0	Horn C	H/V	-34.9	25.5	37.0	60.6	74.0	13.4	High
14	7206.0	Horn XN	H/V	-	25.5	36.0	-	N/A	-	
15	7323.0	Horn XN	H/V	-43.6	25.5	36.0	52.9	74.0	21.1	Mid
16	7440.0	Horn XN	H/V	-43.6	25.5	36.0	52.9	74.0	21.1	High
17	9608.0	Horn X	H/V	-	25.5	34.0	-	N/A	-	
18	9764.0	Horn X	H/V	-	25.5	34.0	-	N/A	-	
19	9920.0	Horn X	H/V	-	25.5	34.0	-	N/A	-	
20	12010.0	Horn X	H/V	-58.0	25.5	34.0	40.5	74.0	33.5	Low, noise
21	12205.0	Horn X	H/V	-58.9	25.5	34.0	39.6	74.0	34.4	Mid, noise
22	12400.0	Horn X	H/V	-60.0	25.5	34.0	38.5	74.0	35.5	High, noise
23	14412.0	Horn Ku	H/V	-	25.5	17.3	-	N/A	-	
24	14472.0	Horn Ku	H/V	-63.1	32.3	34.0	42.2	74.0	31.8	Low/Mid, noise
25	14880.0	Horn Ku	H/V	-	32.3	34.0	-	N/A	-	
26	16814.0	Horn Ku	H/V	-	32.3	34.0	-	N/A	-	
27	17087.0	Horn Ku	H/V	-	32.3	34.0	-	N/A	-	
28	17360.0	Horn Ku	H/V	-	32.3	34.0	-	N/A	-	
29	19216.0	Horn K	H/V	-69.1	32.3	32.0	38.2	74.0	35.8	Low
30	19528.0	Horn K	H/V	-69.1	32.3	32.0	38.2	74.0	35.8	Mid
31	19840.0	Horn K	H/V	-69.1	32.3	32.0	38.2	74.0	35.8	High
32	21618.0	Horn K	H/V	-	32.3	32.0	-	N/A	-	
33	21969.0	Horn K	H/V	-	32.3	32.0	-	N/A	-	
34	22320.0	Horn K	H/V	-69.1	32.3	32.0	38.2	74.0	35.8	High
35	24020.0	Horn Ka	H/V	-	32.3	32.0	-	N/A	-	
36	24410.0	Horn Ka	H/V	-	32.3	32.0	-	N/A	-	
37	24800.0	Horn Ka	H/V	-	32.3	32.0	-	N/A	-	
38										
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										

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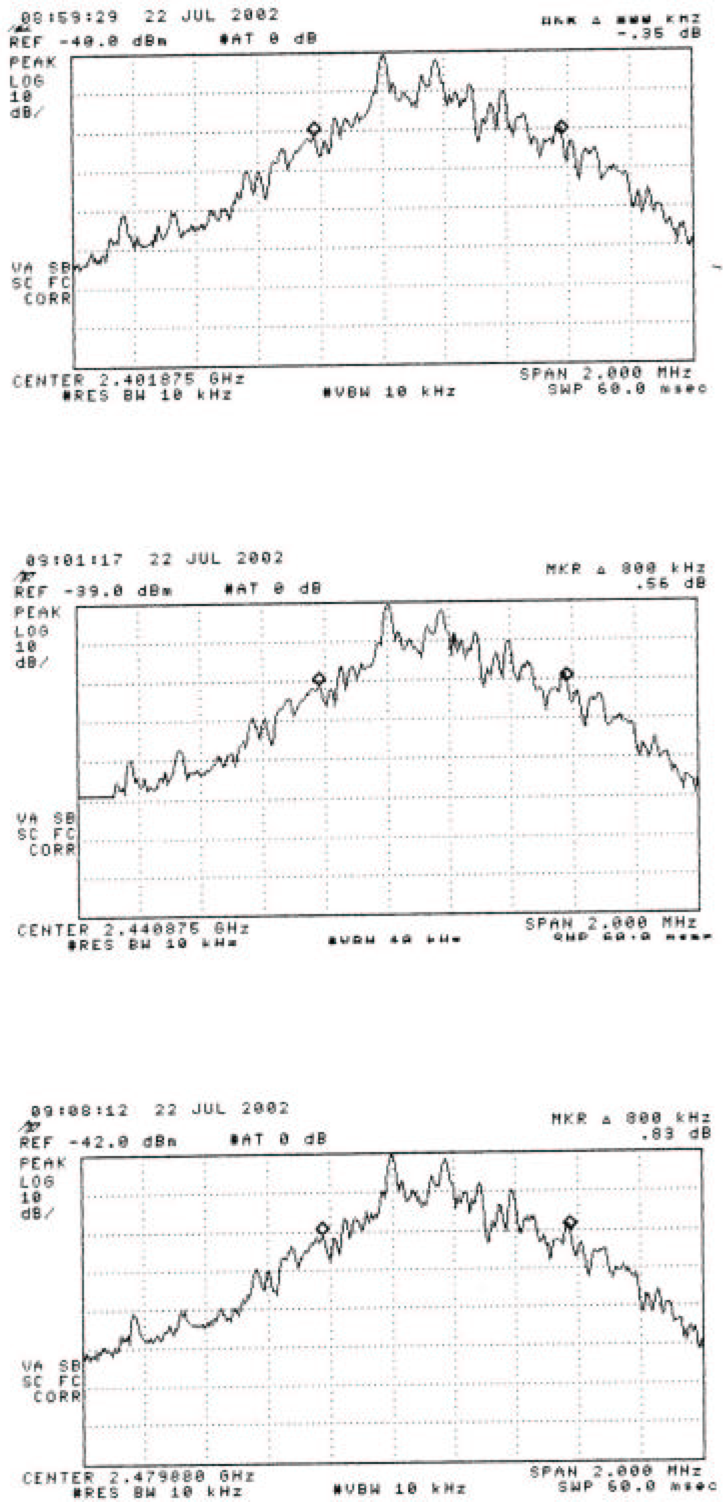
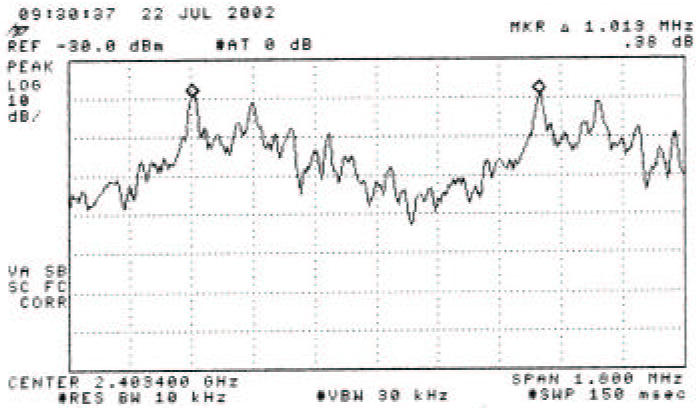
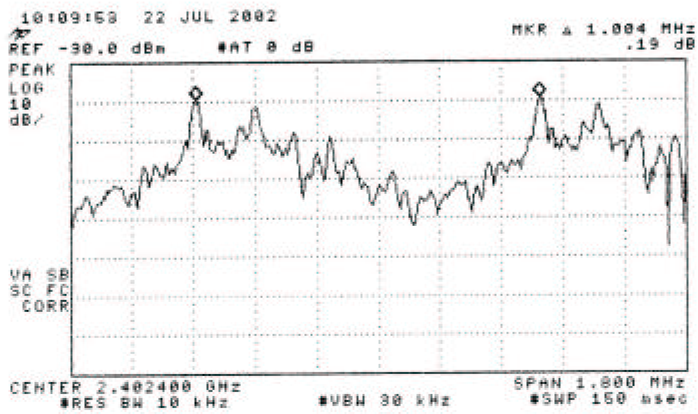


Figure 6.1 Measurement of channel 20 dB bandwidth.
(top) Low Channel, (middle) Middle Channel, (bottom) High Channel





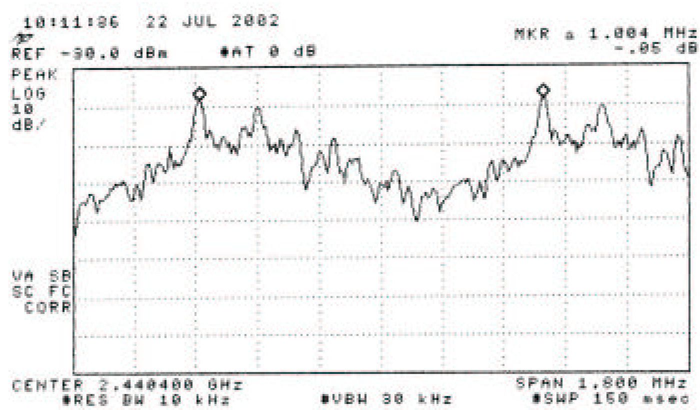


Figure 6.2 Carrier Frequency Separation.
(top) Low Channel, (middle) Middle Channel, (bottom) High Channel

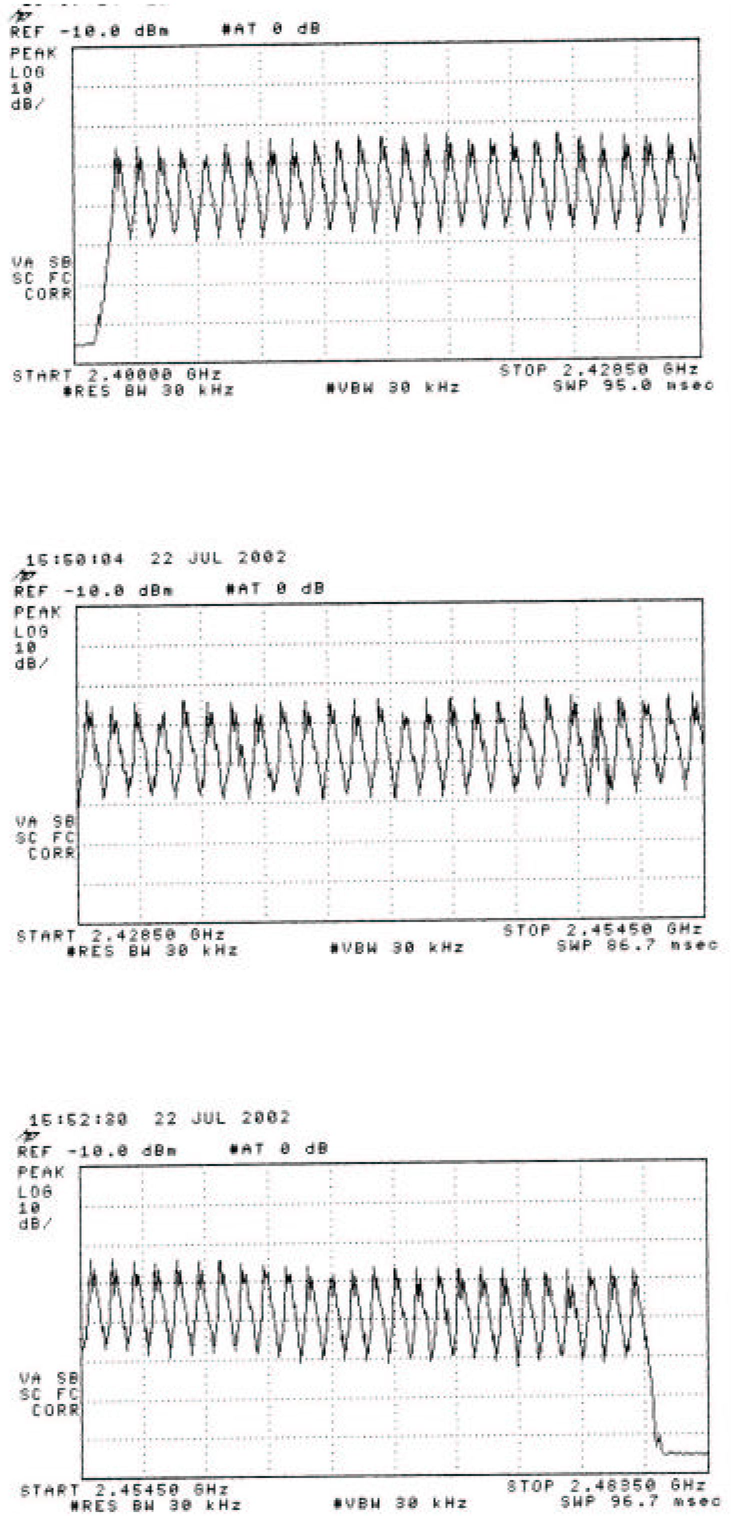
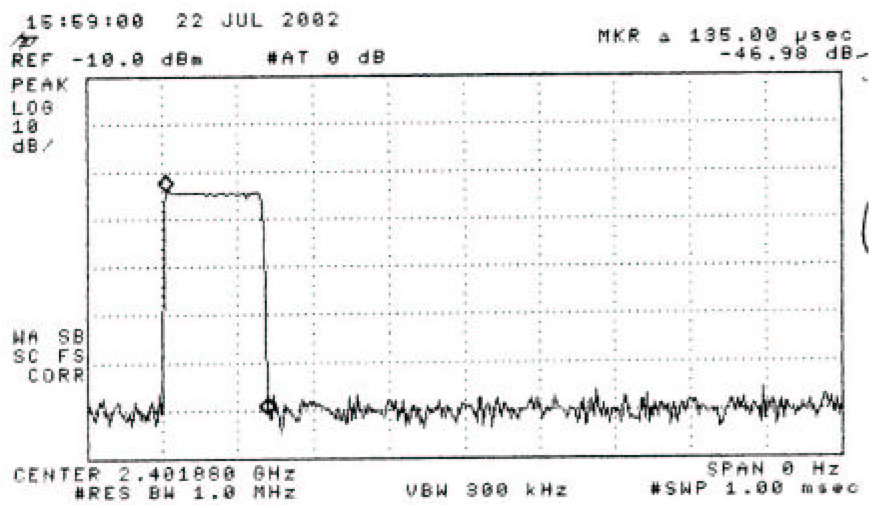


Figure 6.2 Number of Hopping Frequencies.
(top) low, (middle) middle, (bottom) high portion of band



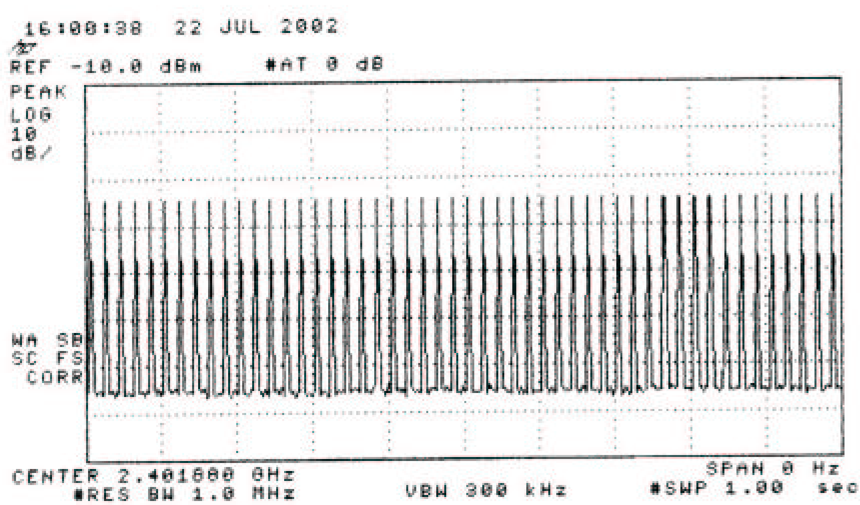
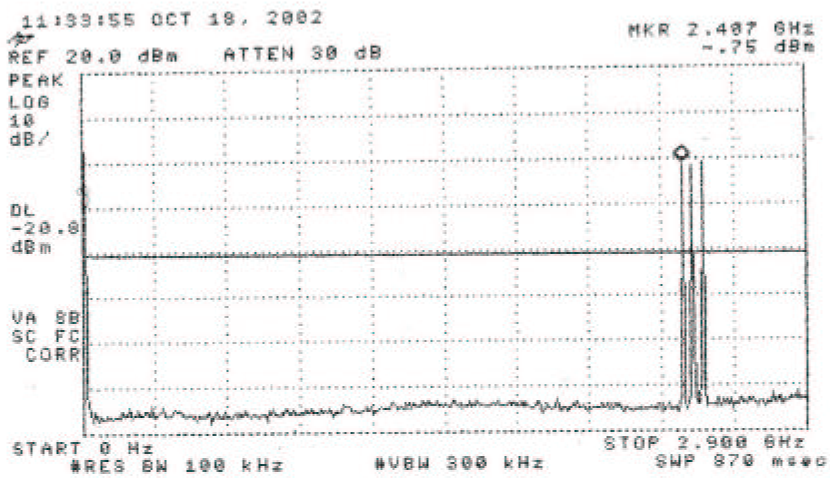
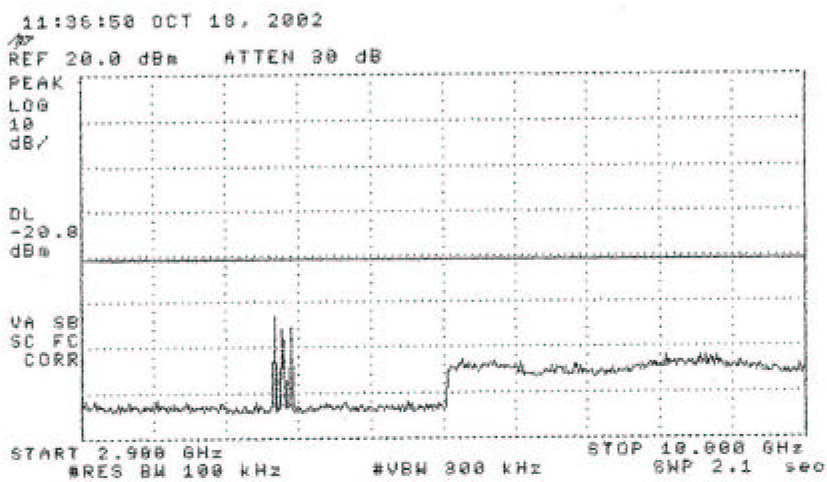


Figure 6.4 Single Channel Dwell Time.
(only Low Channel shown)





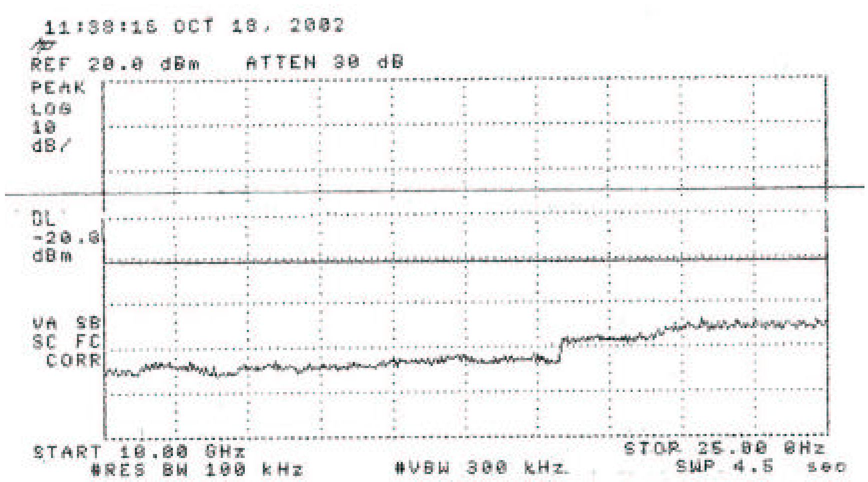
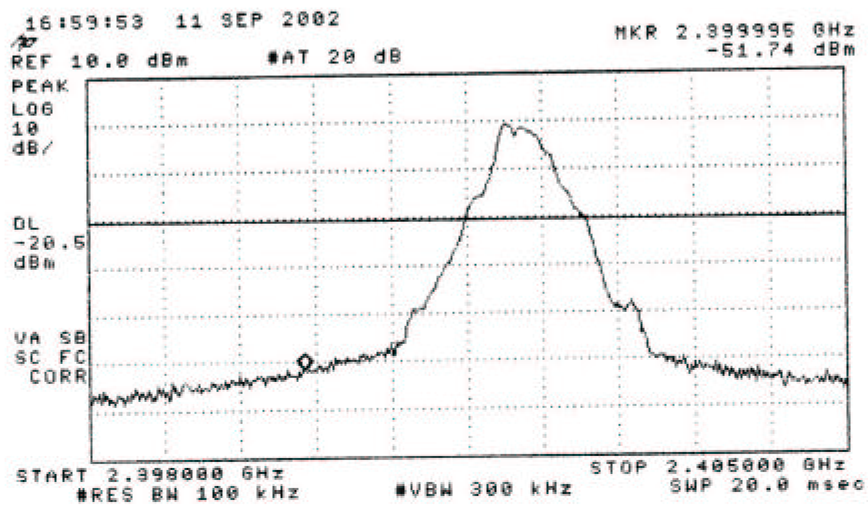


Figure 6.5 Antenna Conducted Spurrious Emissions.
(all channels)



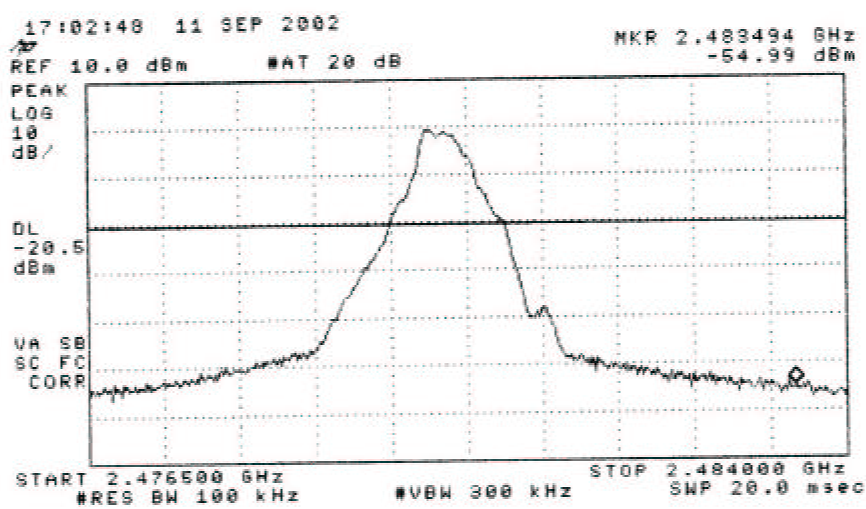


Figure 6.6 Band edge emissions – NOT HOPPING.
(top) Low Channel, (bottom) High Channel

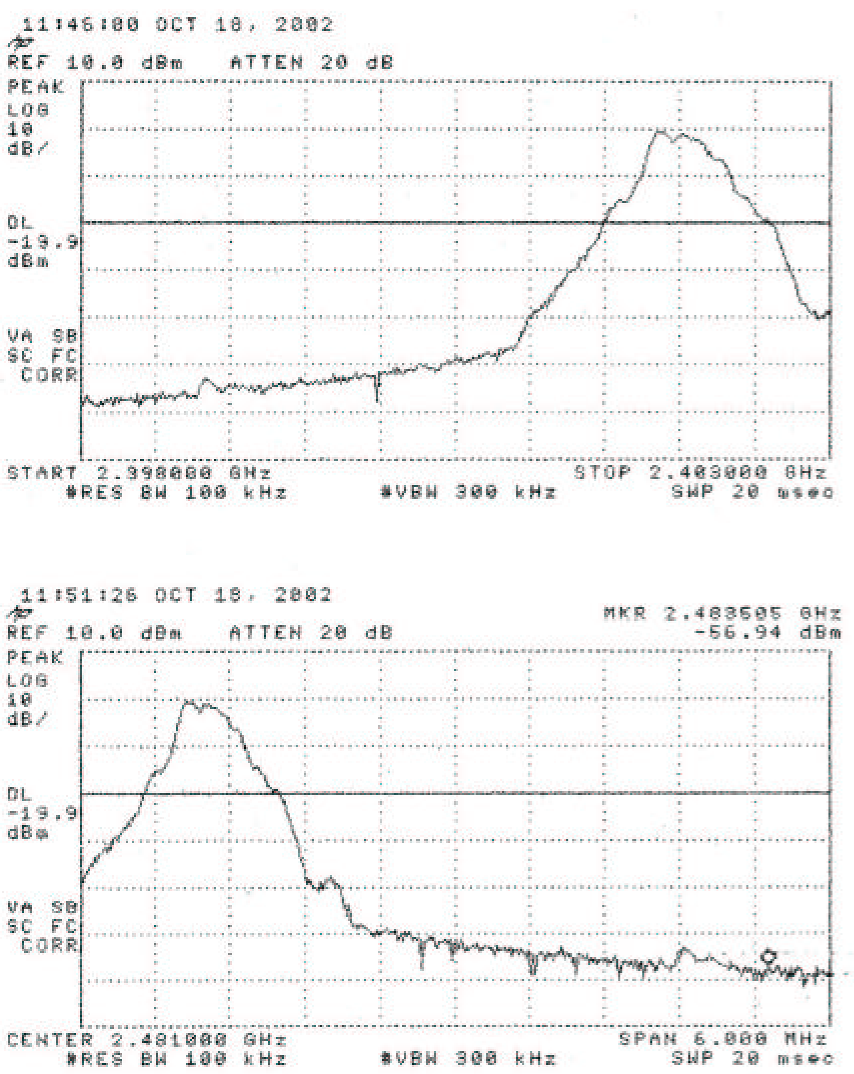


Figure 6.7 Band edge emissions - HOPPING.
(top) Low Channel, (bottom) High Channel