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Measured Radio Frequency Emissions
From

Johnson Controls Bluetooth Module
Model(s): MAZ, MMC

Report No. 415031-308
June 28, 2006

For:
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Summary
Tests for compliance with FCC Regulations, Part 15.247, and IC Regulations, RSS-210 (A8.1) and RSS-GEN, were performed on Johnson Controls model(s) MAZ, MMC frequency hopping spread spectrum (FHSS) transmitter. The DUT is subject to the Rules and Regulations as a transmitter.

In testing competed on March 28, 2006, the radiated emissions in restricted bands were met by 7.8 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(s) MAZ, MMC meet the limitations set forth by the FCC and IC for a 2.4 GHz FHSS transmitter.

Introduction

Johnson Controls models MAZ, MMC 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 5, November, 2001. The tests were performed at the University of Michigan Radiation Laboratory Willow Run Test Range following the procedures described in ANSI C63.4-2003 "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 2057).

1. 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

2. 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 x 3.5 inches and connects to a peripheral laptop computer via a serial interface 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.

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(s): MAZ, MMC
FCC ID: CB2MBLUEC07
IC: 279B-MBLUEC07

Two models were provided. The MMC model is fully populated, while the MAZ module has some digital circuitry depopulated and a change in the exterior foil. Emissions from the MMC were determined to be worst case, and that module was subsequentially tested. 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:_Dell Inspiron, Model: 8000 SN: USD344011D

2.1 EMI Relevant Modifications

No modifications were made to the DUT by this laboratory during 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, Table 1) - 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, Table 2) - Digital device.

Frequency (MHz)	Class A ds = 10 m		Class B ds = 3 m	
	(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 Conducted Emission Limits

Table 4.3 Conducted Emission Limits (FCC:15.107(CISPR); IC: RSS-GEN).

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 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 (moved to 1 m distance if needed).

Standard gain horn antennas were used for the measurements. Up to 4.5 GHz the horns were connected to a spectrum analyzer via RG-214 coaxial cable, and above 4.5 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.

4.2 Outdoor Measurements

None made.

4.3 Computations and Results

To convert the dBm measured on the spectrum analyzer to dB(μV/m), we use the 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 7.8 dB at 2483.5 MHz.

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

4.4 Duty Factor for Normal Operation

No duty factor is used.

5. Other Measurements and Computations

5.1 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=30 kHz, VBW=30 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	905 kHz	1 MHz
39	2.441 GHz	900 kHz	1 MHz
79	2.480 GHz	905 kHz	1 MHz

5.2 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=30 kHz, VBW= 100 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	0.940 MHz	915 kHz
38	2.440 GHz		
39	2.441 GHz	1.035 MHz	910 kHz
78	2.479 GHz		
79	2.480 GHz	0.981 MHz	915 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 value.

5.3 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 – 2429.5	28		
2429.5 – 2454.5	25	79	>75
2455.0 – 2483.5	26		

5.4 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	27	2.950 ms	0.2390 sec	0.4 sec
39	2.441 GHz	31	2.950 ms	0.2744 sec	0.4 sec
79	2.480 GHz	17	2.950 ms	0.1505 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.

5.5 Peak-to-Average Ratio (15.35(b))
The measured difference between peak and average is always greater than 20 dB for a Bluetooth device, and this was verified in our measurements.

5.6 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	4.9	30
2441	5.0	30
2480	4.9	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 with regard to this parameter.

5.7 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 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	3.16	3.98	0.000792

The following equations were used in calculating the power density (S).

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

and

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

5.8 Power Line Conducted Emissions (15.270)

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

5.9 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).

5.10 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

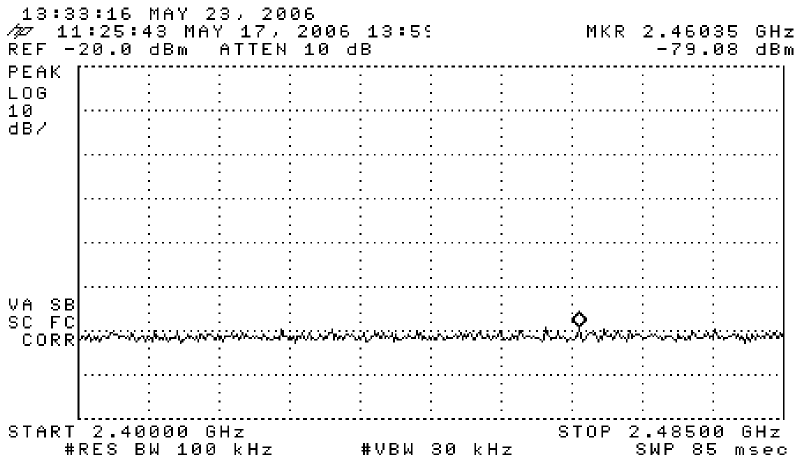
Channel	Frequency	Band Edge	Attenuation	Limit(max)
1	2402.0 MHz	2400.0 MHz	41.7 dBc	> 20 dBc
79	2480.0 MHz	2483.5 MHz	40.8 dBc	> 20 dBc

Hopping

Channel	Frequency	Band Edge	Attenuation	Limit(max)
1	2402.0 MHz	2400.0 MHz	34.6 dBc	> 20 dBc
79	2480.0 MHz	2483.5 MHz	36.5 dBc	> 20 dBc

5.11 Receiver Emissions (RSS-GEN, 4.8)

For this test, the DUT was put into receive only mode. The spectrum analyzer was connected where the antenna attaches to the system. The analyzer was set for RBW = 100 kHz, VBW= 30 kHz, and the spectrum was searched from 1 to 10 GHz. No receiver emissions were detected. Sample plots showing the noise floor level across portions of the band are included below.



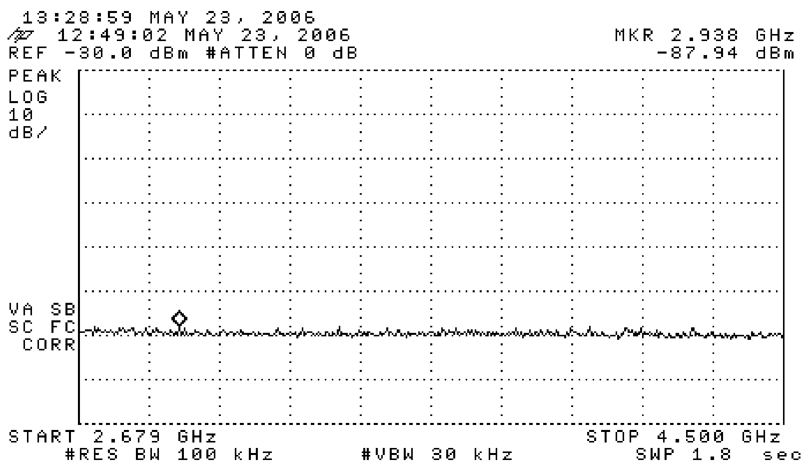


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Table 5.1 Highest Emissions Measured

	Radiated Emissions									JCI Mitsu/Maz Bluetooth
#	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	-76.4	21.5	- 1.5	53.6	74.0	20.4	Low, noise
6	2390.0	Horn S	H/V	-75.5	21.5	- 1.5	54.5	74.0	19.5	Mid, noise
7	2390.0	Horn S	H/V	-76.7	21.5	- 1.5	53.3	74.0	20.7	High, noise
8	2483.5	Horn S	H/V	-76.0	21.5	- 1.5	54.0	74.0	20.0	Low, noise
9	2483.5	Horn S	H/V	-63.8	21.5	- 1.5	66.2	74.0	**7.8**	Mid
10	2483.5	Horn S	H/V	-65.0	21.5	- 1.5	65.0	74.0	9.0	High
11	4804.0	Horn C	H/V	-29.9	24.6	38.0	63.7	74.0	10.3	Low
12	4882.0	Horn C	H/V	-29.7	24.6	38.0	63.9	74.0	10.1	Mid
13	4960.0	Horn C	H/V	-30.5	24.6	38.0	63.1	74.0	10.9	High
14	7206.0	Horn XN	H/V	-	25.1	36.8	-	N/A	-	Low
15	7323.0	Horn XN	H/V	-43.9	25.2	36.8	51.5	74.0	22.5	Mid
16	7440.0	Horn XN	H/V	-42.8	25.3	36.8	52.7	74.0	21.3	High
17	9608.0	Horn X	H/V	-	27.8	36.8	-	N/A	-	Low
18	9764.0	Horn X	H/V	-	27.9	36.8	-	N/A	-	Mid
19	9920.0	Horn X	H/V	-	28.0	36.8	-	N/A	-	High
20	12010.0	Horn X	H/V	-52.5	31.7	35.8	50.4	74.0	23.6	Low, noise
21	12205.0	Horn X	H/V	-53.0	31.8	34.1	51.7	74.0	22.3	Mid, noise
22	12400.0	Horn X	H/V	-53.2	32.0	32.4	53.3	74.0	20.7	High, noise
23	14412.0	Horn Ku	H/V	-	33.2	17.3	-	N/A	-	Low
24	14646.0	Horn Ku	H/V	-	33.3	17.3	-	N/A	-	Mid
25	14880.0	Horn Ku	H/V	-	33.4	17.3	-	N/A	-	High
26	16814.0	Horn Ku	H/V	-	34.6	34.0	-	N/A	-	Low
27	17087.0	Horn Ku	H/V	-	34.8	34.0	-	N/A	-	Mid
28	17360.0	Horn Ku	H/V	-	35.0	34.0	-	N/A	-	High
29	19216.0	Horn K	H/V	-58.7	32.2	32.0	48.5	74.0	25.5	Low, noise
30	19528.0	Horn K	H/V	-56.7	32.3	32.0	50.6	74.0	23.4	Mid, noise
31	19840.0	Horn K	H/V	-56.2	32.3	32.0	51.1	74.0	22.9	High, noise
32	21618.0	Horn K	H/V	-	32.7	32.0	-	N/A	-	Low
33	21969.0	Horn K	H/V	-	32.8	32.0	-	N/A	-	Mid
34	22320.0	Horn K	H/V	-69.1	32.8	32.0	38.7	74.0	35.3	High
35	24020.0	Horn Ka	H/V	-	33.2	32.0	-	N/A	-	Low
36	24410.0	Horn Ka	H/V	-	33.3	32.0	-	N/A	-	Mid
37	24800.0	Horn Ka	H/V	-	33.3	32.0	-	N/A	-	High
38										
39	* Peak: measured with 1 MHz RBW and 3 MHz VBW									
40	* Average measurements are not shown, the Pk to Avg ratio is greater than 20 dB (FCC 15.35)									
41	Note: Digital emissions > 20 dB below FCC/IC Class B Limit.									
42										

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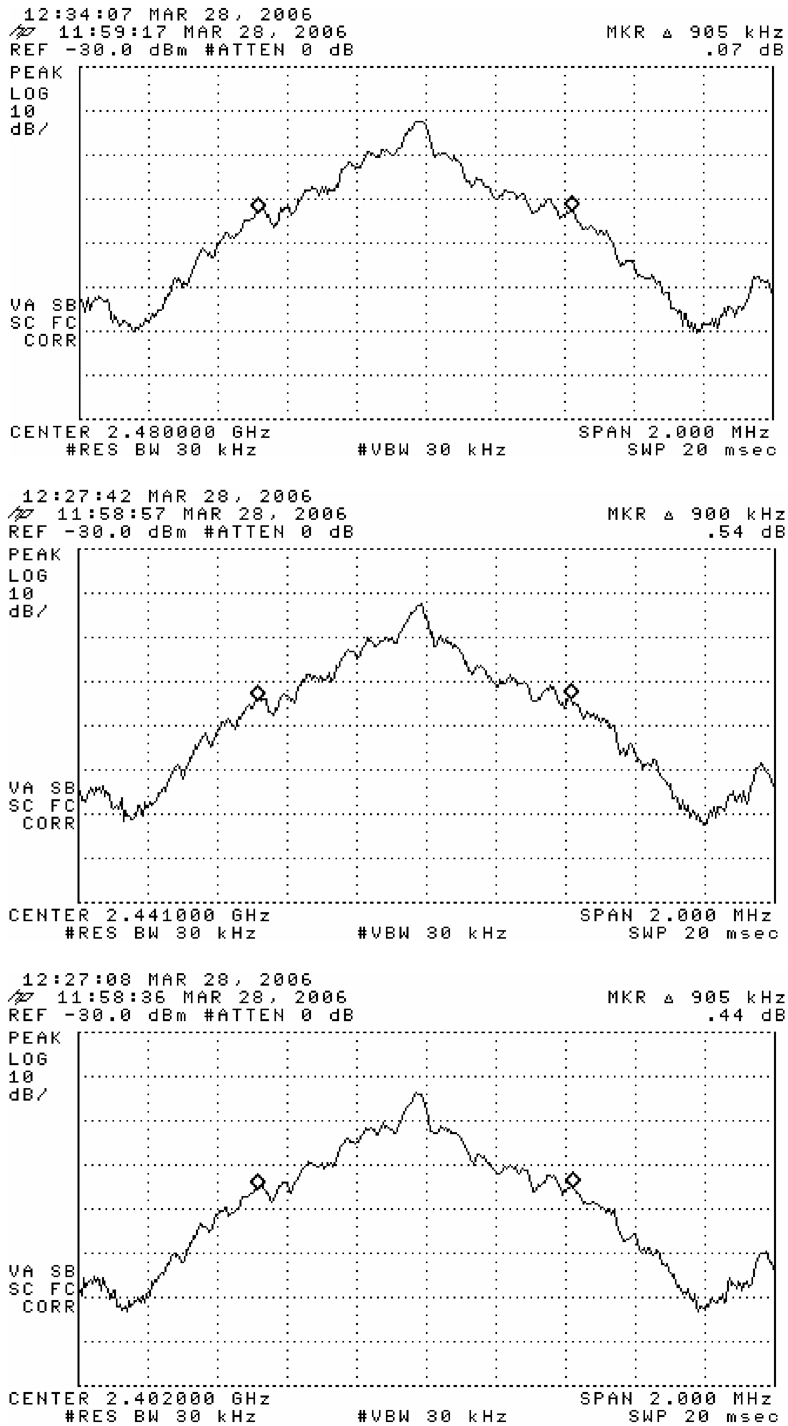


Figure 6.1 Measurement of channel 20 dB bandwidth.
(top) Low Channel, (middle) Middle Channel, (bottom) High Channel

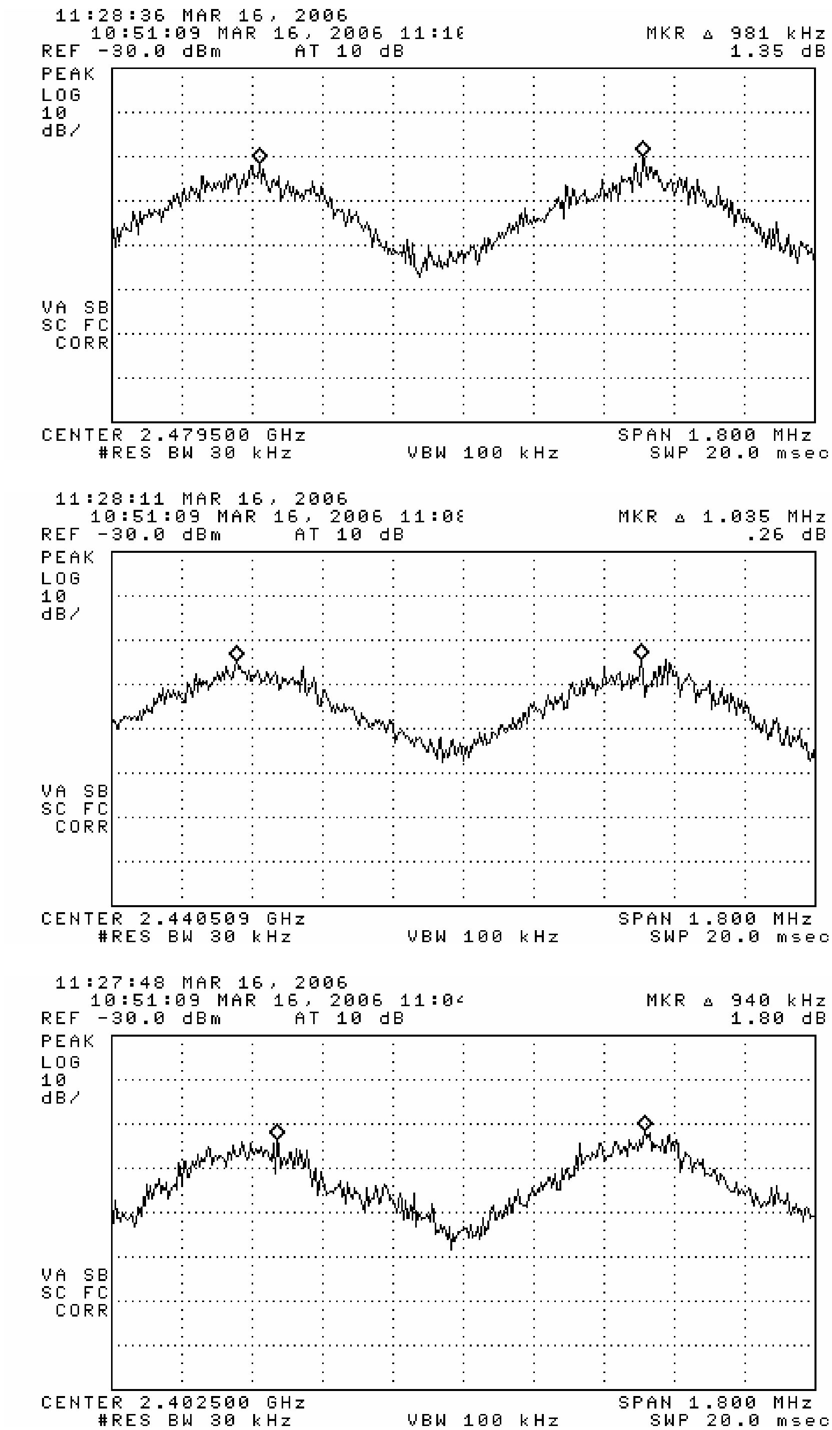


Figure 6.2 Carrier Frequency Separation.
(top) Low Channel, (middle) Middle Channel, (bottom) High Channel

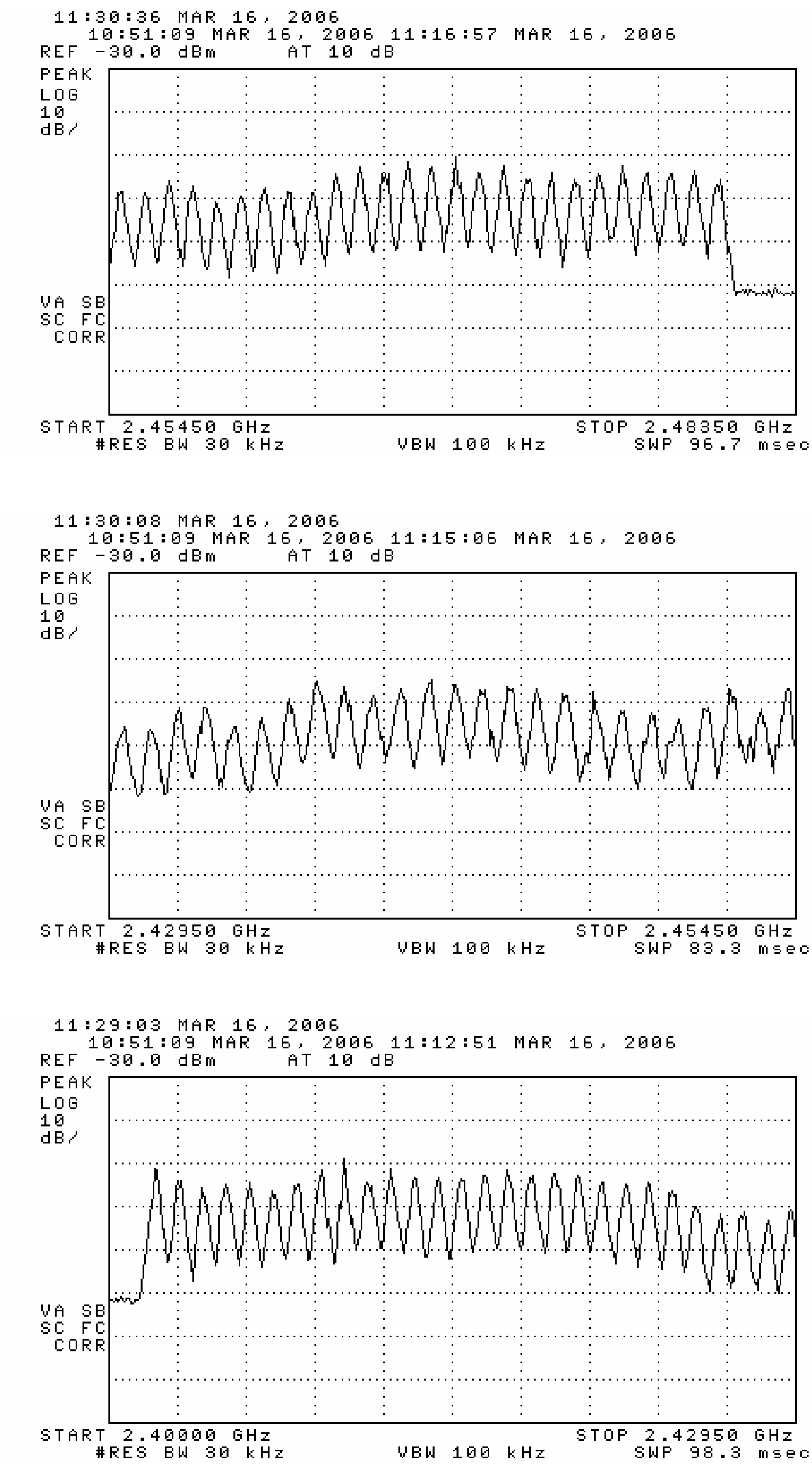
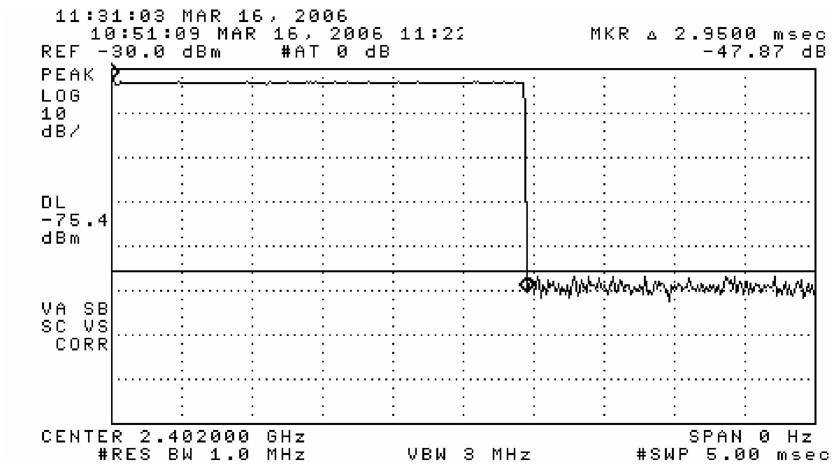


Figure 6.2 Number of Hopping Frequencies.
(top) low - last channel repeated in next plot, (middle) middle, (bottom) high portion of band



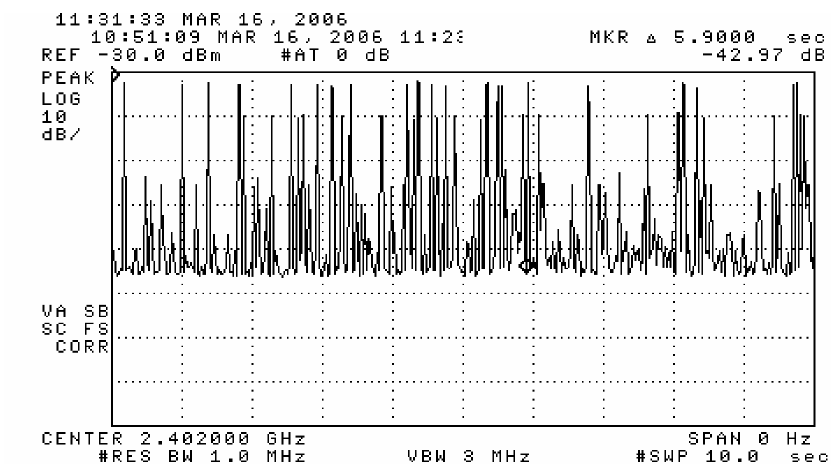


Figure 6.4 Single Channel Dwell Time.
(only Low Channel shown)

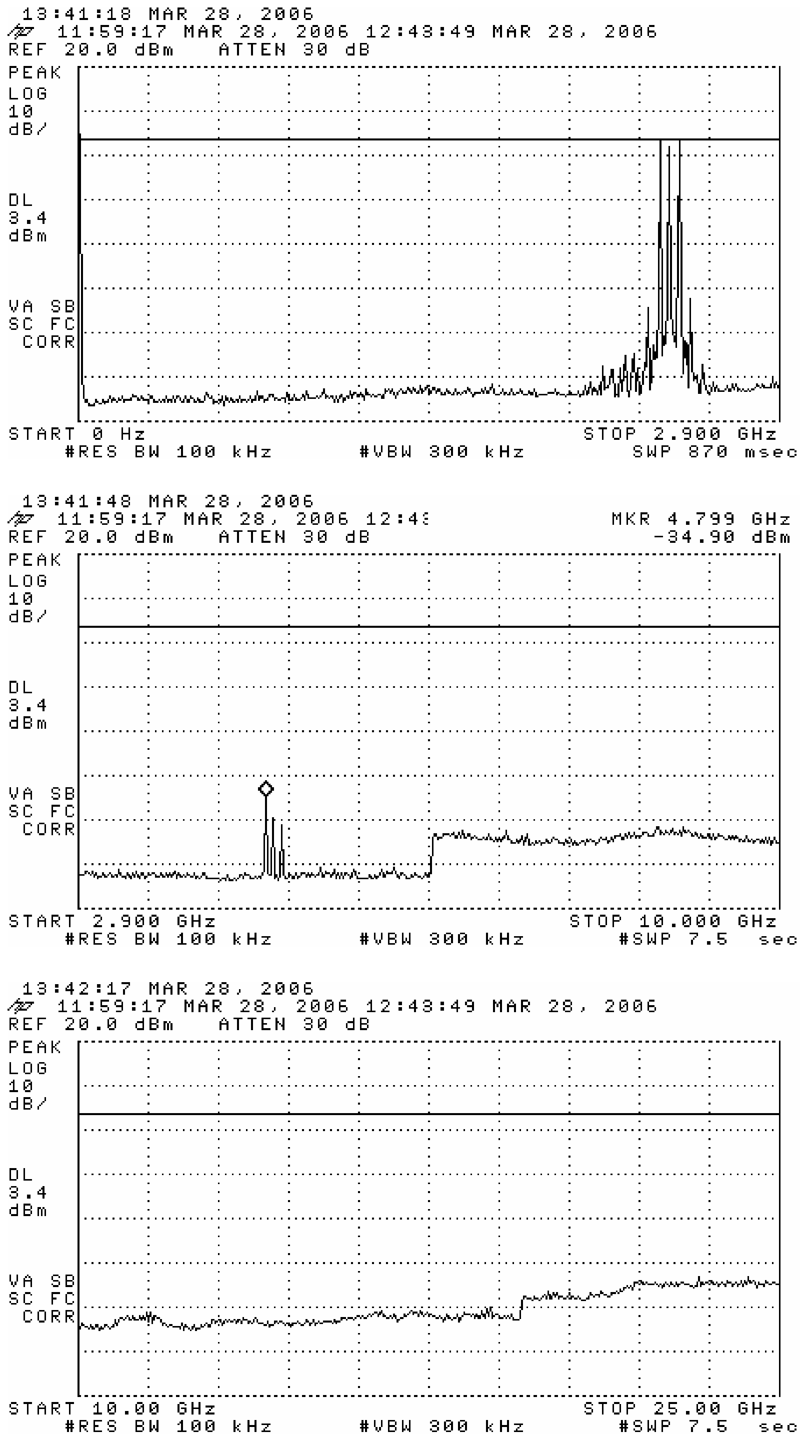
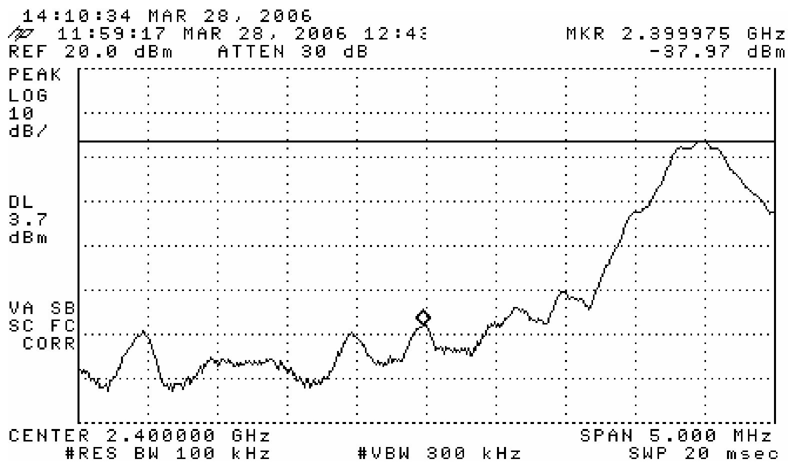


Figure 6.5 Antenna Conducted Spurrious Emissions.
(low, mid, and high channels)



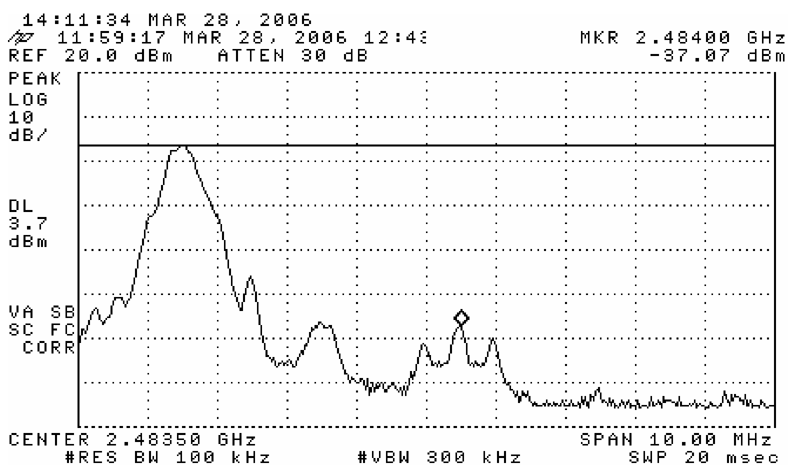
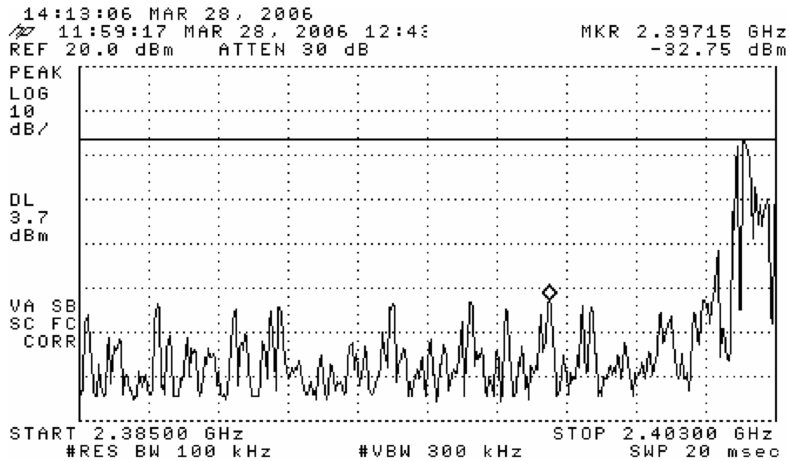


Figure 6.6 Band edge emissions – NOT HOPPING.
(top) Low Channel, (bottom) High Channel



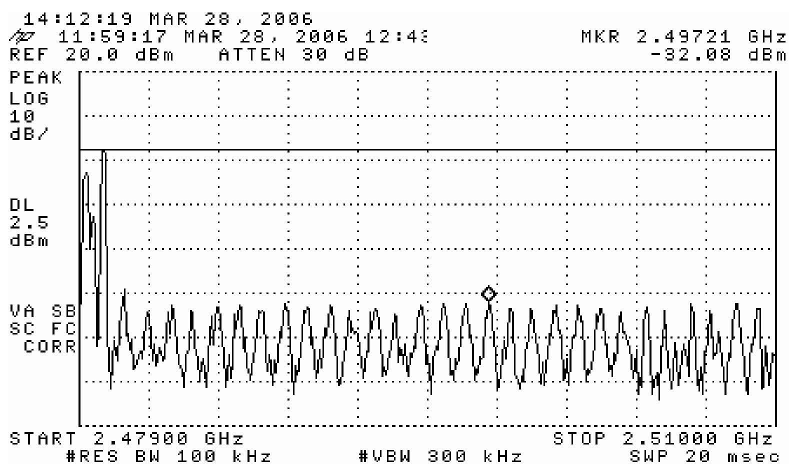
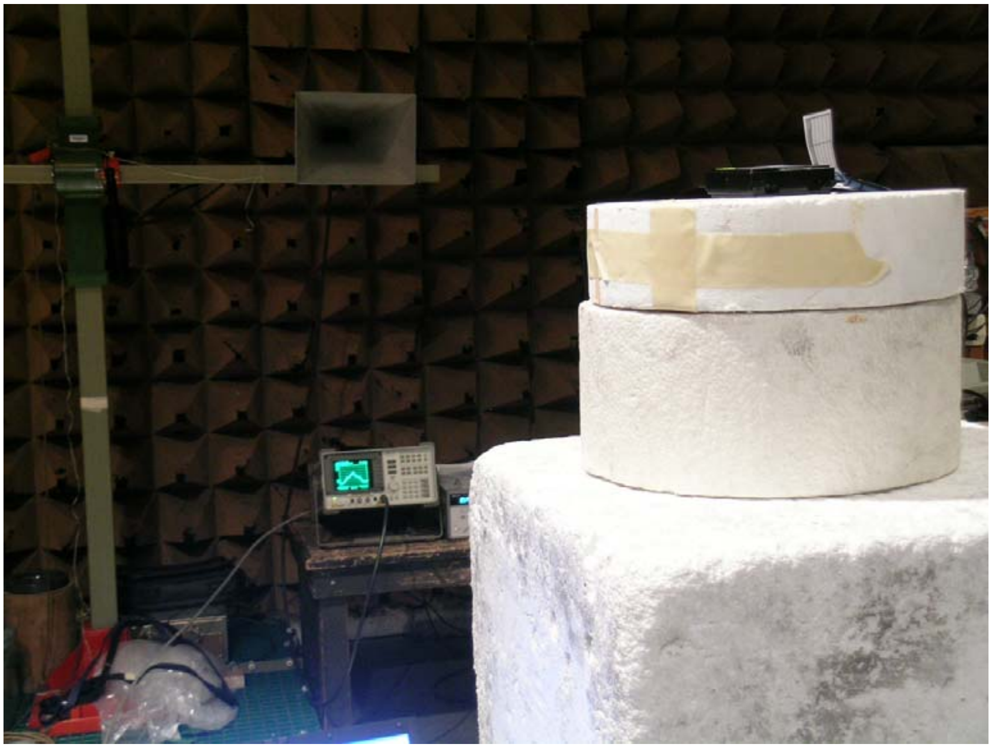
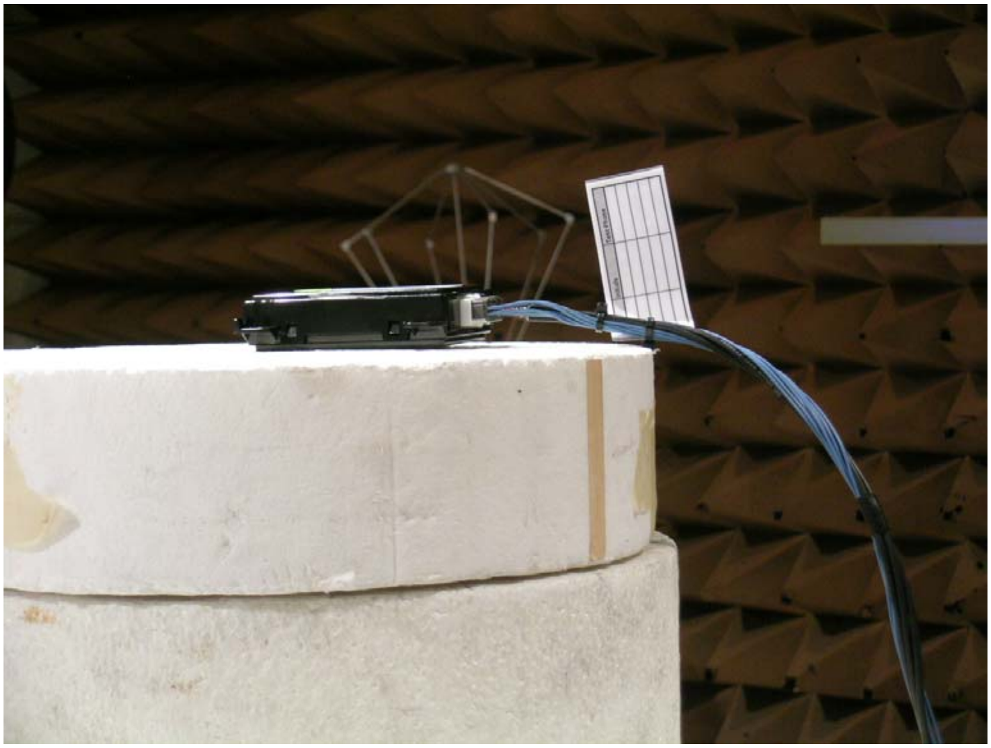


Figure 6.7 Band edge emissions - HOPPING.
(top) Low Channel, (bottom) High Channel



DUT in Chamber



DUT in Chamber (close-up)