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Measured Radio Frequency Emissions
From

Lionel TMCC Handheld Transceiver
FCC ID: LIV-CAB2
Model(s): #991

Report No. 415031-370
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For:
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Summary

Tests for compliance with FCC Regulations Part 15, Subpart C, and Industry Canada RSS-210/GEN, were performed on Lionel model #991 Tranceiver. This device works in conjunction with an In-Home Carrier Current system and base transceiver; both of which are addressed separately.

In testing completed on June 4, 2007, the device tested met fundamental emission limits by more than 15.1 dB and harmonic limits by more than 5.5 dB. Spurious emissions meet the FCC/IC Class B limit by more than 1.7 dB. AC power line conducted emissions meet the FCC/IC Class B limit by more than 0.4 dB.

1. Introduction

Lionel L.L.C. model(s) #991 was(were) tested for compliance with FCC Regulations, Part 15, adopted under Docket 87-389, April 18, 1989 as amended, and with Industry Canada RSS-210/Gen, Issue 7, June 207. 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" and the document, "FCC Regulatory Requirements for Design and Sale of SDARS In-Home Repeater v.2.3" 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.

Table 2.1 Test Equipment.

Test Instrument	Eqpt. Used	Manufacturer/Model
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
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		S/A, Model SGH-2.6
C-Band Std. Gain Horn	X	University of Michigan, NRL design
XN-Band Std. Gain Horn		University of Michigan, NRL design
X-Band Std. Gain Horn		S/A, Model 12-8.2
X-band horn (8.2- 12.4 GHz)		Narda 640
K-band horn (18-26.5 GHz)		FXR, Inc., K638KF
Ka-band horn (26.5-40 GHz)		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)		Avantek, AFT-12665
Amplifier (6-16 GHz)		Trek
Amplifier (16-26 GHz)		Avantek
LISN Box	X	University of Michigan
Signal Generator		Hewlett-Packard 8657B

3. Configuration and Identification of Device Under Test

The Device Under Test (DUT) is a 2404-2480 MHz, 150 channel handheld transceiver used to control Lionel model trains via a base station. The size of the DUT is 4(W) x 9(H) x 1.5(D) inches. Nominal operating voltage is 3.6 VDC, supplied by three rechargeable 1.2 VDC AA size batteries, charged by placing the DUT in the base station cradle. The antenna is on a small PCB integral to the DUT. The DUT is designed by Lionel L.L.C., 26750 23 Mile Road, Chesterfield, Michigan 48051. It is identified as:

Lionel TMCC II CAB Transceiver
Model(s): #991
FCC ID: LIV-CAB2
IC: 7032A-CAB2

3.1 Variants

There is only a single model of the device. A software modifiable version was supplied capable of selected transmission on low, middle, and high channels as well as receive-only operation. The DUT was tested (where applicable) with all accessories, including a TMCC II base station, Lionel locomotive, and associated transformer/controller. AC line conducted and digital radiated emissions below 1 GHz are reported for the entire system with the handheld transceiver in continuous communication with the base station; Carrier Current communication disabled.

3.2 Modes of Operation

The DUT operates between the 2.404 GHz and 2.480 GHz using 150 individual channels and is capable of only a single operating mode. The DUT transmits on a single user-selected channel at any give time. Each channel is spaced 500 kHz apart and is MSK encoded at a data rate of 250 kbps. See Figure 6.1.

3.3 EMI/EMC Relevant Modifications

No changes where made to the DUT by this test laboratory. However, during pre-testing a Lionel employee made modifications to the DUT to bring the device into compliance prior to testing.

4. Emission Limits

4.1 Radiated Emission Limits (FCC 15.249, 15.209; IC RSS-210e:A2.9)

The DUT tested is a 2404-2480 MHz Transmitter, subject to FCC 15.249, 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-210 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: 15.33, 15.35, 15.109/15.209; IC: RSS-210, 2.7 Table 2)

Freq. (MHz)	Class A, E_{lim} dB(μV/m)	Class B, E_{lim} dB(μV/m)
30-88	49.5	40.0
88-216	54.0	43.5
216-960	56.9	46.0
Above 960	60.0	54.0

Note: Average readings apply above 1000 MHz (1 MHz BW)
Quasi-Peak readings apply up to 1000 MHz (120 kHz BW)

4.2 Conducted Emission Limits (FCC 15.107)

Table 4.3. Conducted emission limits (FCC 15.107; IC RSS-Gen 7.2.2 Table 2 (CISPR)).

Frequency MHz	Class A (dBμV)		Class B (dBμV)	
	QPk	Avg	QPk	Avg
0.150 - 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 0.15-0.50MHz:
*Class B Quasi-peak: dBμV = 50.25 - 19.12 Log_{10}(f)
*Class B Average: dBμV = 40.25 - 19.12 Log_{10}(f)
3. 9 kHz RBW

4.3 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.

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 Test Procedure: Radiated Emissions

5.2.1 Semi-Anechoic Chamber Measurements

To familiarize with the radiated emission behavior of the DUT, the DUT was first studied and measured in a shielded anechoic chamber. In the 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.

In testing for radiated emissions, the DUT was stimulated as mentioned in the previous section. It was placed on the test table flat, on its side, or on its end. In the chamber we studied and recorded all the emissions using a Bicone antenna up to 300 MHz and ridged horn and standard gain horn antennas above 300 MHz. The measurements made in the chamber below 1 GHz are used for pre-test evaluation only. The measurements made above 1 GHz are used in pre-test evaluation and in the final compliance assessment. Photographs included in this filing show the indoor testing of the DUT.

Note 1: For the horn antenna, the antenna pattern is more directive and hence the measurement is essentially that of free space (no ground reflection). Consequently it is not essential to measure the DUT for both antenna polarizations, as long as the DUT is measured on all three of its major axis. In the chamber we also recorded the spectrum and modulation characteristics of the carrier. These data are presented in subsequent sections. As a general procedure, emissions are first tested using a peak detector. If the DUT does not meet the quasi-peak (or average) limits via these measurements, quasi-peak (or average) measurements are then made to demonstrate compliance.

5.2.2 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).

5.2.3 Field Computations

To convert the dBm measured to E(dBμV/m) at the test receiver antenna, E(dBμV/m) is computed from

$$E(dB\mu V/m) = 107\ dB + Pr(R_{meas})(dBm) + K_a - Kg$$

or

$$E(dB\mu V/m) = Pr(R_{meas})(dB\mu V) + K_a - Kg$$

Where P_r = power recorded on spectrum analyzer, dBm or dBμV
K_a = antenna factor, dB/m
K_g = pre-amp gain and/or cable loss, dB

When presenting the data, the highest measured emission at each frequency under all of the possible orientations is given.

5.3 Test Procedure: Conducted Emissions

The DUT is powered either from a 3.6 VDC internal battery, and is charged via the associated base unit with AC power adapter. Conducted emissions were measured using a LISN in the standard set-up with the transceiver running and the batteries charging after full a discharge.

6. Measurement Results

6.1 Digital Radiated Emissions
Table 6.1. Spurious Radiated Emissions 30 MHz to 1000 MHz. RBW = 120 kHz, VBW>RBW. DUT meets FCC/IC Class B spurious emissions limits by more than 1.7 dB.

6.2 Duty Factor / Peak to Average Ratio
Figure 6.1. Peak to Average Ratio. The DUT transmits a MSK periodic signal with a worst case on time of 2.2125 ms / 10 ms period, or 13.1 dB.

6.3 Radiated Emissions – Fundamental, Transmitter Spurious
Table 6.2. Fundamental, Harmonic, and Band Edge Radiated Emissions. Pk. 120 kHz RBW, VBW > RBW for f < 1 GHz, 1 MHz RBW, VBW>RBW for f > 1 GHz; measurement distance is 3 m. Band edge emissions are also shown in Figure 6.2.

6.4 Potential Health Hazard EM Radiation Level
This is a mobile device and the peak EIRP is 0.023 mW (see below). The output power is lower than $P_o = 60/f_{(GHz)}$ mW = 24.19 mW for d<2.5 cm (general population category). Thus, a SAR measurement is not necessary. The power density at a distance of 20 cm from the device as calculated from FCC OET Bulletin 65.

EIRP = 78.9 dBuV/m - 95.2 dB(uV/m / mW) = -16.3 dBm = 0.023 mW
$S(mW/cm^2) = EIRP\ (mW) / (4\pi\ (20\ cm)^2) =$ **0.000005 mW/cm^2**

6.5 Radiated Emissions – Receiver Spurious
Table 6.2. Receiver Spurious Radiated Emissions. Pk. 120 kHz RBW, VBW > RBW for f < 1 GHz, 1 MHz RBW, VBW>RBW for f > 1 GHz; measurement distance is 3 m.

6.6 Conducted Emissions
Table 6.3. Worst case conducted emissions for both base and train AC transformer. Train is running and handheld is charging after full discharge. 9 kHz RBW, VBW > RBW. The DUT meets conducted emissions limits by more than 0.4 dB in the worst case.

6.7 Emission Bandwidth
The measured spectrum of the signal is shown in Figure 6.3. The 20-dB bandwidth was measured for low, mid, and high channels used by the DUT.

Channel	Frequency	20 dB BW
1	2.404 GHz	760 kHz
76	2.442 GHz	765 kHz
150	2.480 GHz	785 kHz

6.8 Effect of Supply Voltage Variation
The DUT is designed to operate from a 3.6 VDC supply. The relative radiated emissions and frequency were recorded at the fundamental as the supply voltage was varied from 85% to 115% of the nominal voltage. Figure 6.3 shows the emission power variation. Current at 3.6 VDC was 37 mA.

Table 6.1 Highest Radiated Emissions Measured

Lionel TMCC System; FCC/IC B											
#	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	40.5	Bic	H	-72.7	Pk	10.7	26.0	18.9	40.0	21.1	
2	40.5	Bic	V	-59.8	Pk	10.7	26.0	31.8	40.0	8.2	
3	62.7	Bic	H	-58.7	Pk	7.9	25.7	30.5	40.0	9.5	
4	62.7	Bic	V	-58.6	Pk	7.9	25.7	30.6	40.0	9.4	
5	68.5	Bic	V	-54.2	Pk	7.6	25.6	34.8	40.0	5.2	
6	77.0	Bic	H	-57.0	Pk	7.5	25.5	32.0	40.0	8.0	
7	77.0	Bic	V	-58.6	Pk	7.5	25.5	30.4	40.0	9.6	
8	86.2	Bic	H	-57.6	Pk	7.7	25.4	31.8	40.0	8.2	
9	110.9	Bic	V	-58.0	Pk	9.2	25.0	33.2	43.5	10.3	
10	113.5	Bic	H	-57.7	Pk	9.4	25.0	33.7	43.5	9.8	
11	120.4	Bic	H	-58.5	Pk	10.0	24.9	33.6	43.5	9.9	
12	137.6	Bic	H	-60.7	Pk	11.5	24.7	33.1	43.5	10.4	
13	137.6	Bic	V	-63.9	Pk	11.5	24.7	29.9	43.5	13.6	
14	139.4	Bic	H	-58.0	Pk	11.6	24.7	36.0	43.5	7.5	
15	142.8	Bic	H	-63.6	Pk	11.9	24.6	30.7	43.5	12.8	
16	154.7	Bic	H	-53.5	Pk	12.8	24.5	41.8	43.5	**1.7**	
17	154.7	Bic	V	-55.9	Pk	12.8	24.5	39.4	43.5	4.1	
18	171.9	Bic	H	-57.0	QPk	13.8	24.2	39.6	43.5	3.9	
19	171.9	Bic	V	-57.4	Pk	13.8	24.2	39.2	43.5	4.3	
20	189.2	Bic	H	-57.3	Pk	14.5	24.0	40.2	43.5	3.3	
21	206.3	Bic	V	-67.6	Pk	14.7	23.8	30.4	43.5	13.1	
22	223.6	Bic	H	-64.2	Pk	14.7	23.6	34.0	46.0	12.0	
23	223.6	Bic	V	-57.4	Pk	14.7	23.6	40.8	46.0	5.2	
24	231.2	Bic	H	-54.2	Pk	14.7	23.5	44.0	46.0	2.0	
25	240.7	Bic	H	-61.8	Pk	14.6	23.4	36.5	46.0	9.5	
26	240.7	Bic	V	-71.2	Pk	14.6	23.4	27.1	46.0	18.9	
27	276.0	SBic	H	-66.2	Pk	16.8	22.9	34.7	46.0	11.3	
28	326.5	SBic	H	-67.1	Pk	18.9	22.3	36.5	46.0	9.5	
29	343.6	SBic	H	-68.8	Pk	19.5	22.2	35.5	46.0	10.5	
30											
31											
32	* Handheld Remote and Base Unit communicating continuously (Both Tx. & Rx. functionality demonstrated).										
33											
34											
35											
36											
37											
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39											

Meas. 03/16/2007; U of Mich.

Table 6.2 Highest Emissions Measured

Radiated Emissions - Transmitte											Lionel, TMCC 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	2404.0	Horn S	H	-38.0	Pk	21.5	- 1.5	78.9	94.0	15.1	low channel (L)
2	2442.0	Horn S	H	-38.6	Pk	21.5	- 1.5	78.3	94.0	15.7	mid channel (M)
3	2480.0	Horn S	H	-38.2	Pk	21.5	- 1.5	78.7	94.0	15.3	high channel (H)
4	2400.0	Horn S	H	-71.7	Pk	21.5	- 1.5	45.2	54.0	8.8	band edge, LMH channels
5	2483.5	Horn S	H	-66.8	Pk	21.5	- 1.5	50.1	54.0	**3.9**	band edge, LMH channels
6	4808.0	Horn C	H	-40.8	Pk	24.6	38.0	39.7	54.0	14.3	
7	4884.0	Horn C	H	-42.2	Pk	24.6	38.0	38.3	54.0	15.7	
8	4960.0	Horn C	H	-43.3	Pk	24.6	38.0	37.2	54.0	16.8	
9	7212.0	Horn XN	H	-50.3	Pk	25.1	36.8	31.9	54.0	22.1	
10	7326.0	Horn XN	H	-49.8	Pk	25.2	36.8	32.5	54.0	21.5	
11	7440.0	Horn XN	H	-54.6	Pk	25.3	36.8	27.8	54.0	26.2	
12	9616.0	Horn X	H	-58.1	Pk	27.8	36.8	26.8	54.0	27.2	noise
13	9768.0	Horn X	H	-57.9	Pk	27.9	36.8	27.1	54.0	26.9	
14	9920.0	Horn X	H	-56.2	Pk	28.0	36.8	28.9	54.0	25.1	
15	12020.0	Horn X	H	-61.0	Pk	31.7	35.7	28.9	54.0	25.1	noise, all channels
16	14424.0	Horn Ku	H	-61.3	Pk	33.2	17.3	48.5	54.0	5.5	noise, all channels
17	16828.0	Horn Ku	H	-61.1	Pk	34.6	34.0	33.4	54.0	20.6	noise, all channels
18	19232.0	Horn K	H	-57.2	Pk	32.2	32.0	36.9	54.0	17.1	noise, all channels
19	21636.0	Horn K	H	-54.0	Pk	32.7	32.0	40.6	54.0	13.4	noise, all channels
20	24040.0	Horn Ka	H	-52.6	Pk	33.2	32.0	42.5	54.0	11.5	noise, all channels
21											
22	* Includes 13.1 dB duty factor										
23	* Peak measured with 1 MHz RBW and 3 MHz VBW										
Radiated Emissions - Receiver											TMCC Remote+Base
#	Freq. MHz	Ant. Used	Ant. Pol.	Pr dBm	Det.* Used	Ka dB/m	Kg dB	E3* dBμV/m	E3lim dBμV/m	Pass dB	Comments
27	1088.0	R-Horn	H	-66.0	Pk	20.0	28.1	19.9	54.0	34.1	
28	1198.0	R-Horn	H	-65.5	Pk	20.4	28.1	20.7	54.0	33.3	
29	1838.0	R-Horn	H	-66.5	Pk	22.1	28.1	21.4	54.0	32.6	
30	1898.0	R-Horn	H	-66.9	Pk	22.2	28.1	21.1	54.0	32.9	
31	2535.5	R-Horn	H	-66.5	Pk	23.9	26.0	25.4	54.0	28.6	
32	2580.5	R-Horn	H	-66.4	Pk	24.0	25.8	25.7	54.0	28.3	
33	2720.0	R-Horn	H	-66.5	Pk	24.5	25.3	26.6	54.0	27.4	
34	2848.3	R-Horn	H	-66.3	Pk	24.9	24.7	27.8	54.0	26.2	
35	3204.0	R-Horn	H	-69.7	Pk	26.0	23.5	26.8	54.0	27.2	
36	3464.0	R-Horn	H	-70.3	Pk	26.8	23.2	27.2	54.0	26.8	
37	3756.0	R-Horn	H	-70.6	Pk	27.7	23.0	28.0	54.0	26.0	
38	3932.0	R-Horn	H	-69.3	Pk	28.2	22.2	30.6	54.0	**23.4**	
39											

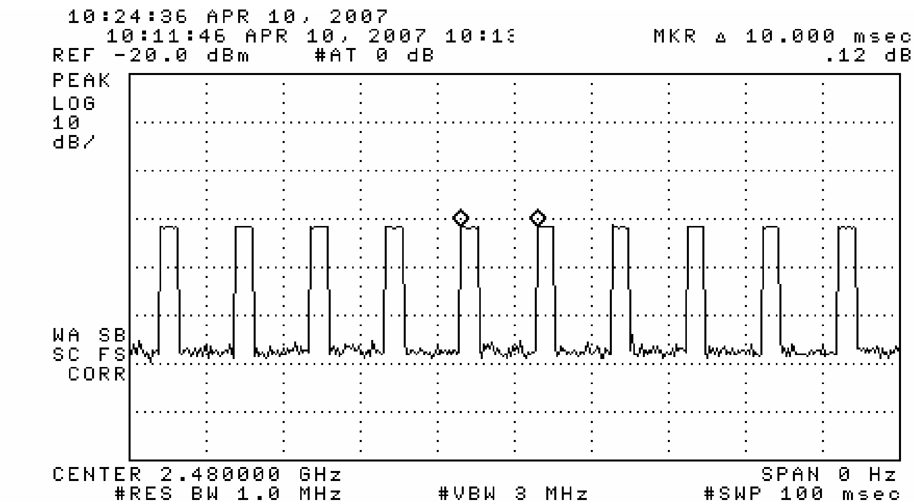
Meas. 04/10/2007; U of Mich.

Table 6.3 Highest Conducted Emissions Measured

Lionel TMCC System; FCC/CISPR B												
	Freq.	Line	Peak Det., dBµV		Pass	QP Det., dBµV		Pass	Ave. Det., dBµV		Pass	
#	MHz	Side	Vtest	Vlim*	dB*	Vtest	Vlim	dB	Vtest	Vlim	dB	Comments
TMCC System - Transformer Power Line (Train Running, Tx. & Rx. operating)												
1	0.18	Hi	72.5	54.6	-17.9	62.9	64.7	1.8	45.5	54.6	9.1	
2	0.20	Hi	71.8	53.7	-18.1	61.5	63.7	2.2	46.9	53.7	6.8	
3	0.21	Lo	73.8	53.3	-20.5	63.0	63.4	**0.4**	43.6	53.3	9.7	
4	0.23	Hi	68.2	52.6	-15.6	57.8	62.6	4.8	43.1	52.6	9.5	
5	0.25	Hi	67.6	51.7	-15.9	58.5	61.8	3.3	40.8	51.7	10.9	
6	0.29	Lo	68.5	50.5	-18.0	55.6	60.6	5.0	34.3	50.5	16.2	
7	0.30	Hi	64.0	50.3	-13.7	53.8	60.3	6.5	35.3	50.3	15.0	
8	0.33	Hi	68.4	49.5	-18.9	50.1	59.5	9.4	36.7	49.5	12.8	
9	0.34	Hi	59.7	49.1	-10.6	49.9	59.1	9.2	38.2	49.1	10.9	
10	0.37	Hi	59.5	48.6	-10.9	46.2	58.6	12.4	35.8	48.6	12.8	
11	0.41	Lo	58.2	47.6	-10.6	45.7	57.6	11.9	32.5	47.6	15.1	
12	0.45	Lo	56.5	46.8	- 9.7	44.2	56.9	12.7	33.8	46.8	13.0	
13	0.46	Hi	58.5	46.6	-11.9	42.8	56.7	13.9	31.8	46.6	14.8	
14	0.49	Lo	53.5	46.1	- 7.4	42.3	56.1	13.8	31.3	46.1	14.8	
15	0.55	Lo	49.6	46.0	- 3.6	39.3	56.0	16.7	29.0	46.0	17.0	
16	0.64	Lo	46.3	46.0	- 0.3	39.9	56.0	16.1	27.3	46.0	18.7	
17	1.09	Lo	37.0	46.0	9.0	30.1	56.0	25.9	20.8	46.0	25.2	
18	1.37	Lo	42.5	46.0	3.5		56.0			46.0		
19	2.00	Lo	45.5	46.0	0.5	42.9	56.0	13.1	40.1	46.0	5.9	
20												
TMCC System - Base Power (Train Running, Tx. & Rx. Operating)												
1	0.16	Hi	44.1	55.7	11.6		65.7			55.7		
2	0.16	Lo	42.4	55.4	13.0		65.5			55.4		
3	0.17	Lo	41.3	54.9	13.6		65.0			54.9		
4	0.18	Hi	44.8	54.4	9.6		64.5			54.4		
5	0.19	Hi	44.4	54.0	9.6		64.1			54.0		
6	0.21	Hi	44.8	53.2	8.4		63.2			53.2		
7	0.22	Lo	38.7	52.8	14.1		62.8			52.8		
8	0.23	Hi	43.0	52.6	9.6		62.6			52.6		
9	0.26	Lo	31.0	51.4	20.4		61.4			51.4		
10	0.90	Lo	29.2	46.0	16.8		56.0			46.0		
11	1.53	Hi	27.4	46.0	18.6		56.0			46.0		
12	1.71	Lo	27.2	46.0	18.8		56.0			46.0		
13	2.48	Hi	27.2	46.0	18.8		56.0			46.0		
14	3.60	Lo	30.9	46.0	15.1		56.0			46.0		
15	3.68	Hi	29.1	46.0	16.9		56.0			46.0		
16	7.20	Lo	29.3	50.0	20.7		60.0			50.0		
17	7.23	Hi	28.3	50.0	21.7		60.0			50.0		
18	16.13	Lo	30.3	50.0	19.7		60.0			50.0		
19	24.15	Lo	29.8	50.0	20.2		60.0			50.0		
20	24.23	Hi	29.9	50.0	20.1		60.0			50.0		
21												

**Average limit* Meas. 03/14/2007; U of Mich.

Since Vpeak >= Vqp >= Vave and if Vtestpeak < Vavelim, then Vqplim and Vavelim are met.



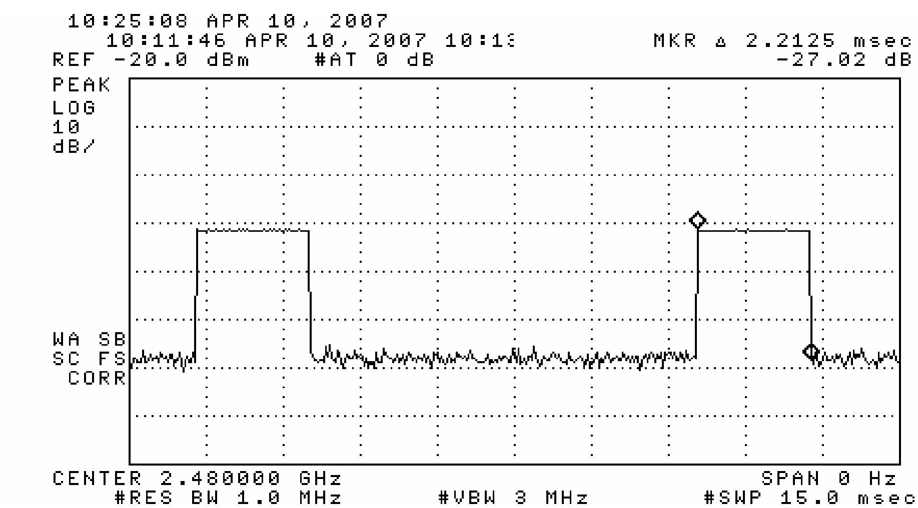
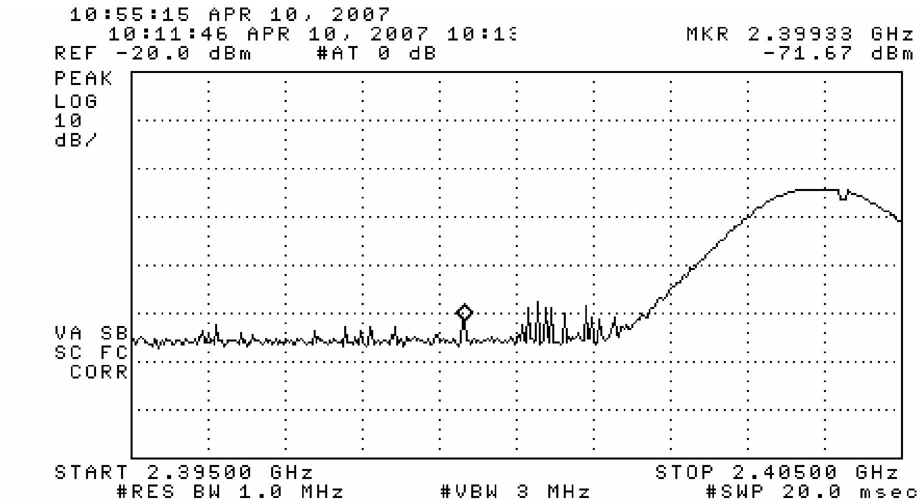
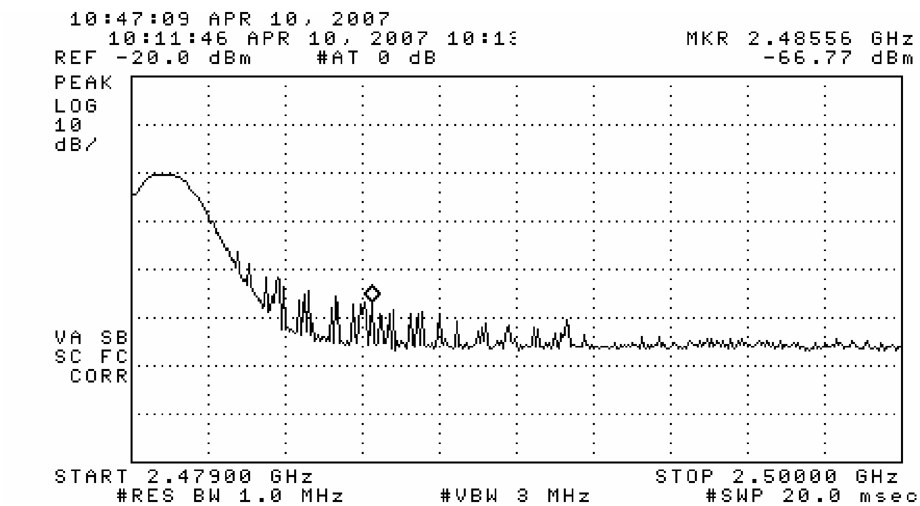
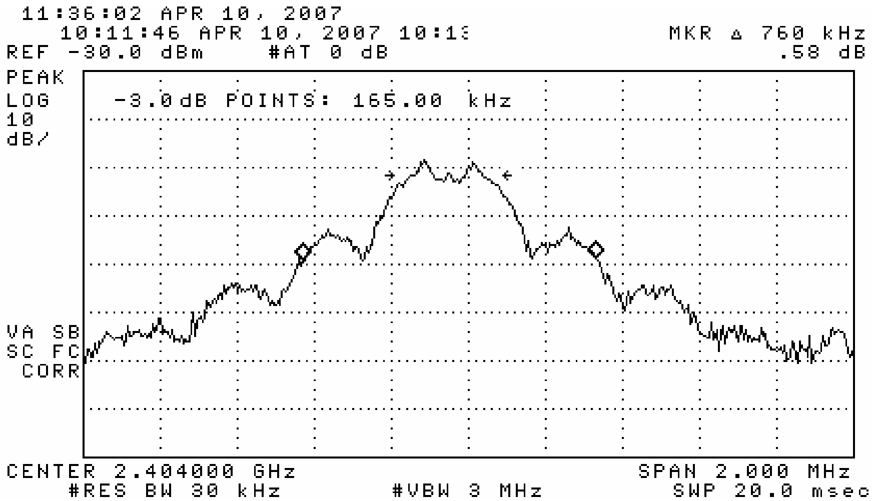


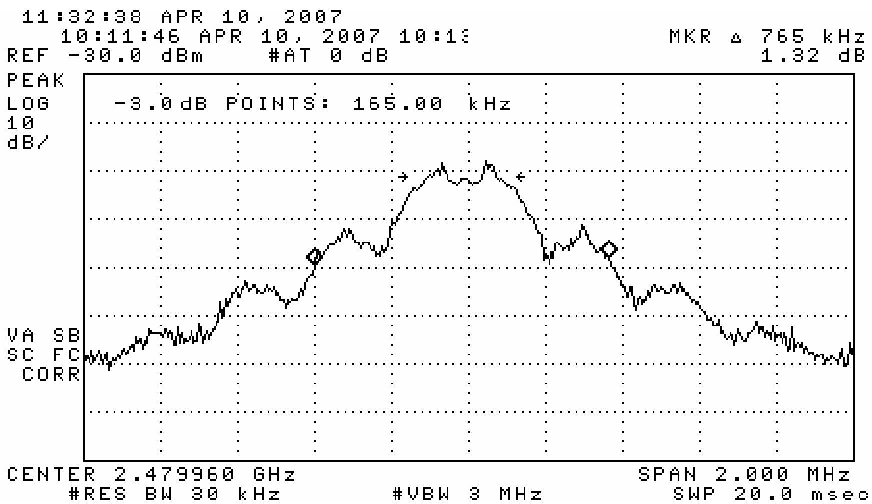
Figure 6.1. Fundamental Emission at high channel.
(top) pulse period, (bottom) pulse width





Figures 6.2. Band edge emissions for low, middle, high channels.
(top) Lower Band Edge, (bottom) Upper Band Edge





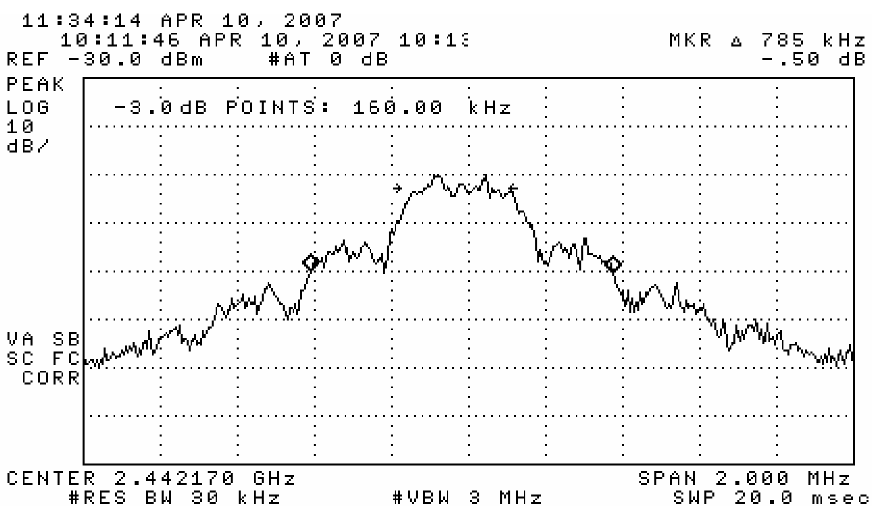


Figure 6.3. Emission Bandwidth (top) Low Channel,
(middle) Middle Channel, (bottom) High Channel

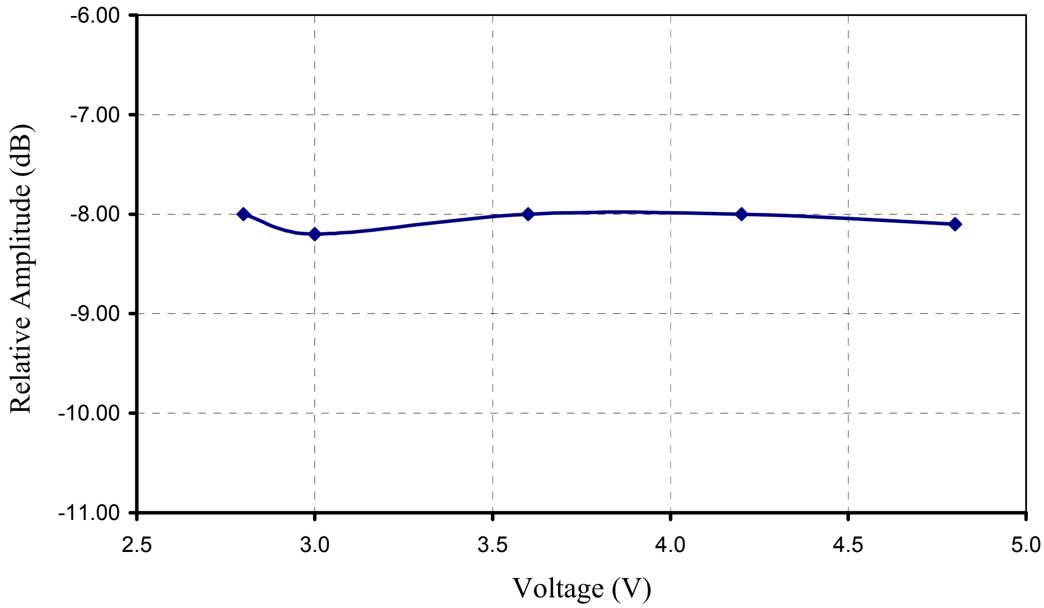


Figure 6.4. Relative emission at fundamental vs. supply voltage.

DUT on OATS

DUT on OATS (Close-up)