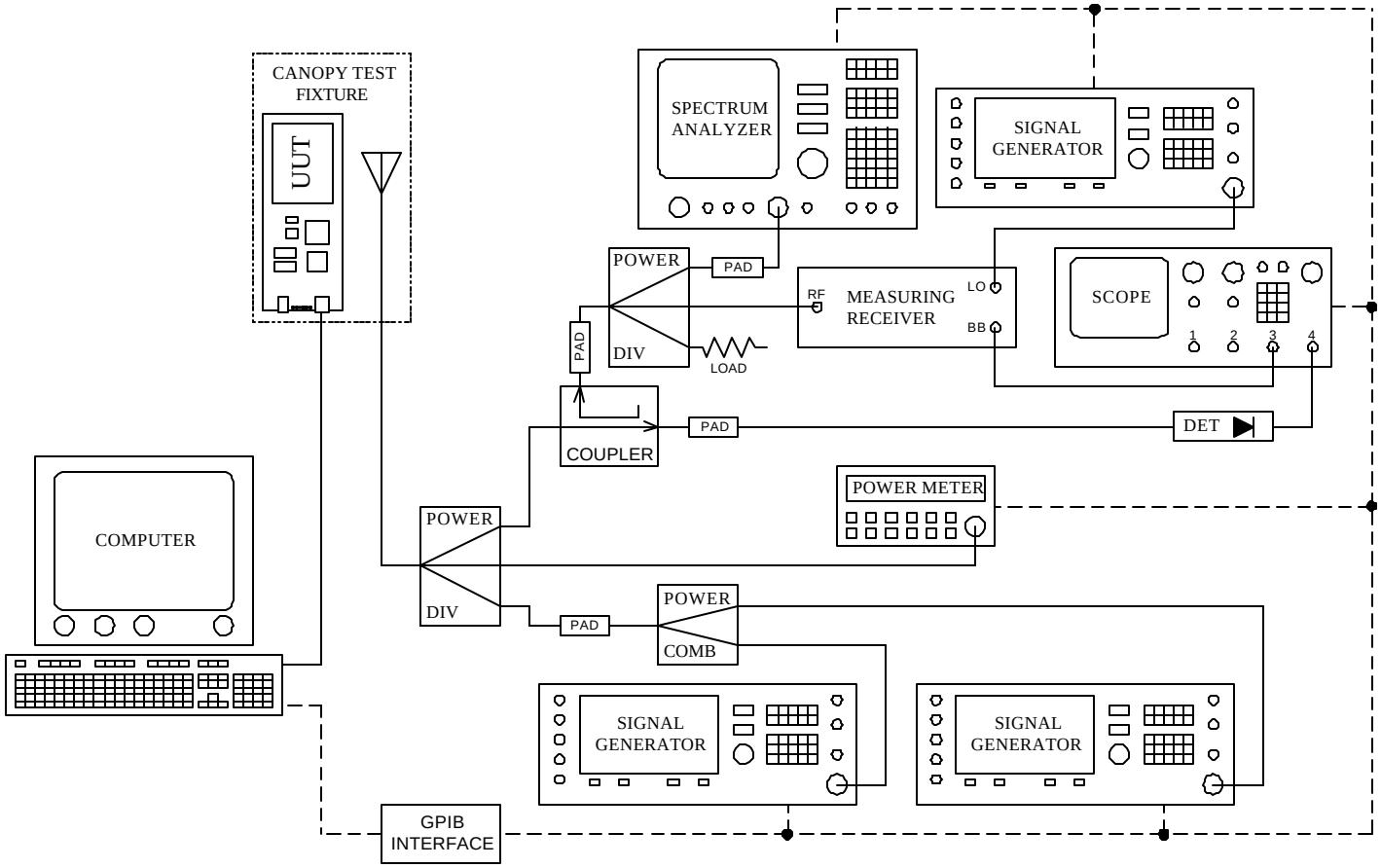
CANOPY 2400ISM Radiated Test
Testing for Compliance with FCC Part 15.247 when Operated in the ISM Band

17 November 2003

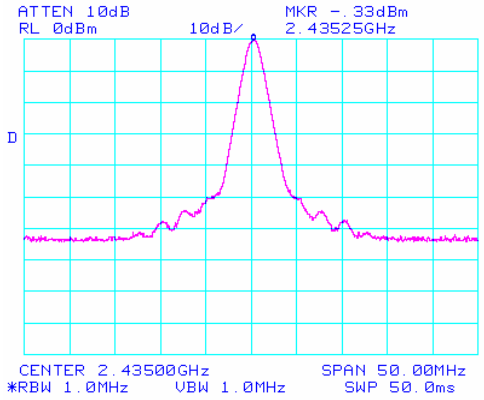
Compliance testing with FCC rules part 15.247 was performed in radiated fashion since production CANOPY units have no RF connector. A test fixture was used to make power spectral density, maximum output power, and occupied bandwidth measurements. A reference antenna replacing the UUT calibrated the coupling factor for the test fixture. Measurements were made on CANOPY unit serial #0A003E200015 and #0A003E200016.
The test setup diagram is as follows:



Spectrum Analyzer Reference Level Calibration

The silent carrier power at all test frequencies was normalized (via the RF attenuator pads in the test station) to 0dBm in the analyzer plots. The dBm units in the plots can be translated to dBc. TX bit error test pattern was initiated at maximum transmit duty cycle and data throughput for the radio under test. This will result in 97.7% duty cycle or an average power versus maximum power ratio of -0.10dB.

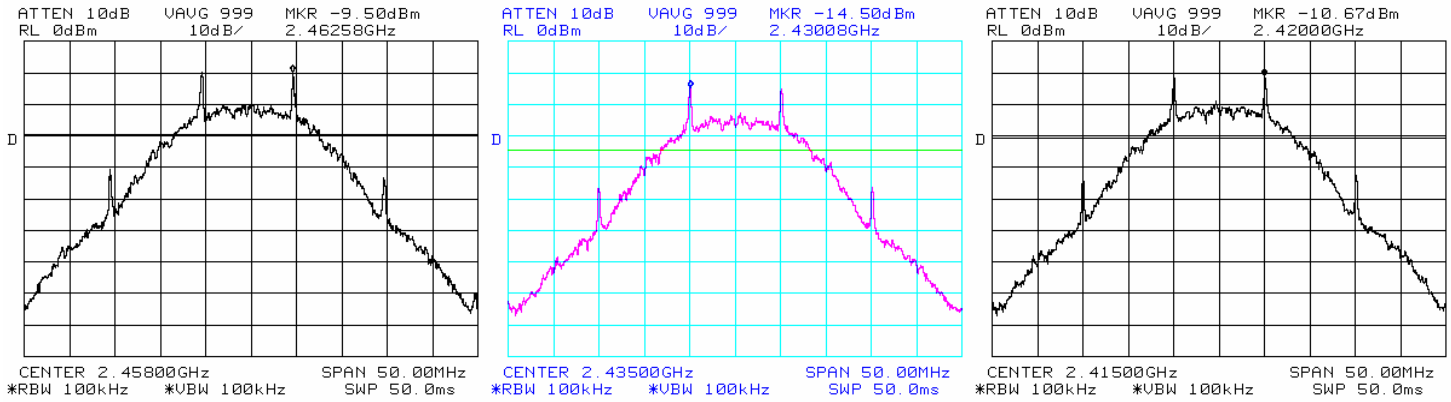
Cal Plot #0A003E200015 carrier power=25.2dBm



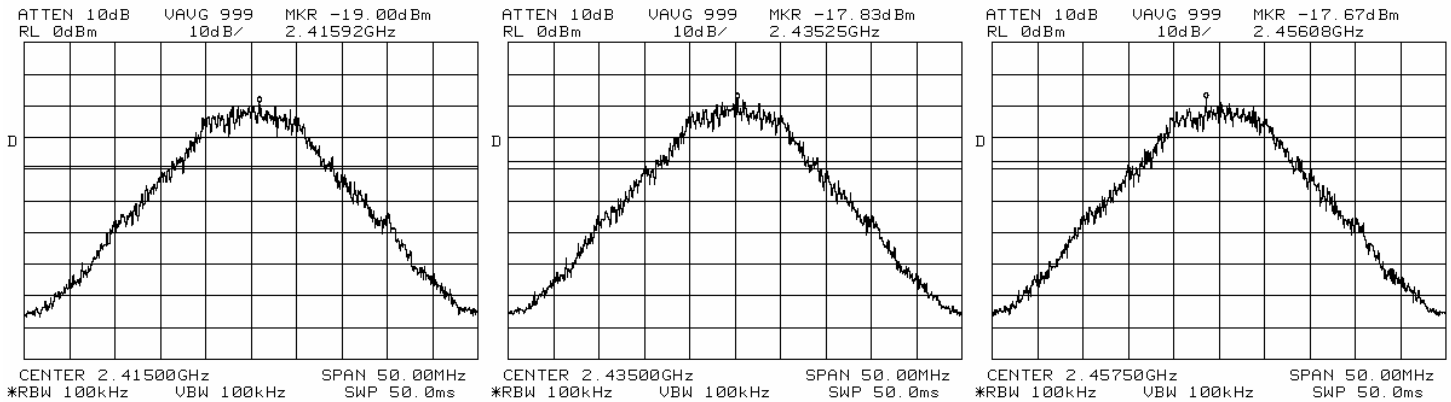
5.247c. Band Edge Requirements

The following plot shows that the CANOPY radio produces an acceptable out-of-band spectral output when operated at the channel limits of 2415MHz at the lowest frequency, and 2457.5MHz at the highest frequency. The display line indicated the –20dB specification limit for non-restricted out-of-band spectral emissions.

2-Level FSK – 20Mb Signaling



4-Level FSK – 20Mb Signaling

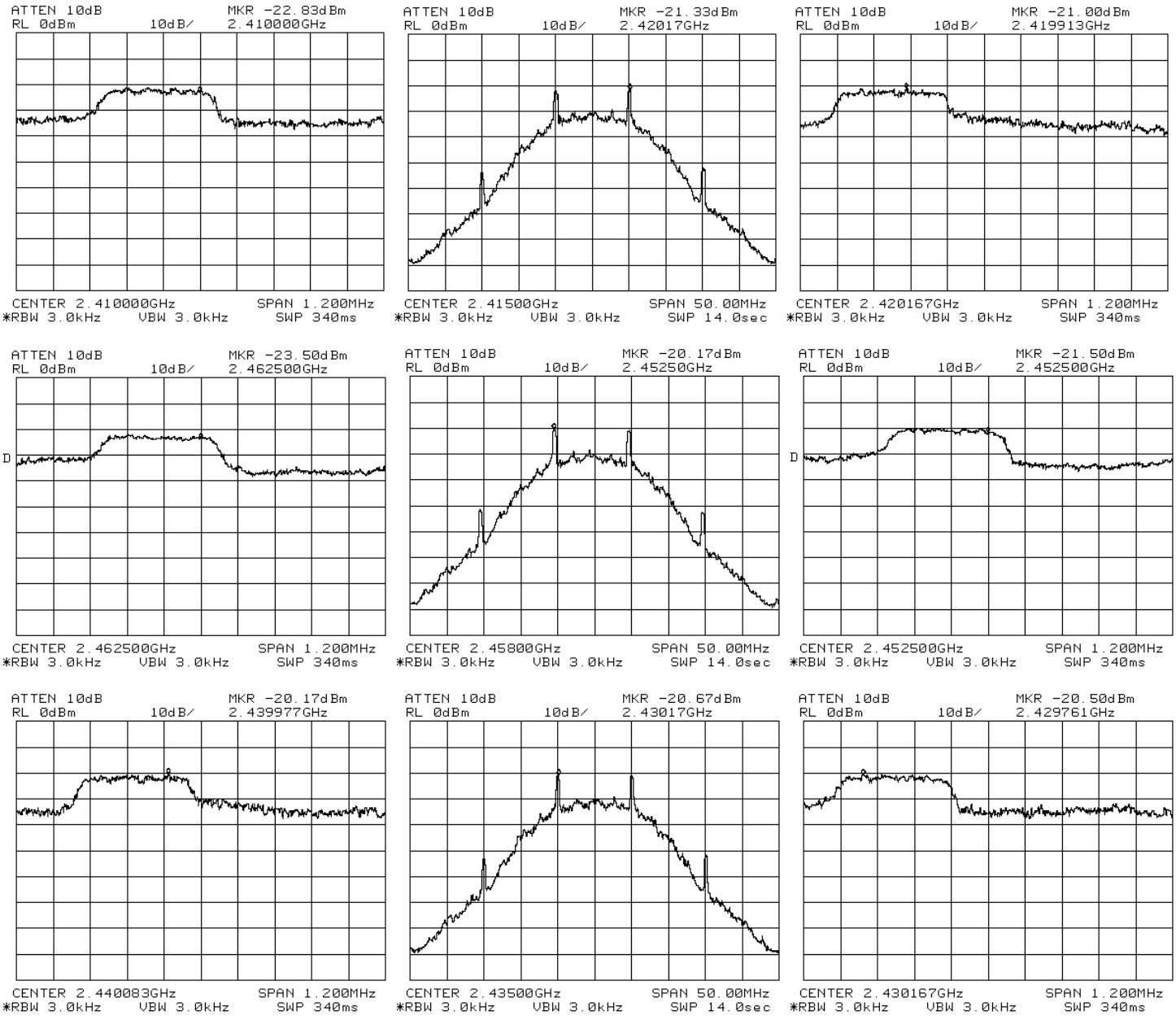


The test results indicated that the band-edge spectral emissions were more than 20dB below the in-band power for both 2-level FSK and 4-level FSK modulation modes. The carrier frequencies tested were 2415MHz, 2435MHz and 2457.5MHz.

15.247d. Conducted Peak Power Spectral Density

The plots showed below display the peak power spectral density results for the radio operation in the frequency band 2415-2457.5MHz. The carrier power (translated to a conducted measurement) at the antenna port was 25.2dBm maximum at 2435MHz. At 2415MHz the carrier power was 24.7dBm. At 2457.5MHz the carrier power was 24.5dBm. The specification limit for this measurement was –17.2dBc (8dBm) in this unit under test.

2-Level FSK – 10Mb Signaling



2-level FSK Modulation Results: The maximum peak power spectral density when measured in a 3 kHz resolution bandwidth was –20.17dBc (4.33dBm) at the uppermost operating frequency of 2457.5MHz. At 2435MHz the maximum peak power spectral density was measured to be -20.17dBc (5.03dBm). At the lowest operating frequency, 2415MHz the maximum peak power spectral density was measured to be –21.0dBc (3.7dBm).

15.247d. Conducted Peak Power Spectral Density

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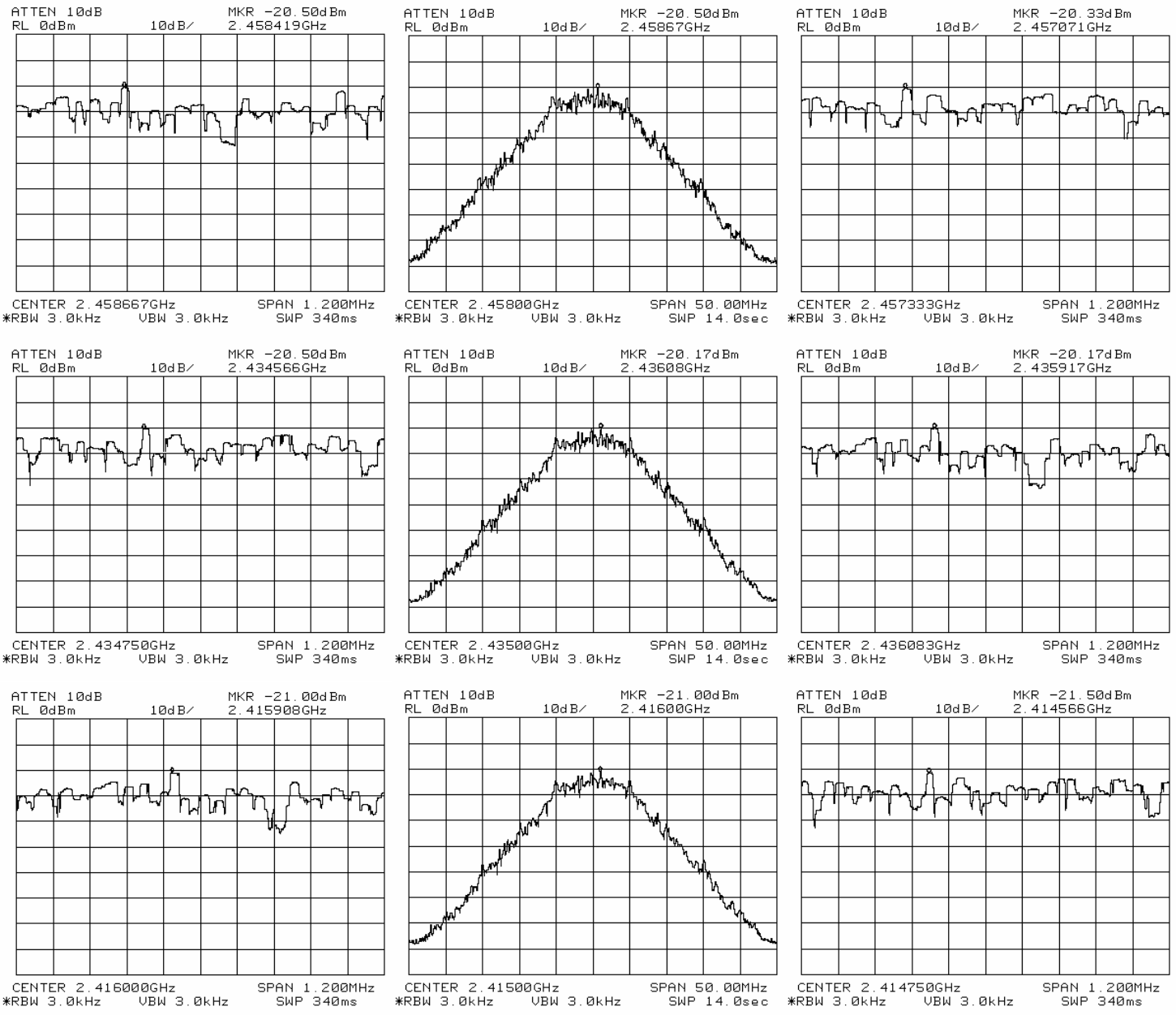
4Level FSK 20MbSignaling



4FSK Modulation Results: The maximum peak power spectral density when measured in a 3 kHz resolution bandwidth was -20.33dBc (4.17dBm) at the uppermost operating frequency of 2457.5MHz. At 2435MHz the maximum peak power spectral density was measured to be -20.5dBc (4.7dBm). At the lowest operating frequency, 2415MHz the maximum peak power spectral density was measured to be –21.0dBc (3.7dBm).

CANOPY 2400ISM Radiated Test
Testing for Compliance with FCC Part 15.209 when Operated in the ISM Band

17 November 2003

A CANOPY 2400 ISM unit, serial#0A003E200016, was tested outdoors to check compliance with FCC requirement 15.209, restricted band emissions for ISM data-modulated radios.

The testing was done using a model 3115 and a model 3116 calibrated dual-ridged waveguide-horn antennas manufactured by EMCO, Inc., an Agilent 8563E 26.5GHz spectrum analyzer, and a laptop to control the DUT and take data from the spectrum analyzer. The two antennas combined allowed a frequency measurement range of 1GHz to 26.5GHz. The spatial separation between the EMCO horn antennas and the DUT was maintained at 3 meters during the test.

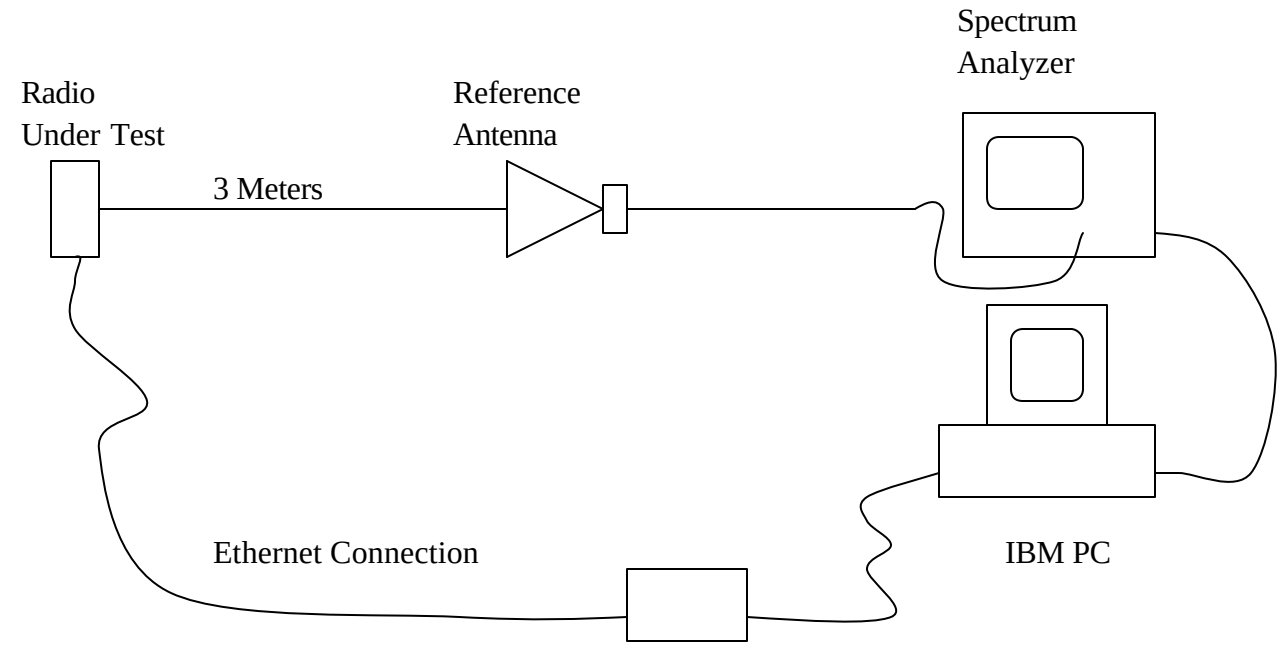
The FCC requirement for restricted band emissions is stated in terms of field strength at 500uV/m at a distance of 3 meters. Using the free space impedance of 377 ohms, the equivalent power density is $-61.78 dBm/m^2$ which is equal to 663 picoWatts/m^2. Multiplying this value by 4 pr^2, where r is the distance in meters, equates to 75nWatts at the radio independent of frequency. Since path loss and cable loss both vary with frequency, an adjusted specification was calculated for each measurement frequency to determine if the power level in dBm measured at the spectrum analyzer was passing.

It was determined that the peak power out of the radio in a 100kHz band was 18.3dBm at 2415MHz and a limit of -1.7dBm was used as pass fail criteria for non restricted band measurements in section 15.249(c).

The operating frequency of the radio presented a challenge to measuring the harmonics radiated by the radio. Since the highest harmonic to be measured is 24.575GHz, finding test equipment that possesses reasonable noise figures and obtaining coax cables with mode-free moderate loss is difficult. The resolution bandwidth of 1MHz also adds to the problem of making an effective radiated power measurement. As an aid in performing these measurements, the radio was designed with the ability to operate in continuous-wave mode, permitting the use of narrow bandwidths on the analyzer.

The test antennas and test radio were mounted on adjustable tripods and placed 3 meters apart.

The test setup diagram is as follows:

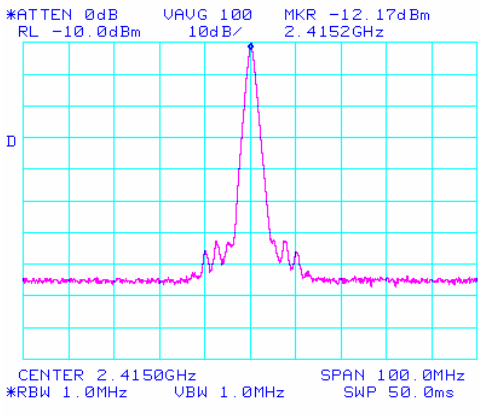


Two different antennas were used, an EMCO model 3115 ridged-waveguide horn antenna covering the 1 to 18GHz frequency range, and an EMCO model 3116 ridged-waveguide horn antenna covering the 18 to 40GHz frequency range.

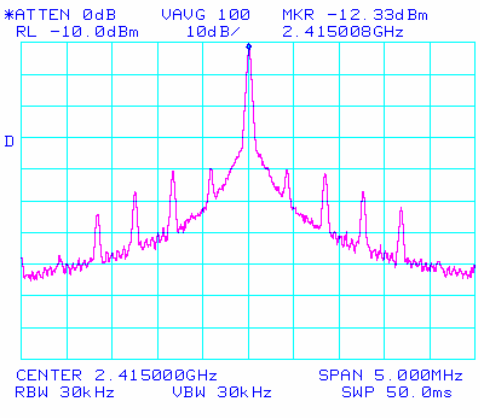
The radio has a CW mode for testing purposes and was used to measure the harmonic levels radiated from the radio. In normal mode operation, the modulated spectrum of the radio has a lower power-spectral density, making accurate measurements difficult. With no modulation, the measurement bandwidth could be reduced to 5MHz, allowing greater dynamic range for the test equipment. Measurements were made using a 30 kHz resolution bandwidth and a 5MHz bandwidth.

Harmonic level as a function of channel frequency was reviewed. After testing the radio at both the high and low channels of the ISM band, we determined that harmonic content was not strongly tied to the channel frequency. An RF frequency of 2415MHz was chosen for this test. Data from the analyzer was transferred to the laptop computer and later processed. The raw spectral plots from the HP8563E analyzer are given below:

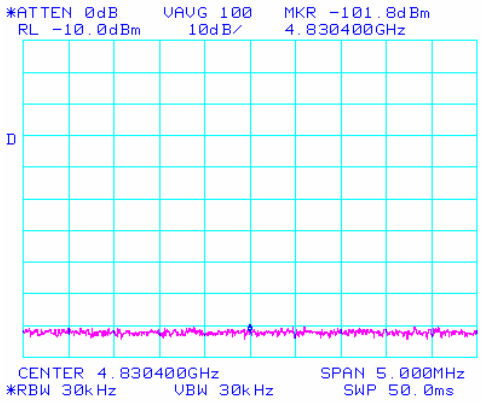
Radio 1MHz RBW



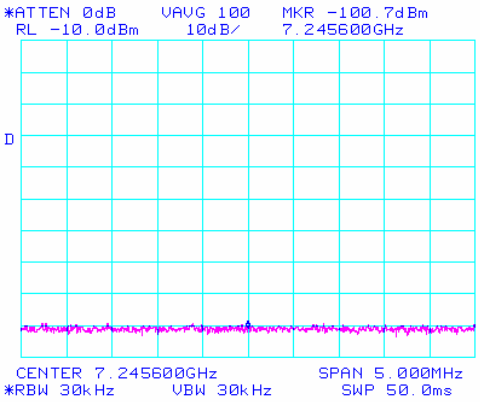
Radio 30kHz RBW



Radio 2nd Harmonic

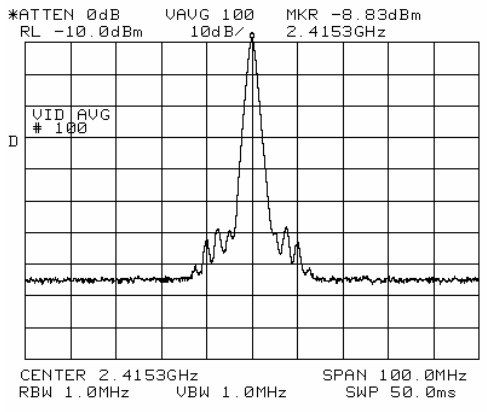


Radio 3rd Harmonic

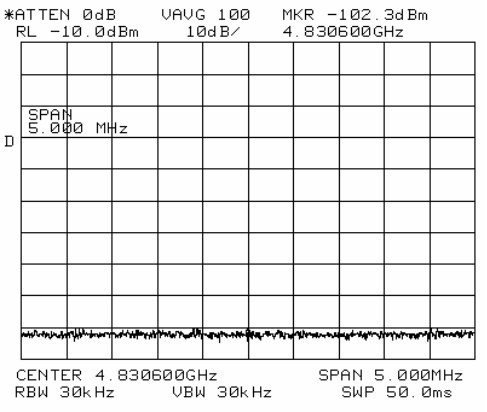


All other harmonic content was below the noise floor of the spectrum analyzer.

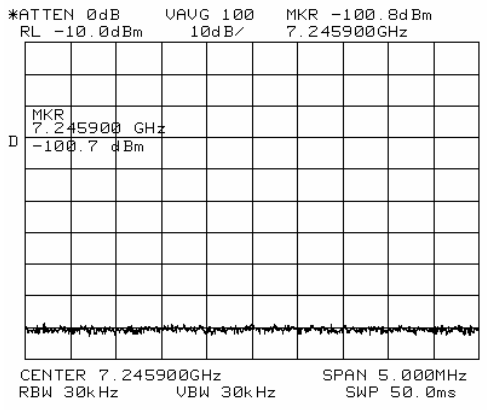
Radio with Dish 1MHz RBW



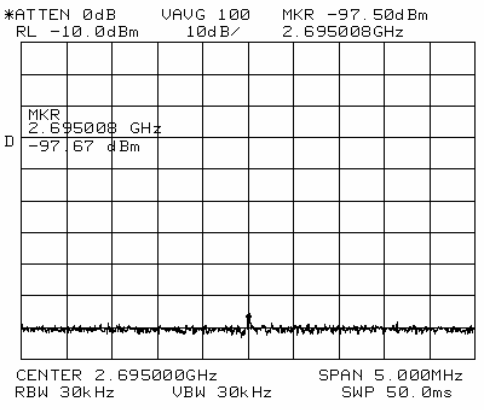
Radio with Dish 2nd Harmonic



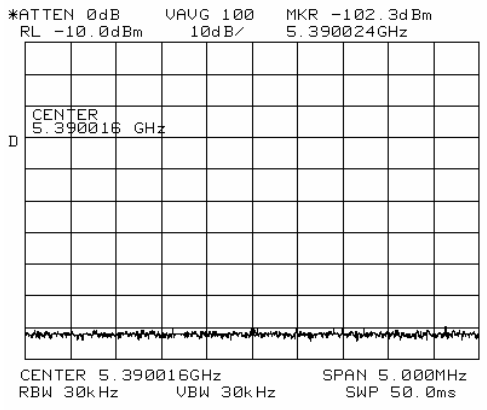
Radio with Dish 3rd Harmonic



Radio with Dish LO



Radio with Dish LO 2nd Harmonic



All other harmonic content was below the noise floor of the spectrum analyzer.

sample of the error budgeting is shown below. The total error is given in the last row, and shows that the error spread ues not exceed +/- 2dB over the frequency range. Although not shown in the sample below, the error terms for the iax cable and the spectrum analyzer are included in the final error terms of the bottom row.

Measurement Error Budget	1-18GHz	18-30GHz
Error Contribution (dB)	**EMCO 3115**	**EMCO 3116**
VSWR Contribution in dB	1.00	0.88
Amplitude Uncertainty (dB)	0.30	0.80
Reference Level		
Total Error, ±dB	***1.37***	***1.48***

or a confidence level of 68%, the error budget is then ±0.93dB.The following Excel spreadsheet cells show the rrected power levels of the radio. The first sheet shows an ERP of +33.6 dBm ±0.93dB when the radio was erating at 2415MHz, well under the FCC limit of +36dBm for part 15.247 (3) devices.

CANOPY ISM Test of Unit #0A003E200016

CW Mode	30kHz or 1MHz RBW/VBW
Frequency (MHz):	**2415**
Harmonic:	**Fund**
Analyzer Reading	-12.17
Noise Floor	-101.8
Adjusted Analyzer Level	-12.17
Cable Loss	-3.93
dBm at Antenna Connector	-8.24
Antenna Factor (dB/m)	30.05
Antenna Gain (dBi)	7.8
Path loss	-49.64
Power Level at Antenna	-16.04
dBuV Level at Antenna	90.96
Radio ERP in dBm	33.6

Harmonic Frequency Testing 3 meter Integral Antenna Spreadsheet Summary:

Canopy 2400 Radiated Test : Unit #0A003E200016

CW Mode	30kHz or 1MHz RBW/VBW			Agilent 8563E Analyzer						
Restricted Band	**Freq:=>**	4830.00	7245.00	9660.00	12075.00	14490.00	16905.00	19320.00	21735.00	24150.00
2415.00	**Fund**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**
Analyzer Reading	-12.17	-101.80	-100.70	-102.00	-102.00	-100.30	-101.00	-99.83	-100.70	-99.50
Noise Floor	-101.80	-102.00	-100.87	-102.16	-102.16	-100.50	-101.16	-100.00	-100.86	-99.67
Adjusted Analyzer Level	-12.17	-115.27	-114.86	-116.42	-116.42	-113.77	-115.42	-113.99	-115.12	-113.66
Cable Loss	-3.93	-5.87	-7.38	-8.80	-10.10	-11.28	-12.35	-13.45	-14.29	-15.61
dBm at Antenna Connector	-8.24	-109.40	-107.48	-107.61	-106.32	-102.48	-103.07	-100.54	-100.83	-98.05
Comversion to dBuV	98.76	-2.40	-0.48	-0.61	0.68	4.52	3.93	6.46	6.17	8.95
Antenna Factor (dB/m)	30.05	34.30	37.25	39.40	40.50	39.10	42.90	44.65	44.60	45.35
Antenna Gain (dBi)	7.80	9.50	10.20	10.40	11.30	12.10	11.90	11.30	12.30	12.60
3 meter path loss	-49.64	-55.66	-59.18	-61.68	-63.62	-65.21	-66.54	-67.70	-68.73	-69.64
Corrected Antenna Connector Power Level	-16.04	-118.90	-117.68	-118.01	-117.62	-114.58	-114.97	-111.84	-113.13	-110.65
Corrected Antenna dBuV Level	90.96	22.40	26.57	28.39	29.88	31.52	34.93	39.81	38.47	41.70
Radio ERP in dBm	33.60	-63.23	-58.49	-56.33	-54.00	-49.38	-48.42	-44.13	-44.40	-41.01
FCC Restricted Band Emissions Limit	N/A	5.00E-04	5.00E-04		5.00E-04	5.00E-04		5.00E-04	5.00E-04	
FCC Out-of-Band Emssions Limit (dBm ERP)	N/A			-14.80			-14.80			-14.80
Emissions Limit in dBuv	N/A	45.22	45.22	84.65	45.22	45.22	84.65	45.22	45.22	84.65
Radio Level to FCC Limit in dB(CW Mode)	N/A	22.81	18.64	56.26	15.34	13.70	49.72	5.41	6.74	42.95
CW to Modulated Mode Reduction(dB)		5	5	5	5	5	5	5	5	5
Radio Level to FCC Limit in dB(Modulated Mode)		27.81	23.64	61.26	20.34	18.70	54.72	10.41	11.74	47.95

Restricted band Limit at antenna (watts/m2)		6.63E-10	6.63E-10		6.63E-10	6.63E-10		6.63E-10	6.63E-10	
Restricted band Limit at radio (watts)		7.49835E-08	7.49835E-08		7.49835E-08	7.49835E-08		7.49835E-08	7.49835E-08	
Restricted band Limit at radio (dBm)		-41.25034465	-41.25034465		-41.25034465	-41.2503446		-41.25034465	-41.25034465	
500uV/m limit translated to Spectrum Analyzer (dBm)		-93.28	-97.62		-103.67	-105.64		-111.10	-111.97	
Margin to spec in dB		27.81	23.64	46.53	20.34	18.70	38.62	10.41	11.74	31.21

Canopy 2400 Radiated Test : Unit #0A003E200016

CW Mode	30kHz or 1MHz RBW/VBW			Agilent 8563E Analyzer					
Restricted Band	2695.00	5390.00	8085.00	10780.00	13475.00	16170.00	18865.00	21560.00	24255.00
2415.00	**VCO**	**2*LO**	**3*LO**	**4*LO**	**5*LO**	**6*LO**	**7*LO**	**8*LO**	**9*LO**
Analyzer Reading	-100.30	-102.70	-102.20	-102.30	-101.20	-101.30	-100.20	-99.67	-99.00
Noise Floor	-100.46	-102.87	-102.30	-102.50	-101.33	-101.50	-100.30	-99.83	-99.17
Adjusted Analyzer Level	-114.72	-116.86	-118.63	-115.77	-116.50	-114.77	-116.63	-114.09	-113.16
Cable Loss	-4.17	-6.16	-7.80	-9.39	-10.89	-11.95	-13.29	-14.31	-15.26
dBm at Antenna Connector	-110.54	-110.70	-110.83	-106.37	-105.62	-102.82	-103.33	-99.77	-97.90
Comversion to dBuV	-3.54	-3.70	-3.83	0.63	1.38	4.18	3.67	7.23	9.10
Antenna Factor (dB/m)	30.85	35.52	38.20	39.84	40.30	40.69	44.70	44.40	45.40
Antenna Gain (dBi)	8.00	9.30	10.10	11.10	12.50	13.90	11.00	12.40	12.60
3 meter path loss	-50.60	-56.62	-60.14	-62.64	-64.57	-66.16	-67.50	-68.66	-69.68
Corrected Antenna Connector Power Level	-118.54	-120.00	-120.93	-117.47	-118.12	-116.72	-114.33	-112.17	-110.50
Corrected Antenna dBuV Level	19.30	22.52	24.27	29.37	29.18	30.97	37.37	39.23	41.90
Radio ERP in dBm	-67.95	-63.38	-60.79	-54.84	-53.54	-50.56	-46.84	-43.52	-40.82
FCC Restricted Band Emissions Limit		5.00E-04	5.00E-04	5.00E-04		5.00E-04	5.00E-04		
FCC Out-of-Band Emssions Limit (dBm ERP)	-14.80				-14.80			-14.80	-14.80
Emissions Limit in dBuv	84.65	45.22	45.22	45.22	84.65	45.22	45.22	84.65	84.65
Radio Level to FCC Limit in dB(CW Mode)	65.35	22.69	20.94	15.85	55.47	14.24	7.85	45.42	42.75
CW to Modulated Mode Reduction(dB)	5	5	5	5	5	5	5	5	5
Radio Level to FCC Limit in dB(Modulated Mode)	70.35	27.69	25.94	20.85	60.47	19.24	12.85	50.42	47.75

Restricted band Limit at antenna (watts/m^2)		6.63E-10	6.63E-10	6.63E-10		6.63E-10	6.63E-10		
Restricted band Limit at radio (watts)		7.49835E-08	7.49835E-08	7.49835E-08		7.49835E-08	7.49835E-08		
Restricted band Limit at radio (dBm)		-41.25034465	-41.25034465	-41.25034465		-41.25034465	-41.25034465		
500uV/m limit translated to Spectrum Analyzer (dBm)		-94.73	-99.09	-102.18		-105.46	-111.04		
Margin to spec in dB	58.15	27.69	25.94	20.85	43.74	19.24	12.85	33.72	31.02

The results show that the radio with integral antenna meets the FCC limit of 500uV/m on the harmonics that fall in the restricted band. Harmonics falling outside of restricted bands meet the effective radiated power limit of -14.8dBm.

Since the radio can be equipped with a reflector dish for increased range, testing was done to determine the harmonic energy levels for this configuration. The spreadsheet summary is given below:

Harmonic Frequency Testing 7 meter Integral Antenna Spreadsheet Summary:

Canopy 2400 Radiated Test : Unit #0A003E200016 with External Reflector

	30kHz or 1MHz RBW/VBW			Agilent 8563E Analyzer						
Restricted Band										
	Freq:=>	4830.00	7245.00	9660.00	12075.00	14490.00	16905.00	19320.00	21735.00	24150.00
2415.00	**Fund**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**
Analyzer Reading	-8.83	-102.30	-100.80	-103.00	-103.30	-97.67	-99.50	-100.70	-100.00	-99.00
Noise Floor	-85.50	-102.50	-101.00	-103.30	-104.00	-97.80	-99.67	-100.85	-100.17	-99.17
Adjusted Analyzer Level	-8.83	-115.77	-114.27	-114.76	-111.57	-112.97	-113.66	-115.39	-114.16	-113.16
Cable Loss	-3.93	-5.87	-7.38	-8.80	-10.10	-11.28	-12.35	-13.45	-14.29	-15.61
dBm at Antenna Connector	-4.90	-109.90	-106.89	-105.95	-101.48	-101.69	-101.31	-101.94	-99.87	-97.55
Comversion to dBuV	102.10	-2.90	0.11	1.05	5.52	5.31	5.69	5.06	7.13	9.45
Antenna Factor (dB/m)	30.05	34.30	37.25	39.40	40.50	39.10	42.90	44.65	44.60	45.35
Antenna Gain (dBi)	7.80	9.50	10.20	10.40	11.30	12.10	11.90	11.30	12.30	12.60
7 meter path loss	-57.00	-63.02	-66.54	-69.04	-70.98	-72.57	-73.90	-75.06	-76.09	-77.00
Corrected Antenna Connector Power Level	-12.70	-119.40	-117.09	-116.35	-112.78	-113.79	-113.21	-113.24	-112.17	-110.15
Corrected Antenna dBuV Level	94.30	21.90	27.16	30.05	34.72	32.31	36.69	38.41	39.43	42.20
Radio ERP in dBm	44.30	-56.37	-50.54	-47.31	-41.79	-41.22	-39.30	-38.18	-36.08	-33.15
FCC Restricted Band Emissions Limit		5.00E-04	5.00E-04		5.00E-04	5.00E-04		5.00E-04	5.00E-04	
FCC Out-of-Band Emssions Limit (dBm ERP)				-14.80			-14.80			-14.80
Emissions Limit in dBuv		45.22	45.22	84.65	45.22	45.22	84.65	45.22	45.22	84.65
Radio Level to FCC Limit in dB(CW Mode)		23.31	18.05	54.60	10.49	12.91	47.96	6.81	5.79	42.45
CW to Modulated Mode Reduction(dB)		5	5	5	5	5	5	5	5	5
Radio Level to FCC Limit in dB(Modulated Mode)		28.31	23.05	59.60	15.49	17.91	52.96	11.81	10.79	47.45

Restricted band Limit at antenna (watts)		6.63E-10	6.63E-10		6.63E-10	6.63E-10		6.63E-10	6.63E-10	
Restricted band Limit at radio (watts)		7.49835E-08	7.49835E-08		7.49835E-08	7.49835E-08		7.49835E-08	7.49835E-08	
Restricted band Limit at radio (dBm)		-41.25034465	-41.25034465		-41.25034465	-41.2503446		-41.25034465	-41.25034465	
500uV/m limit translated to Spectrum Analyzer (dBm)		-100.64	-104.98		-111.03	-113.00		-118.46	-119.33	
Margin to spec in dB		28.31	23.05	37.51	15.49	17.91	29.50	11.81	10.79	23.35

Canopy 2400 Radiated Test : Unit #0A003E200016 with External Reflector

Restricted Band	2695.00	5390.00	8085.00	10780.00	13475.00	16170.00	18865.00	21560.00	24255.00
2415.00	**VCO**	**2*LO**	**3*LO**	**4*LO**	**5*LO**	**6*LO**	**7*LO**	**8*LO**	**9*LO**
Analyzer Reading	-97.50	-102.30	-100.70	-101.20	-100.30	-99.33	-100.63	-101.00	-98.67
Noise Floor	-101.50	-103.20	-102.70	-101.80	-100.50	-99.50	-100.80	-101.17	-98.80
Adjusted Analyzer Level	-99.70	-109.58	-105.03	-110.09	-113.77	-113.49	-114.79	-115.16	-113.97
Cable Loss	-4.17	-6.16	-7.80	-9.39	-10.89	-11.95	-13.29	-14.31	-15.26
dBm at Antenna Connector	-95.53	-103.42	-97.23	-100.70	-102.88	-101.54	-101.49	-100.85	-98.71
Comversion to dBuV	11.47	3.58	9.77	6.30	4.12	5.46	5.51	6.15	8.29
Antenna Factor (dB/m)	30.85	35.52	38.20	39.84	40.30	40.69	44.70	44.40	45.40
Antenna Gain (dBi)	8.00	9.30	10.10	11.10	12.50	13.90	11.00	12.40	12.60
7 meter path loss	-57.95	-63.98	-67.50	-70.00	-71.93	-73.52	-74.86	-76.02	-77.04
Corrected Antenna Connector Power Level	-103.53	-112.72	-107.33	-111.80	-115.38	-115.44	-112.49	-113.25	-111.31
Corrected Antenna dBuV Level	34.31	29.80	37.87	35.04	31.92	32.25	39.21	38.15	41.09
Radio ERP in dBm	-45.58	-48.74	-39.83	-41.80	-43.44	-41.92	-37.64	-37.23	-34.27
FCC Restricted Band Emissions Limit		5.00E-04	5.00E-04	5.00E-04		5.00E-04	5.00E-04		
FCC Out-of-Band Emssions Limit (dBm ERP)	-14.80				-14.80			-14.80	-14.80
Emissions Limit in dBuv	84.65	45.22	45.22	45.22	84.65	45.22	45.22	84.65	84.65
Radio Level to FCC Limit in dB(CW Mode)	50.34	15.41	7.35	10.17	52.73	12.97	6.01	46.50	43.56
CW to Modulated Mode Reduction(dB)	5	5	5	5	5	5	5	5	5
Radio Level to FCC Limit in dB(Modulated Mode)	55.34	20.41	12.35	15.17	57.73	17.97	11.01	51.50	48.56

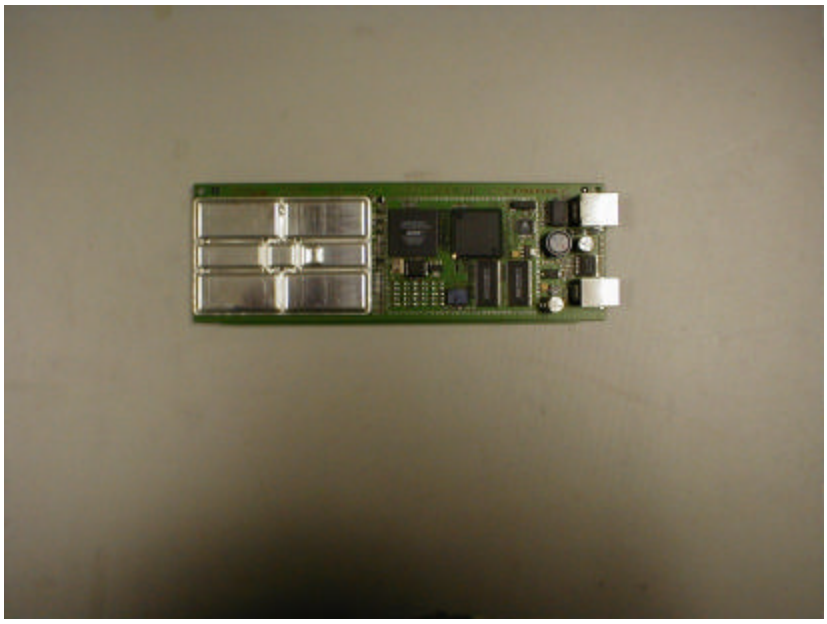
Restricted band Limit at antenna (watts)		6.63E-10	6.63E-10	6.63E-10		6.63E-10	6.63E-10		
Restricted band Limit at radio (watts)		7.49835E-08	7.49835E-08	7.49835E-08		7.49835E-08	7.49835E-08		
Restricted band Limit at radio (dBm)		-41.25034465	-41.25034465	-41.25034465		-41.25034465	-41.25034465		
500uV/m limit translated to Spectrum Analyzer (dBm)		-102.09	-106.45	-109.54		-112.82	-118.40		
Margin to spec in dB	35.78	20.41	12.35	15.17	33.64	17.97	11.01	27.43	24.47

Testing distance was 7 meters to insure far-field operation of reflector. Unit was rotated in both azimuth and elevation planes to find peak harmonic energy. The results show that the reflector-equipped unit also meets FCC limits for harmonic content.

Outdoor testing site

Canopy unit #0A003E200015 in housing

CANOPY unit #0A003E200015, Radio Printed Wiring Board (Component Side):



CANOPY Unit #0A003E200015, Radio Printed Wiring Board (Solder Side):