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Measured Radio Frequency Emissions
From

Delphi Delco 77 GHz Short Range Radar Sensor
PN: 09369080

Report No. 415031-082
April 25, 2001

For:
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Summary
Tests for compliance with FCC Regulations, according to Part 15.253, were performed on 77 GHz Delphi-Delco Short Range Radar Sensor. In testing performed between March 23 and April 20, 2001, the device tested met the emissions at fundamental by 22.3 dB, at harmonics by 28.8 dB, and spurious by 6.2 dB.

As for RF Health Hazard levels, maximum level measured was 0.33 mW/cm2 at the surface of the radome.

1. Introduction

Delphi Delco Short Range Radar (SRR) Sensor, Model: 09369080, was tested for compliance with FCC Regulations, Part 15, adopted under Docket 87-389, April 18, 1989, and with Industry Canada RSS-210, Issue 2, dated February 14, 1998. 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" and the new FCC Section 15.253, "Operation within the bands 46.7-46.9 GHz and 76.0-77.0 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 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)		Hewlett-Packard 8592L, SN: 3710A00856
Spectrum Analyzer (9kHz-26GHz)	X	Hewlett-Packard 8593E, SN: 3412A01131
Spectrum Analyzer (9kHz-26GHz)	X	Hewlett-Packard 8563E, SN: 3310A01174
Spectrum Analyzer (9kHz-40GHz)		Hewlett-Packard 8564E, SN: 3745A01031
Power Meter		Hewlett-Packard, 432A
Power Meter	X	Anritsu, ML4803A/MP
Harmonic Mixer (40-60 GHz)	X	Hewlett-Packard 11970U, SN: 2332A00500
Harmonic Mixer (75-110 GHz)	X	Hewlett-Packard 11970W, SN: 2521A00179
Harmonic Mixer (140-220 GHz)	X	Pacific Millimiter Prod., GMA, SN: 26
X-band horn (8.2- 12.4 GHz)		Narda 640
X-band horn (8.2- 12.4 GHz)	X	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)	X	Custom Microwave, HO19
W-band horn(75-110 GHz)	X	Custom Microwave, HO10
G-band horn (140-220 GHz)	X	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)		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)		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
LISN (50 μH)		University of Michigan
Signal Generator (0.1-2060 MHz)		Hewlett-Packard, 8657B
Signal Generator (0.01-20 GHz)		Hewlett-Packard

3. Configuration and Identification of Device Under Test

The Device Under Test (DUT) was a 77 GHz Short Range Radar. It is a CW device and uses a triangular 350 MHz frequency chirp at 240 Hz rate to provide range information and a mechanical antenna scanning at 5 Hz to obtain angular resolution. The RF power source is a 10 mW Gunn oscillator; there is also another RF source operating at 12.70 GHz. The device is a basic radar unit; additional signal processing and analyses are done by other processors on a vehicle. It will operate (transmit) only when the vehicle is in motion, 20 MPH and above. The size of the DUT is 2.5 x 6 x 4 inches and it has a 12-pin connector in the back. For testing, three wires were connected, power and ON control. Nominal operating voltage is 13.8 VDC. For the tests this was supplied by a laboratory power supply.

The DUT was manufactured for Delphi Delco by HE Microwave LLC, P.O. Box 23340, Tuscon, AZ 85734. It is identified as:

Delphi Delco Short Range Radar (SRR) Sensor
PN: 09369080
S/N: 1027007, 10161001 (mod. for peak power meas.)
FCC ID: L2C00015TR
CAN: to be provided by IC

Two devices were provided: one in a standard mode, and the other with frequency chirp and antenna scanning disabled.

3.1 Changes made to the DUT

None.

4. Microwave Emission Limits

4.1 Radiated Emission Limits

The DUT tested falls under the category of an Intentional Radiators subject to Section 15.253 and all other sections referred to therein. The applicable critical testing frequencies with corresponding emission limits are given in Tables 4.1. As a digital device, it is exempt.

Table 4.1. Radiated Emission Limits (Ref: 15.253) --Transmitter.

Frequency (GHz)	Fundamental and Spurious*
0.030 - 40000	see 15.209
76.0 - 77.0	60 µW/cm2
77.0 - 200.0	600 pW/cm2
200.0 - 231.0	1000 pW/cm2
up to 38.6 only	Restricted Bands

4.2 Conductive Emission Limit

The conductive emission limits for intentional radiators are 250 mV, over the range from 450 kHz to 30 MHz. This is same level as for a digital device, Class B.

4.3 (Digital) Radiated Emission Limits

Table 4.2. Radiated Emission Limits (Ref: 15.33, 15.35, 15.109,) -- Digital.

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
960-2000	60.0	54.0

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

5. Radiated Emission Tests and Results

5.1 Test Procedure

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.

For the tests, the unit was hand-held at a 3 or 1 (or even 0.25m) meter distance, depending on the available signal strength, and rotated through 360 degrees to determine the most intense radiation lobe. Care is taken such that there is no interference from the hand nor the body. Due to the rigid connection of the receive antenna to the spectrum analyzer, the DUT is also rotated around its antenna axes to match the polarizations of the emission for maximum readings.

5.2 Measurements

Because this was a new device to be tested by this test laboratory, probably more measurements were taken than necessary, and most were repeated to verify the procedure and the measurement accuracy. We started with measurements at the fundamental (76.5 GHz) and there recorded number of plots to provide values for compliance assessment, as well as for understanding the operation of the device. The following plots are presented:

Figure 5.1. Fundamental spectrum. RBW=1 MHz, VBW=3 MHz; 3 meters, peak hold.
Here we observe the frequency chirp is from 76.335 GHz to 76.525 GHz, or 190 MHz BW. Note the maximum reading is -10.0 dBm, which for a chirp radar is also a peak value (assuming the chirp is sufficiently slow to be detected in a given RBW/VBW).

Figure 5.2. Time response at set frequency due to chirp. RBW=2 MHz, VBW=3 MHz, zero span.
The pulses occur as the frequency sweeps by the receiver fixed at 76.35 GHz. Since the measurement is near the low side of the spectrum, the first peak represents the frequency going down followed by the peak representing frequency going up. Note, the period of the chirp is 4.183 ms or 239 Hz.

Figure 5.3. Time response at set frequency due to the antenna scan. RBW=2 MHz, VBW=3 MHz, zero span, peak hold.
Here the pulses occur as the antenna scans past the receiving antenna. These pulses contain pulses shown in Figure 5.2. Since the scan is back-and-forth, the scan rate is 200 ms or 5 Hz.

Figure 5.4. Peak power measurement from modified DUT for fixed CW emission. RBW=1 MHz, VBW=3 MHz; 3 meters.

For this measurement the modified DUT was used. The chirp and the antenna scan had been disabled. Note, here we measured -10.97 dBm as compared to -10.0 dBm for the scanning device. The lower reading may be due to variation in devices or the fact that there is an increase in level as the frequency increases. In figure 5.1 the reading was taken at the upper frequency, whereas in Figure 5.4 the device was set to operate near middle of the band.

Figure 5.5. Average measurement. RBW=1 MHz, VBW=1 Hz; 3 meters, 100 sec. sweep, linear display.

Here the measurement was "zeroed in" to at upper frequency where emission is highest. The detector was set to linear and the sweep to the lowest speed. Observe, we measure -62 dBm which is 52 dB below the peak reading (Figure 1). Looking at Figures 2 and 3, this is not unreasonable. The duty factor is a product of the duty factors in the two plots 0.02 and 0.15, respectively (estimate at -3 dB points). This gives 50.5 dB. (Here, even we were surprised at agreement with the measured 51.0 dB value.)

After the fundamental measurements, the spurious and the harmonics were measured from 30 MHz to 231 GHz. Appendix shows the setup for measurement of spurious emissions at X-band.

5.3 Computations and Results

When the measurement is made at a distance other than 3m, the reading is extrapolated to the 3 m. This is done using the 20 dB/decade field behavior relation when translating in the far field, and 40 dB/decade relation when translating in the near field. The near-field/far-field criterion, N/F, is based on

$$N/F = 2*D*D/\text{wavelength}$$

where D is the max. dimension of the transmitter or receiver antenna , and the wavelength is that of the measurement frequency. Suppose N/F = 2 m and the measurement is made at 1 m. Here the 40 dB/ decade relation is applied from 1 to 2 m, and 20 dB/decade relation is applied from 2 to 3 m. In dBs, this gives a 15.6 dB adjustment.

To convert the dBm measured and extrapolated to 3 m, the E3(dBmV/m) is computed from

$$E3(dB\mu V/m) = 107 + Pr + K_a + Kg + K_e$$

where P_r = power recorded on spectrum analyzer, dBm (or extrapolated to 3 m distance)
K_a = antenna factor, dB/m
K_g = pre-amp gain, dB
K_e = pulse operation correction factor, dB (see 6.1)

For conversion to power densities specified in 15.253, we used

$$dB(mW/cm2) = -155.76 + E(dB\mu V/m)$$

and we note that

$$60\ \mu W/cm2 = -12.2\ dBm/cm2$$
$$1000\ pW/cm2 = -60.0\ dB\ m/cm2$$
$$600\ pW/cm2 = -62.2\ dBm/cm2$$

For microwave measurements, either the receive antenna is connected directly to the spectrum analyzer, or it is connected to an external mixer followed by an insignificant length of cable. Hence, no cable loss term is used. The mixer conversion losses are programmed in the spectrum analyzer and are included in the dB values. However, for 125 GHz and up, an external mixer with an external LO and pre-amplifier was used. The mixer conversion loss, IF amp gain and cable losses are included in gain Kg above.

The results are given in Table 5.1. There we see that the DUT had maximum emissions of -34.5 dBm/cm2 (0.353µW/cm2) at 76.46 GHz. In summary, the DUT met the limits at fundamental by 22.3 dB, at harmonics by 28.8 dB, and at spurious by 6.2 dB.

6. Other Measurements and Computations

6.1 Peak-to-Average Ratio

The DUT is designed to operate in continuous transmit mode, but with sweep (chirp) and antenna scan. When observing (measuring) the signal at a stationary point (say at 3m, fixed frequency, and 1 MHz RBW), the signal the signal appears pulsed due to 240 Hz sweep rate multiplied by 5 Hz antenna scan rate. Recall, the pulsing appears at twice the rate due to "up-and-down" nature.

The peak emission was measures two ways: (1) See Figure 5.1. Fundamental spectrum. RBW=1 MHz, VBW=3 MHz; 3 meters, peak hold. Note the maximum reading is -10.0 dBm, which for a chirp radar is also a peak value (assuming the chirp is sufficiently slow to be detected in a given RBW/VBW). (2) See Figure 5.4. Measure modified DUT with disabled chirp and antenna scan. Measured -11.0 dB. Use this value for compliance assessment.

Average measurement. See Figure 5.5. RBW=1 MHz, VBW=1 Hz; 3 meters, 100 sec. sweep, linear display. Read -62.0 dBm.

Thus Peak-to Average Ratio is 51.0 dB.

6.2 Correction for Pulse Operation (Ref. 15.35)

Use maximum allowed by 15.35, i.e. 20.0 dB.

6.3 Effect of Supply Voltage Variation

The DUT has been designed to operate from 13.8 VDC that originates from vehicle 12-volt system. The relative radiated emissions and frequency were recorded at the "fundamental" (76.5 GHz) as the supply voltage was varied from 6 to 18 VDC. Figure 6.2 shows the emission power variation. Current at 13.8 VDC was 510 mA.

6.4 Conducted Emission Measurements

Not applicable.

6.5 Potential Health Hazard EM Radiation Level

The maximum radiation level from the unit was determined by using the W-band Standard Gain horn feeding directly into a power meter. In case the 1 mW/cm2 limit is exceeded, the maximum distance from the DUT is determined by measurement where the field density is 1 mW/cm2. The physical aperture of this antenna is 1.869 x 2.461cm (A = 4.60 cm2). Its effective aperture at 76.5 GHz is 2.23 cm2, based on the Gain of 22.6 dB.

For the subject DUT, we probed throughout the near-field region, rotating the probe on all axis and polarizations. The maximum power was detected at the center of the radome, co-pol with the transmit signal. The reading was 0.733 mW on the power meter. For other axis and polarizations, the power was negligible. Power from spurious and harmonic emissions is also negligible.

Hence the maximum emitted power density of the device is

$$p(\text{mW/cm2}) = P/A_{eff} = 0.733 \text{ mW}/ 2.23 \text{ cm2} = 0.33 \text{ mW/cm2}$$

and, hence, meets the 1.1307, 1.1310, 2.1091, and 2.0193 requirements.

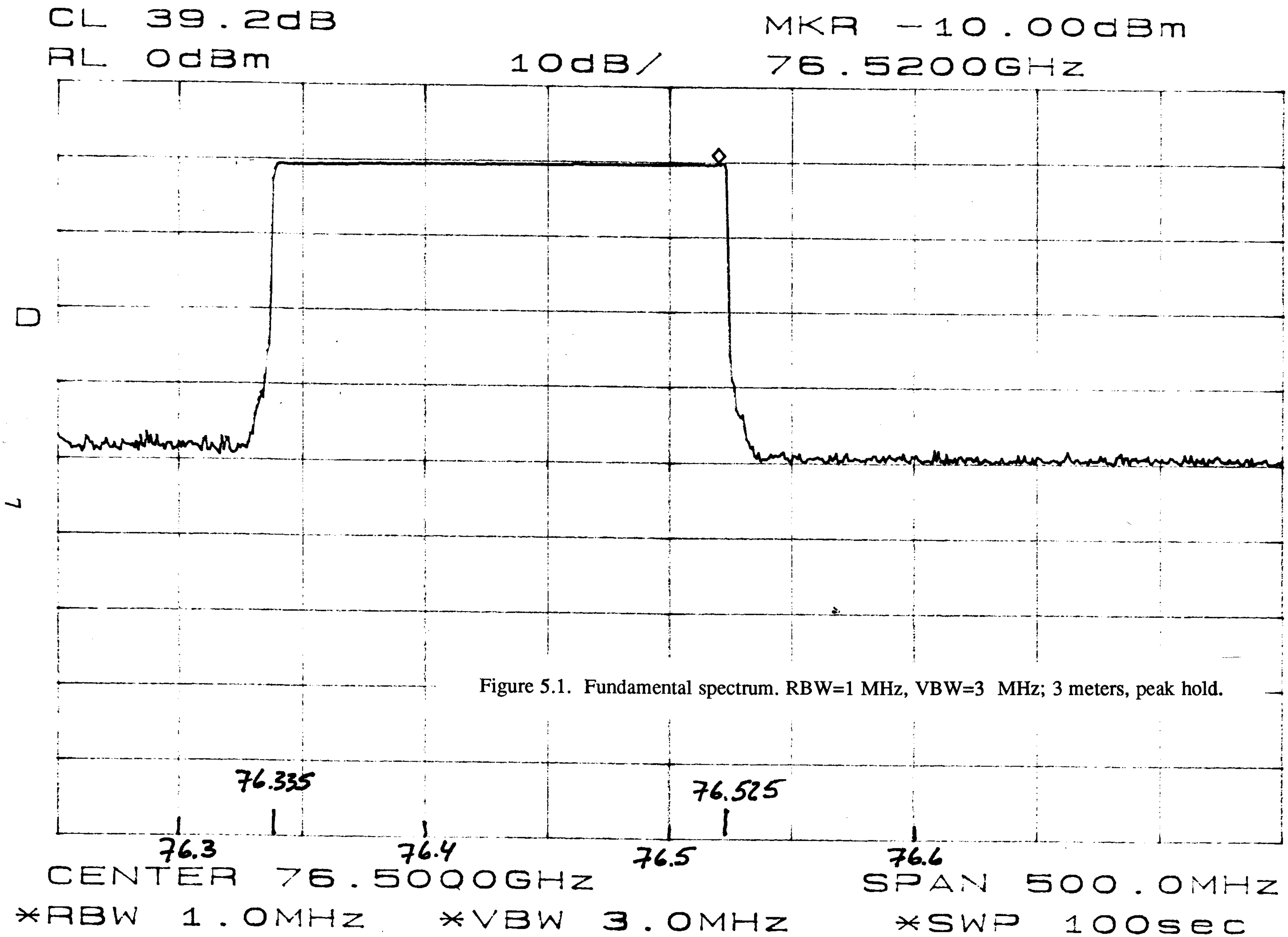

Figure 5.1. Fundamental spectrum. RBW=1 MHz, VBW=3 MHz; 3 meters, peak hold.

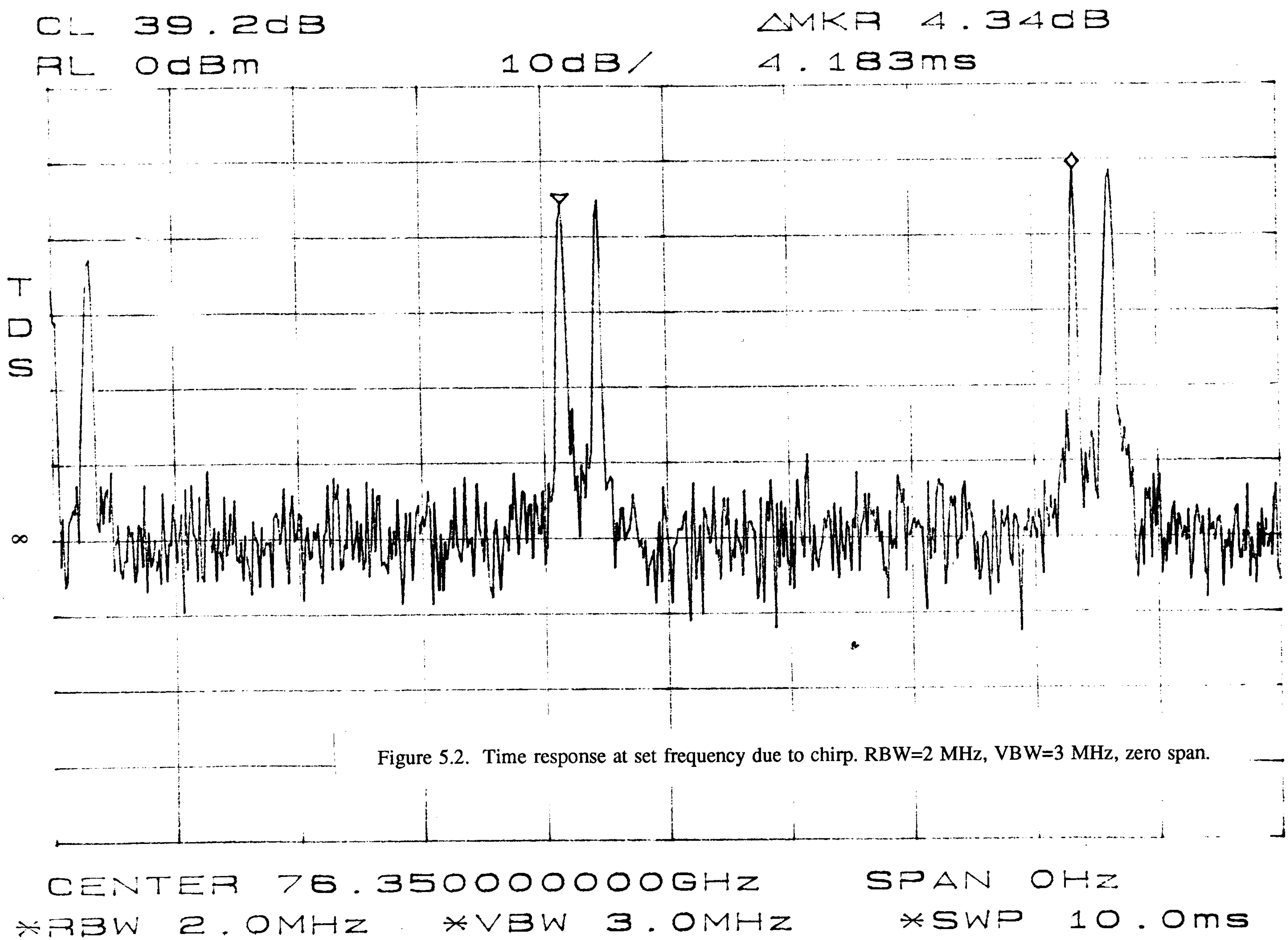

Figure 5.2. Time response at set frequency due to chirp. RBW=2 MHz, VBW=3 MHz, zero span.

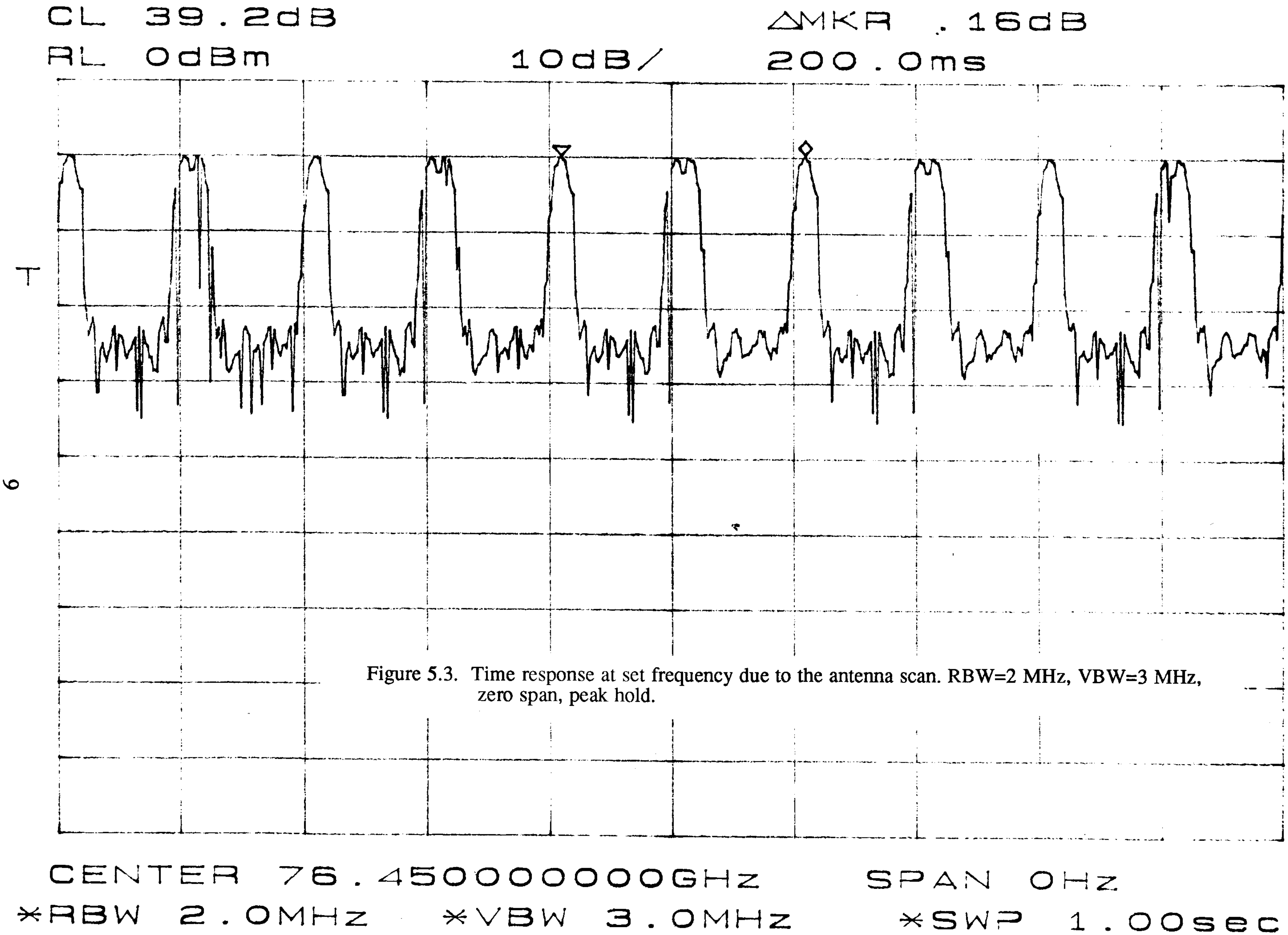

Figure 5.3. Time response at set frequency due to the antenna scan. RBW=2 MHz, VBW=3 MHz, zero span, peak hold.

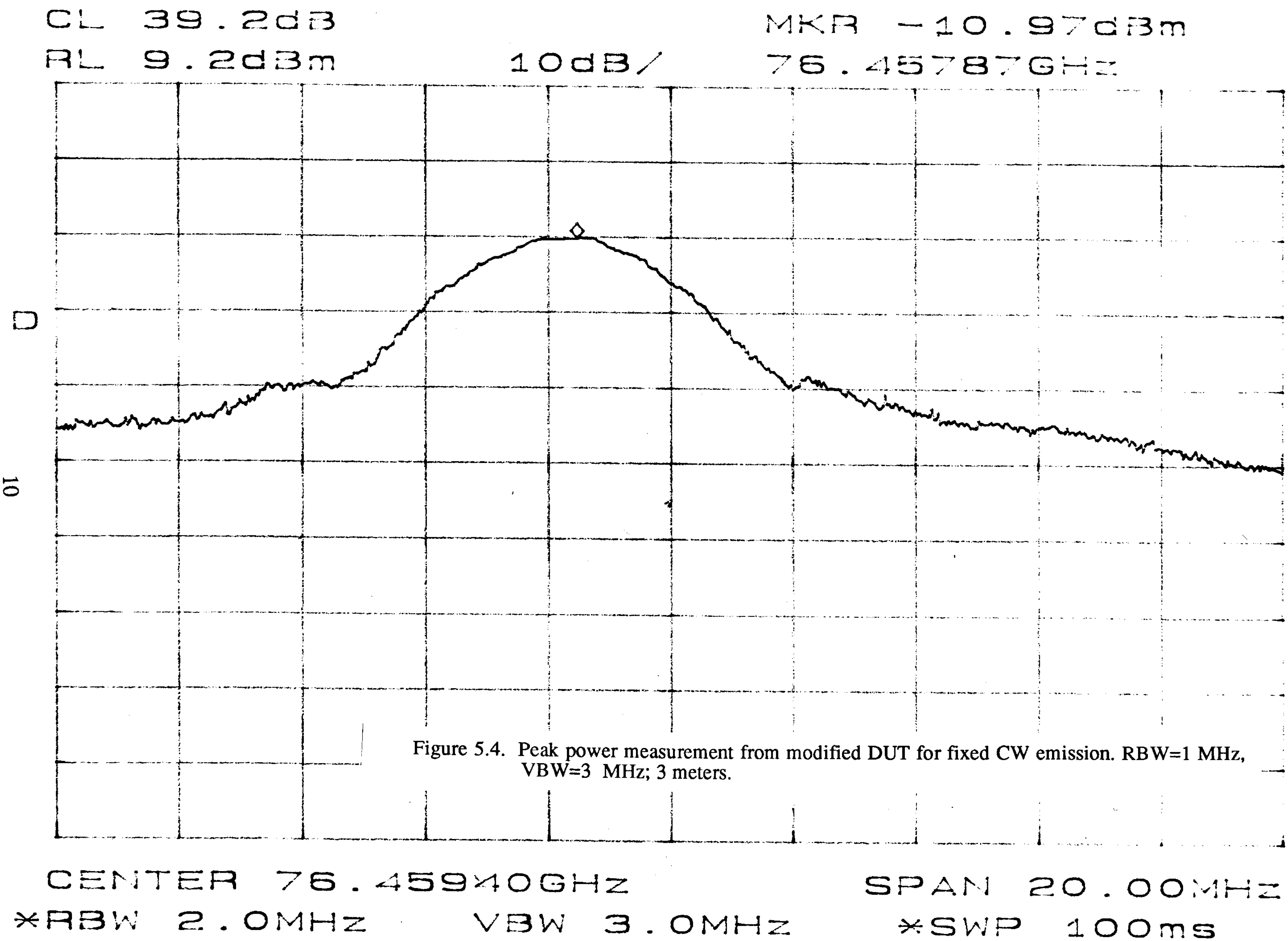

Figure 5.4. Peak power measurement from modified DUT for fixed CW emission. RBW=1 MHz, VBW=3 MHz; 3 meters.

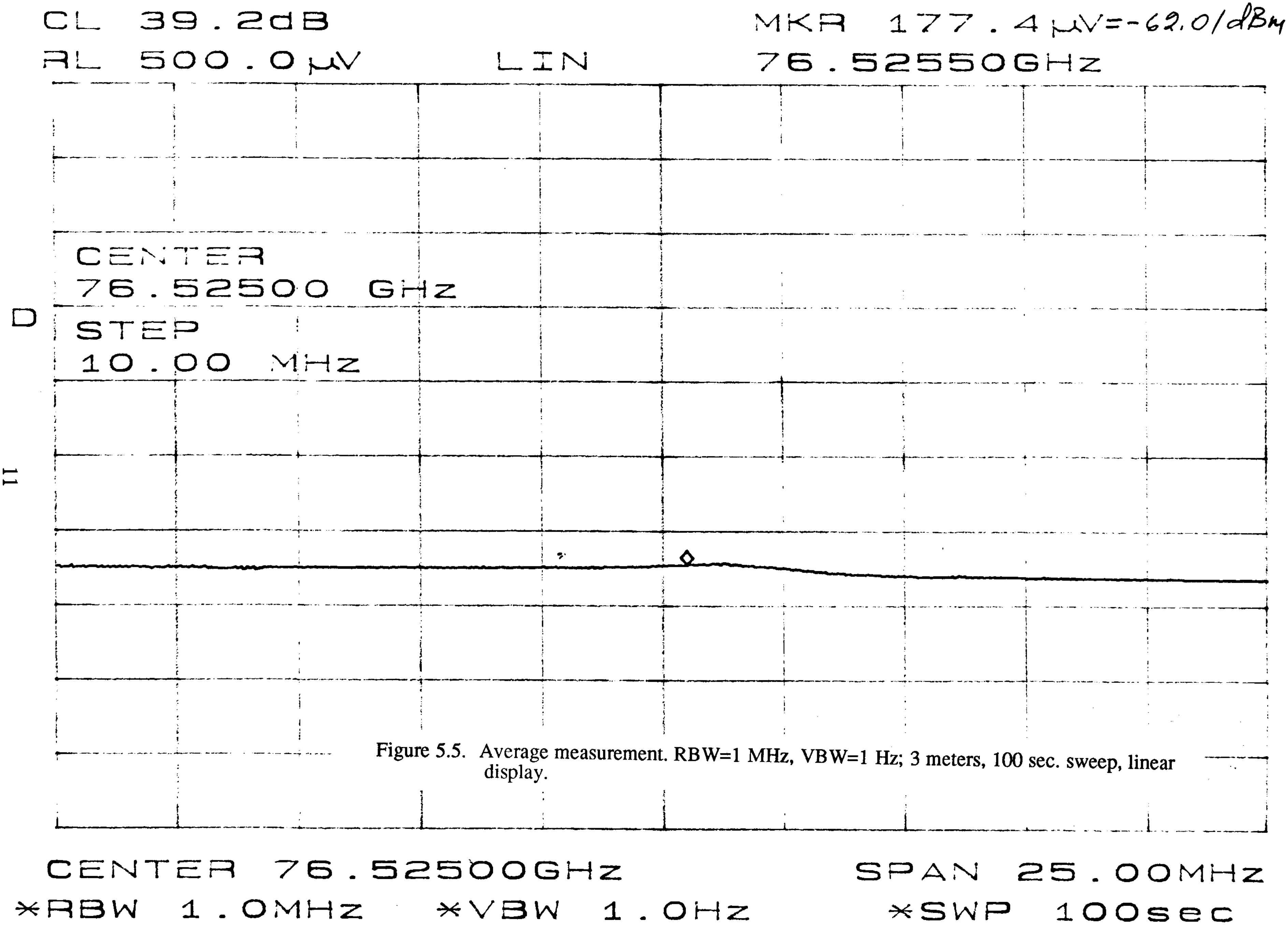

Figure 5.5. Average measurement. RBW=1 MHz, VBW=1 Hz; 3 meters, 100 sec. sweep, linear display.

Table 5.1 Highest Emissions Measured (f<40 GHz)

Microwave Radiated Emissions

Delphi-Delco Sensor

#	Freq. GHz	Ant. Used	Ant. D,cm	Meas. dist, m	Pr dBm	N/F m	Pr(3m) dBm	Ka dB/m	Kg dB	E3 dBµV/m	E3lim dBµV/m	Pass dB	Comments (Notes)
1	1 to 2	Horn	10.0	1.00	-70.0	0.14	-83.3	21.5	28.1	17.1	54.0	36.9	Noise, Pk (1,3,4,5,8)
2	2 to 4.5	Horn	5.0	1.00	-59.0	0.29	-78.1	26.0	25.0	29.9	54.0	24.1	Noise, Pk (1,3,4,5,8)
3	4.5 to 6	C-horn	21.6	1.00	-58.0	1.55	-71.3	24.7	31.0	29.4	54.0	24.6	Noise, Pk (1,3,4,5,8)
4	6 to 8.6	XN-hrn	28.9	1.00	-60.2	3.89	-79.3	25.3	31.0	22.0	54.0	32.0	Noise, Pk (1,3,4,5,8)
5	8.6to13	X-horn	19.4	3.00	-70.8	2.51	-70.8	28.5	31.0	33.7	54.0	20.3	Noise, Pk (1,3,4,5,8)
6	12.70	X-horn	19.4	3.00	-57.7	3.19	-57.7	29.5	31.0	47.8	54.0	**6.2**	**Signal, Ave (4,5)**
7	13to18	Ku-hrn	15.2	0.25	-55.6	2.31	-95.5	29.3	17.0	23.8	54.0	30.2	Noise, Pk (1,3,4,5,8)
8	18to26	K-horn	10.2	0.25	-68.2	2.11	-108.4	33.2	0.0	31.8	54.0	22.3	Noise, Ave (1,3,4,5,8)
9	26to40	Ka-hrn	6.9	0.25	-79.8	3.07	-123.4	36.0	0.0	19.6	54.0	34.4	Noise, Ave (1,2,3,4,5)
10													
11													
12													

NOTES:

(1) When measured at 0.25 cm from the DUT, no signal was detected anywhere, even at the radome

(2) Mixer conversion loss is programmed in the spectrum analyzer and automatically adjusts the readings

(3) When extrapolating to 3 m, use Near (40 dB/dec) and Far Fld (20 dB/dec) behavior

(4) For Ave. measurement a 1 Hz VBW was used, sometimes higher; RBW was always 1 MHz

(5) DUT max. antenna size, D= 12.0 cm

(6) 20 dB peak-to-average correction factor included in P

(7) Extermal mixer, LO, and IF amp were used; Kg inludes mixer loss and IF amp gain (36.5 dB)

(8) For ridge-horn (Horn) use aperture dimension of one half wavelength

Digital Radiated Emissions, Class A

#	Freq. MHz	Ant. Used	Ant. Pol.	Pr dBm	Det. Used			Ka dB/m	Kg dB	E3 dBµV/m	E3lim dBµV/m	Pass Pass	Comments
1													
2													
3	Scanned 30 - 1000 MHz												
4	72.0	Bic	H,V	-89.0	Pk			10.5	- 2.5	31.0	49.5	18.5	Pre-scan measurement
5													
6													
7													
8													
9													

Conducted Emissions, Class B

#	Freq. MHz	Line Side	Det. Used	Vtest dBµV	Vlim dBµV	Pass dB	Comments
1							
2	Not applicable						
4							

Meas. 3/23,4/20,4/25/01; U of Mich.

Table 5.1 Highest Emissions Measured (f>=40 GHz)

Microwave Radiated Emissions

Delphi-Delco Sensor

#	Freq. GHz	Ant. Used	Ant. D,cm	Meas. dist, m	Pr dBm	N/F m	Pr(3m) dBm	Ka dB/m	Kg dB	P dBm/cm2	P3lim dBm/cm2	Pass dB	Comments (Notes)
1	40-76	U-horn	4.6	0.25	-79.0	4.80	-122.2	41.0	0.0	-130.0	-62.2	67.8	Ave. mesurement (1-5)
2	76.53	W-horn	2.5	3.00	-62.0	7.30	-62.0	45.3	0.0	-65.5	-12.2	53.3	Ave. meas. (2-5)
3	76.46	W-horn	2.5	3.00	-11.0	7.30	-11.0	45.3	0.0	-34.5	-12.2	22.3	**From Pk meas.(2-6)**
4	77-125	W-horn	2.5	0.25	-60.2	9.10	-103.4	46.4	0.0	-105.8	-62.2	43.6	Ave. meas. (1-5)
5	153.00	G-horn	1.3	0.25	-56.0	14.60	-99.2	51.3	-12.5	-104.2	-62.2	42.0	From Pk. meas. (2-7)
6	229.50	G-horn	1.3	0.25	-48.5	22.00	-91.7	54.0	-15.5	-91.0	-62.2	28.8	From Pk. meas. (2-7)
7	to 231	G-horn	1.3	0.25	-74.6	22.00	-117.8	54.0	-15.5	-97.1	-62.2	34.9	Ave. meas. (1-5,7)
8													
9													
10													
11													
12													

NOTES:

(1) When measured at 0.25 cm from the DUT, no signal was detected anywhere, even at the radome

(2) Mixer conversion loss is programmed in the spectrum analyzer and automatically adjusts the readings

(3) When extrapolating to 3 m, use Near (40 dB/dec) and Far Fld (20 dB/dec) behavior

(4) For Ave. measurement a 1 Hz VBW was used, sometimes higher; RBW was always 1 MHz

(5) DUT max. antenna size, D= 12.0 cm

(6) 20 dB peak-to-average correction factor included in P

(7) Extermal mixer, LO, and IF amp were used; Kg inludes mixer loss and IF amp gain (36.5 dB)

Digital Radiated Emissions

#	Freq. MHz	Ant. Used	Ant. Pol.	Pr dBm	Det. Used			Ka dB/m	Kg dB		E3lim dBμV/m	Pass Pass	Comments
1													
2													
3		All digital emissions more than 20 dB below Class B limit											
4													
12													

Conducted Emissions, Class B

#	Freq. MHz	Line Side	Det. Used	Vtest dBμV	Vlim dBμV	Pass dB	Comments
1							
2		Not applicable					
4							

Meas. 3/23,4/20/01; U of Mich.

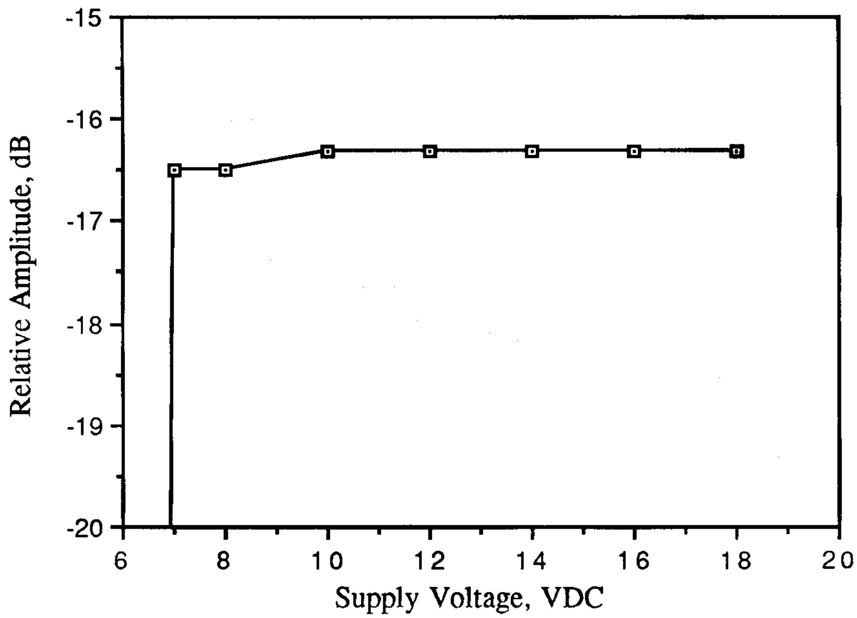

Figure 6.1. Relative emission at fundamental vs. supply voltage.