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Measured Radio Frequency Emissions
From

Fujitsu 76 GHz Adaptive Cruse Control Radar
Model: 271000-2310

Report No. 415031-174
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Summary
Tests for compliance with FCC Regulations, according to Part 15.253, and with Industry Canada Regulations, RSS-210, were performed on Fujitsu 76 GHz Adaptive Cruse Control Radar. In testing performed on April 17 and 18, 2003, the device tested met the emissions at fundamental by 28.2 dB, at harmonics by 52.3 dB, and spurious by 3.8 dB.

As for RF Health Hazard levels, maximum level measured was 0.04 mW/cm2 at the surface of the radome.

1. Introduction

Fujitsu 76 GHz Adaptive Cruse Control Radar was tested for compliance with FCC Regulations, Part 15, adopted under Docket 87-389, April 18, 1989, and with Industry Canada RSS-210, Issue 5, dated November 10, 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" 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)	X	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)	X	Hewlett-Packard

3. Configuration and Identification of Device Under Test

The Device Under Test (DUT) was a 76 GHz Short Range Radar. It is a Tx/Rx 535 kHz switched FM device and uses a triangular frequency chirp at 380 Hz to provide range information. Mechanical antenna scanning at 5 Hz is used to obtain target angular resolution. The RF power source is a 4 mW oscillator; there is also another microwave source at 9.6 GHz. The DUT is a basic radar unit; additional signal processing and analyses are done by an other processors on a vehicle. When installed on a vehicle, the device 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 with a single connector in the back that connects to another (digital) module on a vehicle. For testing, a laptop was used to control the format of modulation. This included: (a) normal mode, (b) CW with 535 kHz switching, (c) FM only, (d) CW only, plus others that were not used in these tests. Nominal operating voltage is 13.8 VDC; this was supplied by a laboratory style power supply.

The DUT was manufactured by Fujitsu Ten Limited; 2-28, Gosho-dori 1-chome; Hyogo-Ku, Kobe 652-8510; Japan. It is identified as:

Fujitsu 76 GHz Adaptive Cruse Control Radar
Model: 271000-2310
S/N: IA039A0309200030 (stdandard unit)
S/N: IA039A030920001M (fixed antenna unit)
FCC ID: BAB271000-231
CAN: 2024B-271231

Two devices were provided: one in a standard model, and the other with antenna scanning disabled mechanically. The latter was used for most of the measurements presented.

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: FCC: 15.253; IC: RSS-210, 6.6) --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 (FCC: 15.33, 15.35, 15.109; IC: RSS-210, 7.3) -- 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 is not a commonly tested device, some of the data that were taken and reported are for understanding of the operation of the device. Also many tests were repeated to verify the procedure and the measurement integrity. We started with measurements at the fundamental (76.3 GHz) and recorded number of plots. 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 76.273 GHz to 76.385 GHz, with 110 MHz BW. Note the maximum reading is about –22.5 dBm, which for a chirp radar is also a peak value (since 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=1 MHz, zero span.
The pulses occur as the frequency sweeps through the receiver fixed at 76.30 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 2.667 ms or 370 Hz.

Figure 5.3. Time response at set frequency due to the antenna scan. RBW=1 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 for fixed CW emission. RBW=1 MHz, VBW=3 MHz; 3 meters. For this measurement the DUT was set in CW mode. Note, here we measured –21.55 dBm as compared to –22.5 dBm for the scanning mode. The lower value could be attributed to not being at the center of the beam, since with modulation, the beam may not be stationary.

Figure 5.5. Tx/Rx switching. RBW=2 MHz, VBW=3 MHz; 3 meters.
To minimize direct (unwanted) signal entering the receiver, the Tx/Rx function is diplexed at 535 kHz. This plot shows that at –20dB, the ON/OFF ratio is 2/3 or 0.667.

Figure 5.6. FM/ CW ratio. RBW=1 MHz, VBW=3 MHz, zero span; 3 meters.
In normal operation, the device transmits FM for 44.3 ms, followed by CW for 55.7 ms. Both, the FM and CW are switched by the 535 kHz Tx/Rx diplexing.

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 E_3(dBμV/m) is computed from

$$E_3(\text{dB}\mu\text{V/m}) = 107 + Pr + K_a - Kg + K_e$$

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

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

and we note that

60 μW/cm2 = -12.2 dBm/cm2
1000 pW/cm2 = -60.0 dBm/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 mixer conversion factor.

The results are given in Tables 5.1 and 5.2. There we see that the DUT met the limits at fundamental by 28.2 dB, at harmonics by 53.2 dB, and at spurious by 3.8 dB.

6. Other Measurements and Computations

6.1 Peak-to-Average Ratio
The DUT is designed to operate in a 535 kHz pulsed Tx/Rx mode, plus FM (chirp) and antenna scan. If one would be observing (measuring) the signal at a stationary point with the receiver able to see the entire bandwidth, the signal would be pulsed due to 535 kHz Tx/Rx swithing rate superimposed (multiplied) by the 5 Hz antenna scan illumination.

From Figure 5.5 we deduce that at -20 dB level the ON to OFF time is 2 to 1. This gives ratio of 2/3, corresponding to -3.6 dB. Then there is the fractional presence of signal due to the narrow antenna beam scan, In Figure 5.3 one can see a 200 ms period and if the observation point is near the edge of the scan, then in a 100 ms window there are two scan-byes each some 17 ms long. One can get a better assessment for illumination time by taking the beamwidth (2.1 deg.) and dividing it by the scan angle (16 deg.). Thus Peak-to Average Ratio is

$$2/3 \times 2(2.1/16) = 0.29 \text{ or } -15.3 \text{ dB}$$

6.2 Correction for Pulse Operation (Ref. 15.35)
Use maximum allowed by 15.35, i.e. –15.3 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" (76.3 GHz) as the supply voltage was varied from 6 to 18 VDC. Figure 6.2 shows the emission power variation. Current at 13.6 VDC was 330 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 spectrum analyzer. The analyzer was set to RBW=1 MHz, VBW=3 MHz for peak power detection. We also measured power received with a (average) power meter. In case the 1 mW/cm2 limit is exceeded, the maximum distance from the DUT would be 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 0.10 mW on the spectrum analyzer and 0.023 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

$$p(\text{mW/cm2}) = P/A_{eff} = 0.10 \text{ mW}/ 2.23 \text{ cm2} = 0.04 \text{ mW/cm2}$$

and, hence, meets the 1.1307, 1.1310, 2.1091, and 2.0193 requirements. Note, this is a peak value; the average is lower.

6.6 Sample Field Computations

FUNDAMENTAL

Refer to: (a) Table 5.2 (f >= 40 GHz); line 3; p. 15.
(b) Section 5.2; Figure 5.4, peak power measurement; p. 11.
(c) Table 4.1; limit; p. 3; (60 µW/cm^2 = -12.2 dBm/cm^2)
(d) Section 6.1; peak-to-average ratio, p. 6; (15.3dB)

The approach is to follow the standard equations for computing the field, i.e. dB(µV/m), and then convert to power density. See equations and conversion factors in Section 5.3, p. 5 of the report.

To compute the field strength we use:µ

E3 dB(µV/m) = 107 + Pr + Ka - Kg + Ke
= 107 – 21.6 + 45.3 + 0 – 15.3
= 115.4 dB(µV/m)
= -40.4 dBm/cm^2

The limit is 60 µW/cm^2 = -12.2 dBm/cm^2

SPURIOUS

Here we present computation for the reference signal emission at 9.57 GHz.

Refer to: (a) Table 5.1 (f < 40 GHz); line 6; p. 14.
(c) Table 4.1; limit; p. 3; (54 dB(µV/m))

Using the same wave equation as above:

E3 dB(µV/m) = 107 + Pr + Ka - Kg + Ke
= 107 – 49.3 + 29.5 – 37 + 0
= 50.2 dB(µV/m)

The limit is 54.0 dB(µV/m).

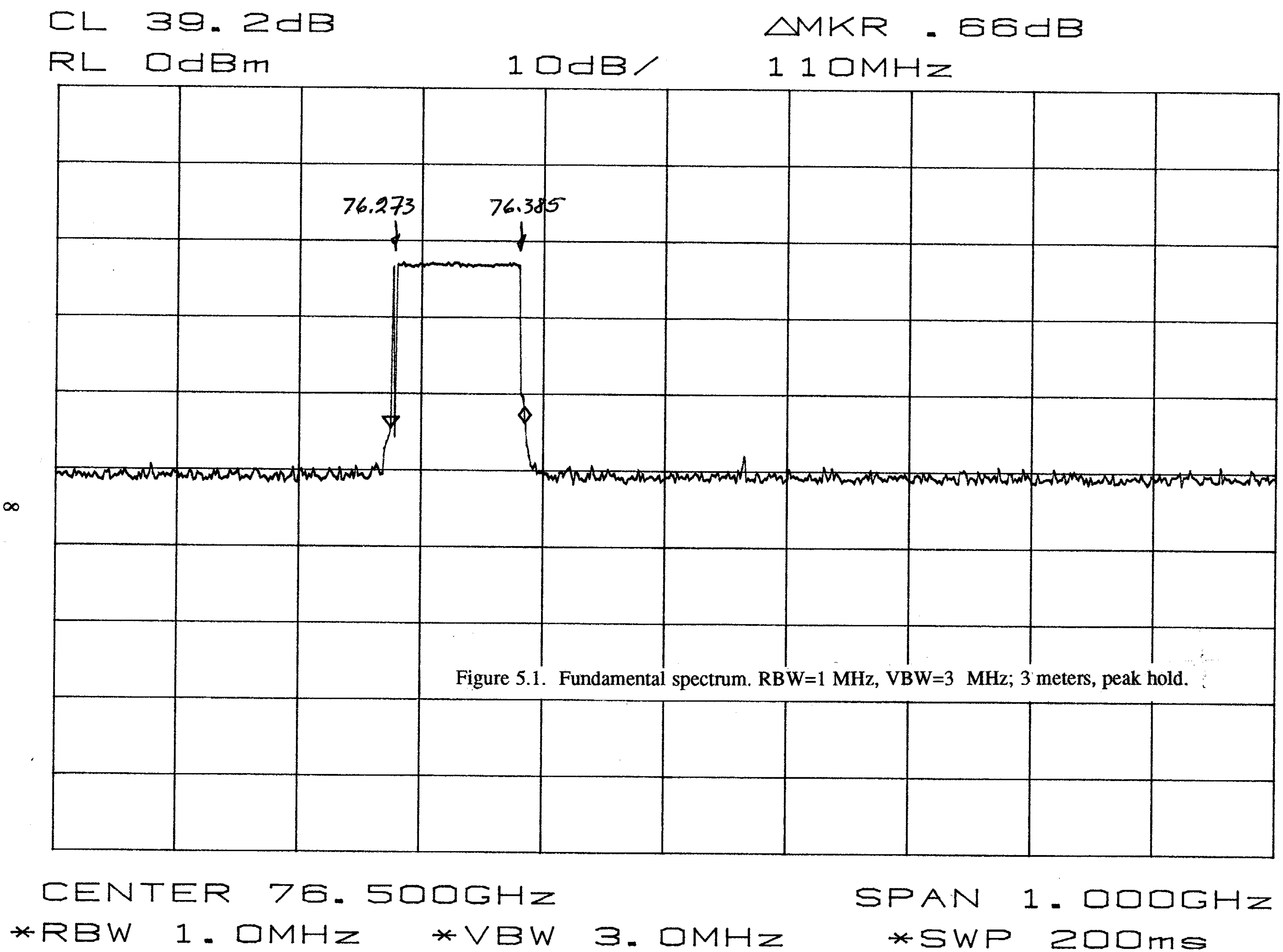

Figure 5.1. Fundamental spectrum. RBW=1 MHz, VBW=3 MHz; 3 meters, peak hold.

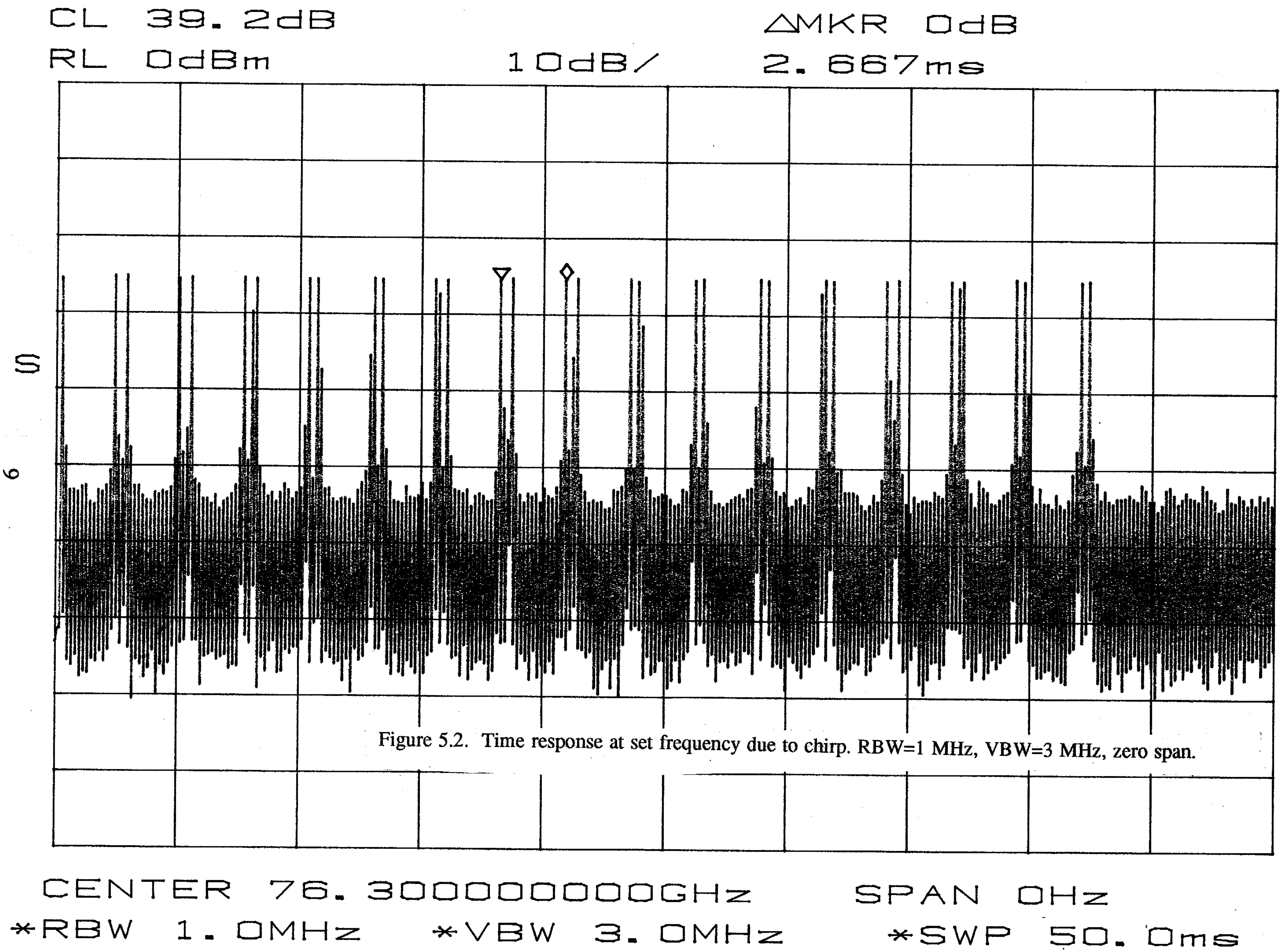

Figure 5.2. Time response at set frequency due to chirp. RBW=1 MHz, VBW=3 MHz, zero span.

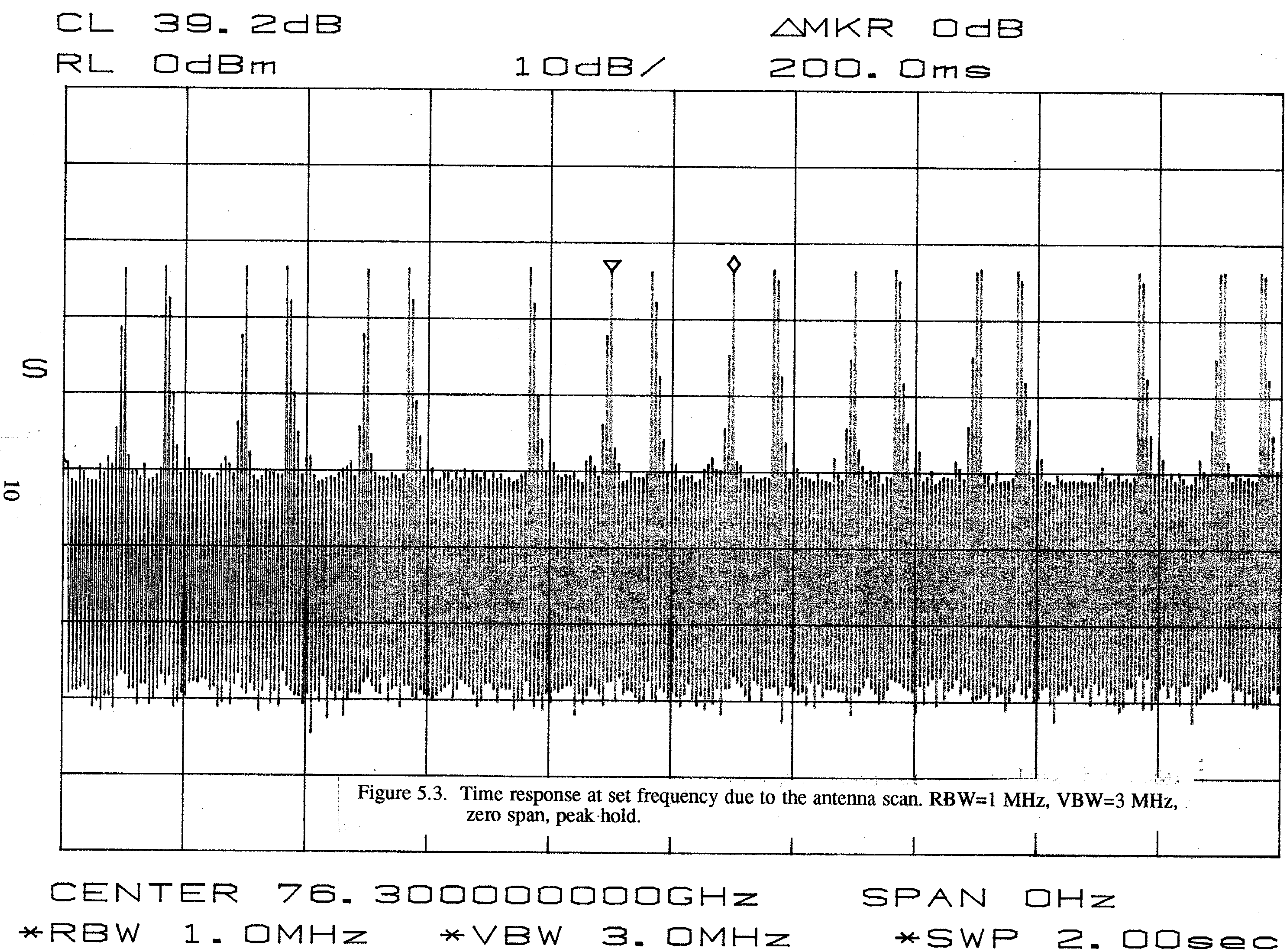

Figure 5.3. Time response at set frequency due to the antenna scan. RBW=1 MHz, VBW=3 MHz, zero span, peak hold.

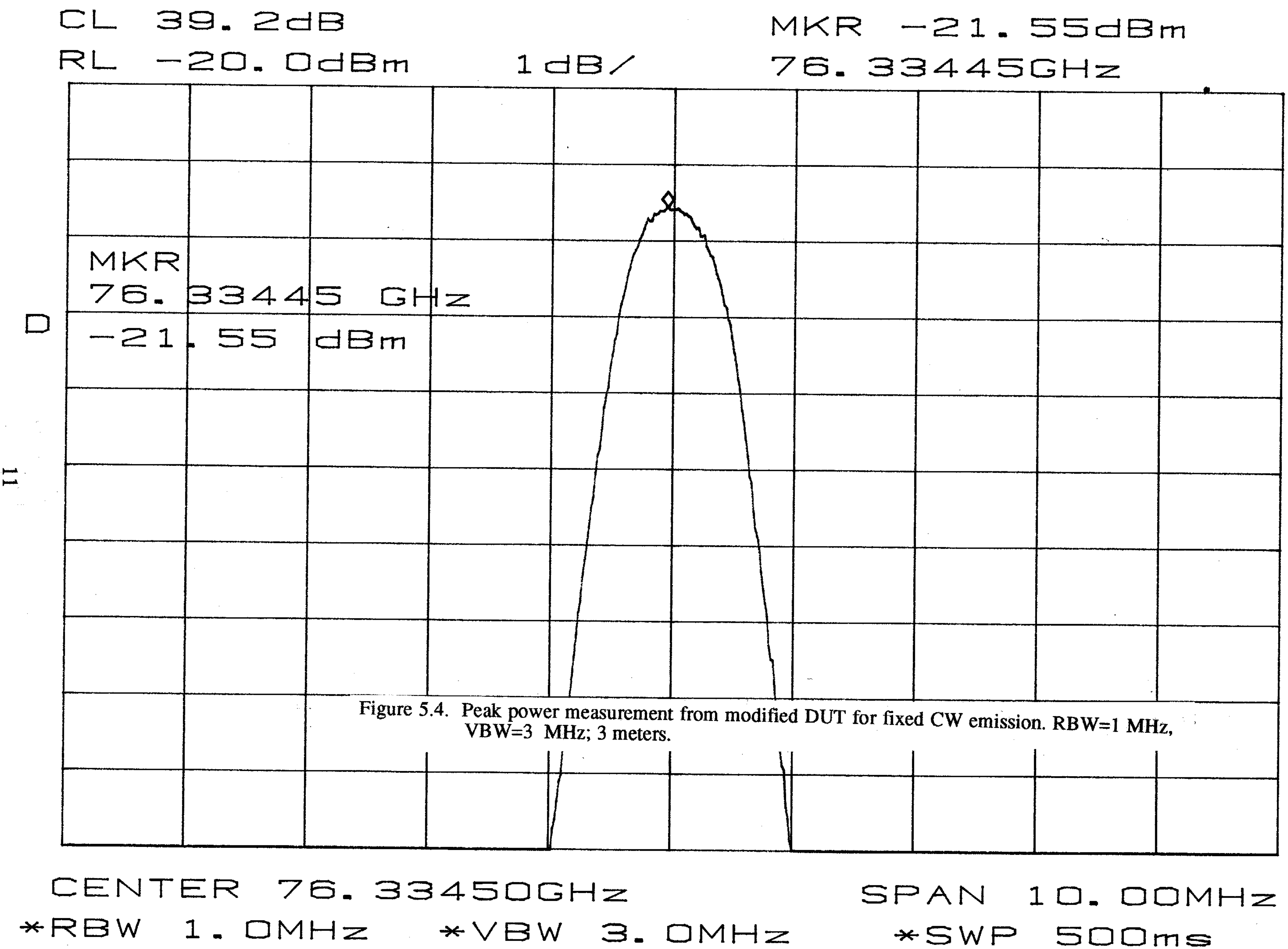

Figure 5.4. Peak power measurement from modified DUT for fixed CW emission. RBW=1 MHz, VBW=3 MHz; 3 meters.

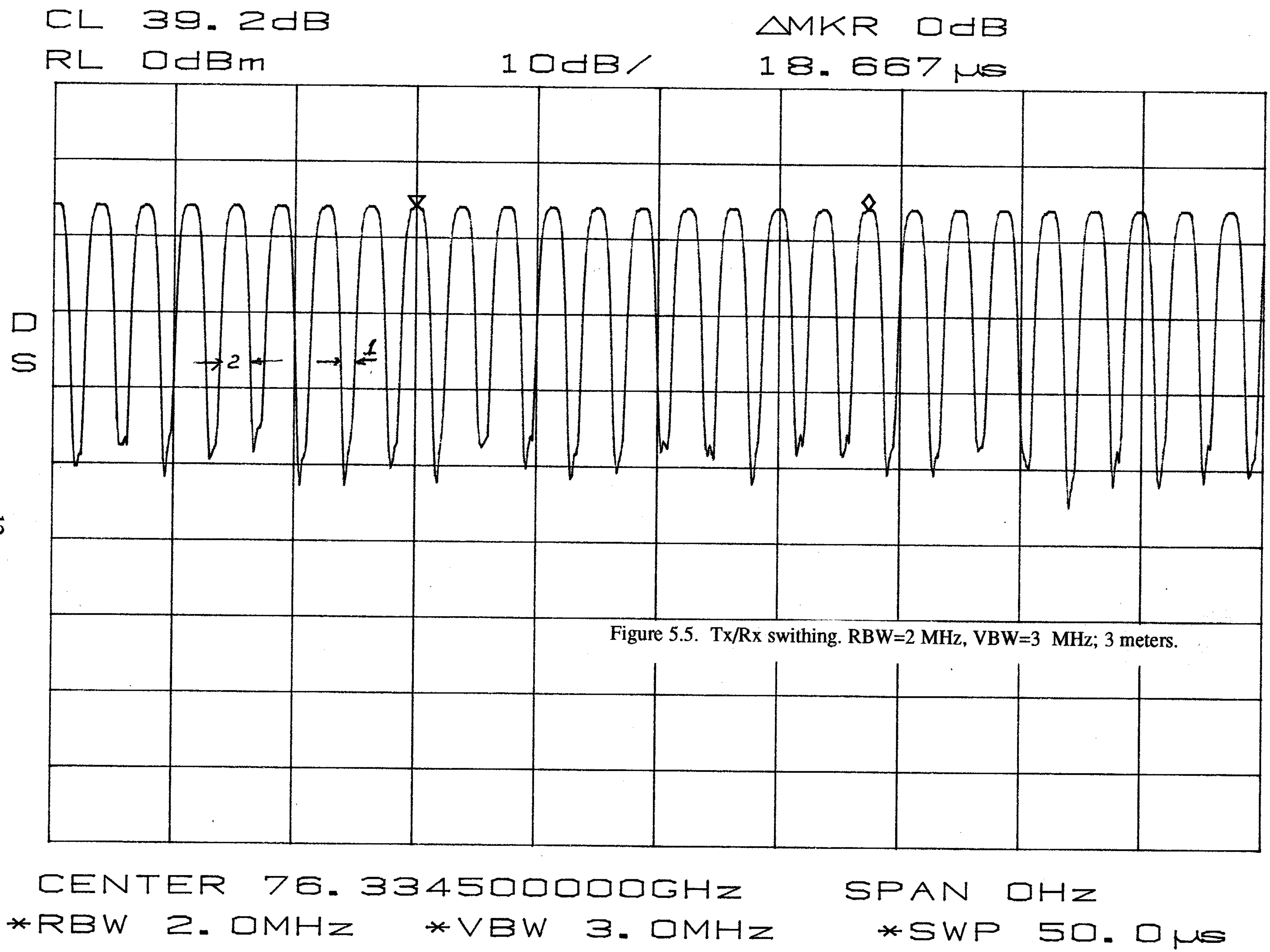

Figure 5.5. Tx/Rx swithing. RBW=2 MHz, VBW=3 MHz; 3 meters.

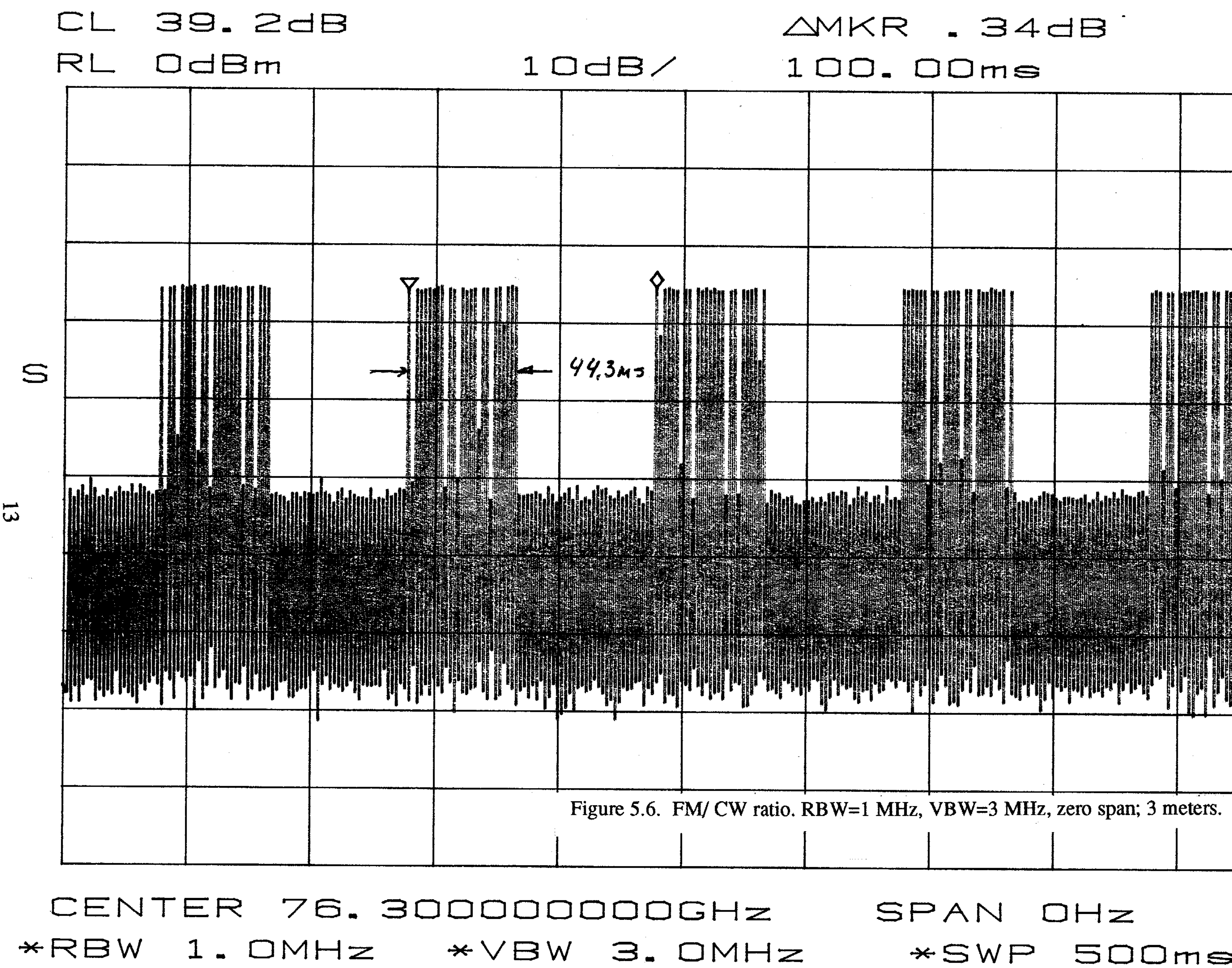

Figure 5.6. FM/ CW ratio. RBW=1 MHz, VBW=3 MHz, zero span; 3 meters.

Table 5.1 Highest Emissions Measured (f<40 GHz)

Microwave Radiated Emissions													Fujitsu 77 GHz 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	.03 - 1	Bic		3.00			-80.0	20.0	28.1	18.9	40.0	21.1	Noise, worst case
2	1 to 2	Horn	10.0	1.00	-60.0	0.14	-79.0	21.5	28.1	21.4	54.0	32.6	Noise, Pk (1,3,4,5,8)
3	2 to 4.5	Horn	5.0	1.00	-69.0	0.29	-88.0	26.0	25.0	20.0	54.0	34.0	Noise, Pk (1,3,4,5,8)
4	4.5 to 6	C-horn	21.6	1.00	-59.0	1.55	-72.3	24.7	31.0	28.4	54.0	25.6	Noise, Pk (1,3,4,5)
5	6 to 8.6	XN-hrn	28.9	1.00	-56.0	3.89	-75.1	25.3	31.0	26.2	54.0	27.8	Noise, Pk (1,3,4,5)
6	8.6to13	X-horn	19.4	3.00	-55.0	2.51	-55.0	28.5	31.0	49.5	54.0	4.5	Noise, Pk (1,3,4,5)
7	9.57	X-horn	19.4	3.00	-49.3	3.19	-49.3	29.5	37.0	50.2	54.0	**3.8**	Signal, Pk (5)
8	13to18	Ku-hrn	15.2	0.25	-47.2	2.31	-87.5	29.3	17.0	31.8	54.0	22.2	Noise, Pk (1,3,4,5)
9	18to26	K-horn	10.2	0.25	-53.8	2.11	-94.0	33.2	0.0	46.2	54.0	7.9	Noise, Pk (1,3,4,5)
10	26to40	Ka-hrn	6.9	0.25	-82.5	3.07	-124	36.0	0.0	18.9	54.0	35.1	Noise, Ave (1,2,3,4,5)
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 36.5 dB IF amp were used

(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		Not applicable											
3													
4													
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. 4/17,18/03; U of Mich.

Table 5.2 Highest Emissions Measured (f>=40 GHz)

Microwave Radiated Emissions

Fujitsu 77 GHz 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	-65.4	4.80	-109	41.0	0.0	-116.4	-62.2	54.2	Noise, ave. meas. (1-5)
2	76.4	W-horn	2.5	3.00	-21.6	7.30	-21.6	45.3	0.0	-40.4	-12.2	**28.2**	From Pk meas. (2-6)
3	77-125	W-horn	2.5	0.25	-61.8	9.10	-105	46.4	0.0	-107.4	-62.2	45.2	Noise, av. meas. (1-5,7)
4	152.8	G-horn	1.3	0.25	-73.5	14.60	-117	51.3	0.0	-114.5	-62.2	52.3	Noise, av. meas. (1-5,7)
5	229.2	G-horn	1.3	0.25	-72.5	22.00	-116	54.0	0.0	-121.4	-60.0	61.4	Noise, av. meas. (1-5,7)
6	to 231	G-horn	1.3	0.25	-72.5	22.00	-116	54.0	0.0	-121.4	-60.0	61.4	Noise, av. meas. (1-5,7)
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) 15.3 dB peak-to-average correction factor included in P

(7) Extermal mixer, LO, and IF amp were used.

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	Not applicable												
3													
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. 4/17,18/03; U of Mich.

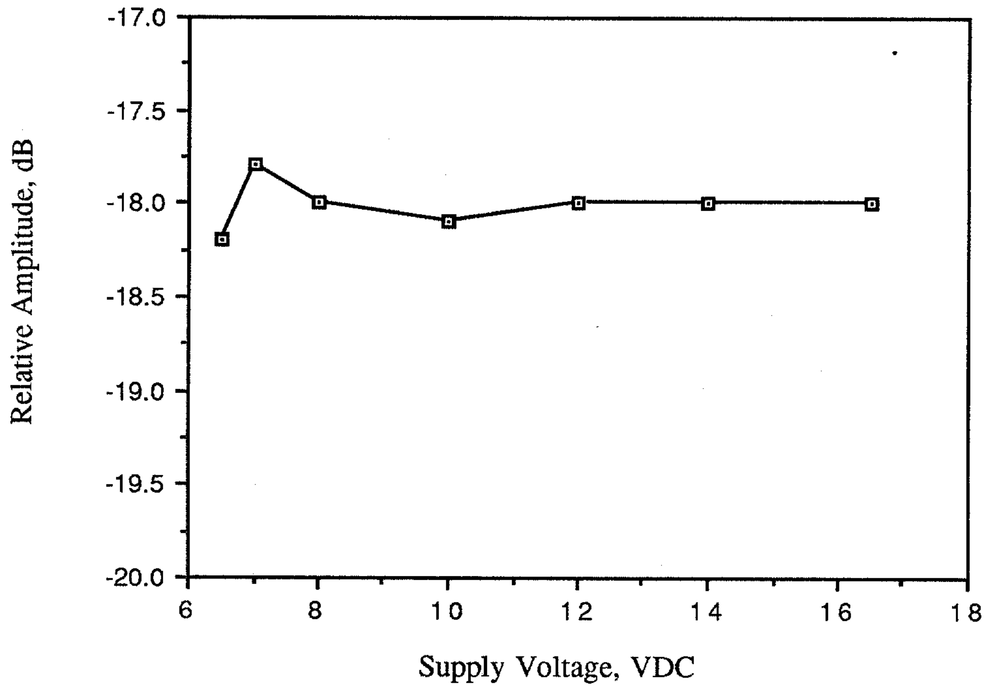

Figure 6.1. Relative emission at fundamental vs. supply voltage.