APPENDIX A

24 GHz Short Range Radar for Automotive Applications

Validation of Test Procedures for Measuring the True Mean Power and Occupied Bandwidth of the Siemens VDO Vehicular Radar in Frequency Hopping Mode

1. Executive Summary

In its UWB Report and Order, the FCC made it clear that frequency hopping systems seeking designation as UWB devices are to be measured with the hop stopped. *UWB Report and Order* at ¶ 32.[1] Application of such a measurement restriction to the Siemens VDO pulsed frequency hopping vehicular radar prohibits the device from satisfying the 500 MHz minimum bandwidth requirement established in the UWB rules because the widest instantaneous bandwidth employed by the Siemens VDO device is approximately 20 MHz.

In the UWB Report and Order, the FCC indicated that it was requiring measurement of frequency hopping systems with the frequency hop stopped because no measurement procedures had been proposed or established for frequency hopping devices. *UWB Report and Order* at ¶ 32. It also indicated that the interference aspects of such devices had not been evaluated based on the different measurement results that would be obtained from measurements taken with the frequency hop active. *Id.* The following analysis demonstrates that accurate measurements of the average power of the Siemens VDO vehicular radar with the frequency hop active can be obtained through: (1) the use of generally accepted theoretical mathematical models and (2) the use of a spectrum analyzer equipped with a root mean square ("RMS") detector. The calculations and measurements presented and discussed below in section 3 and in the annex to this paper confirm that the Siemens VDO vehicular radar complies with the average and peak power limits imposed by the FCC on UWB vehicular radars operating in the 24 GHz band.

Placed in context, this analysis demonstrates that the measurement procedures imposed by the FCC for pulsed or impulse technologies (i.e., a conventional spectrum analyzer equipped with an RMS detector) can also be used to accurately and reliably measure pulsed frequency hopping systems such as the Siemens VDO vehicular radar with the frequency hop active. Moreover, the measurements taken with the use of the RMS detector show that the Siemens VDO vehicular radar complies with the relevant UWB limits. Because an adequate procedure exists for accurately measuring the Siemens VDO vehicular radar, and measurements taken demonstrate compliance with the relevant UWB limits, the Commission should be comfortable accepting measurements of the Siemens VDO vehicular radar with the frequency hop active in support of Siemens VDO's effort to secure approval of its vehicular radar as a UWB device.

In addition to demonstrating that accurate measurement can be taken with the frequency hop active, this paper also explains that the use of a 1 ms or less averaging time, as required by Section 15.521(d), results in an artificially high RMS reading.

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[1] In applying this requirement, the FCC referenced Section 15.31(c), which requires the sweep of swept frequency equipment to be stopped for measurement purposes. Although not codified in the FCC's rules, the Office of Engineering and Technology has previously issued measurement guidelines for frequency hopping systems, suggesting that the hop should be stopped when taking certain measurements. *See Filing and Measurement Guidelines for Frequency Hopping Spread Spectrum Systems*, Public Notice, 15 FCC Rcd 18624 (2000). The Public Notice provided "information on the measurement techniques that have been accepted in the past for equipment authorization purposes," but noted that "the FCC has no established test procedure for frequency hopping spread spectrum devices. Such tests are to be performed following the general guidance in Section 15.31 of the FCC Rules, using good engineering practice."

More accurate and more relevant results can be achieved by employing an averaging time on the order of several milliseconds, consistent with the typical averaging times of EESS satellites operating in the 23.6 – 24.0 GHz band. Finally, in section 4, this paper suggests procedures for measuring the UWB bandwidth, as no such procedures were identified in the UWB Report & Order.

2. System Description

The Siemens VDO vehicular radar consists of several radar modules. These modules are designed to be mounted along the outer contour of an automobile in order to provide a complete 360° observation zone for both safety and comfort applications. Following is a discussion of the device's RF Circuit Conceptual Design and bands of operation.

A. RF Circuit Conceptual Design

The device's high frequency microwave front-end is designed to achieve maximum flexibility for the different applications for which it was designed, including Parking Aid, Precrash Detection, Blind Spot Surveillance and Stop&Go features for ACC system extension. This flexibility is provided through the use of a microcontroller with dedicated hardware capable of controlling the microwave circuit in different ways. Basic operation principles are a classical Doppler (or CW) mode for precise speed measurements and a pulsed chirp mode similar to spread spectrum frequency hopping systems. Depending on the prevailing application, the applied pulse width and frequency hopping bandwidth of the Siemens VDO vehicular radar can be varied consistent with the range presented in the RF specification contained in Table 1.

Figure 1 presents the basic design of the microwave front-end.

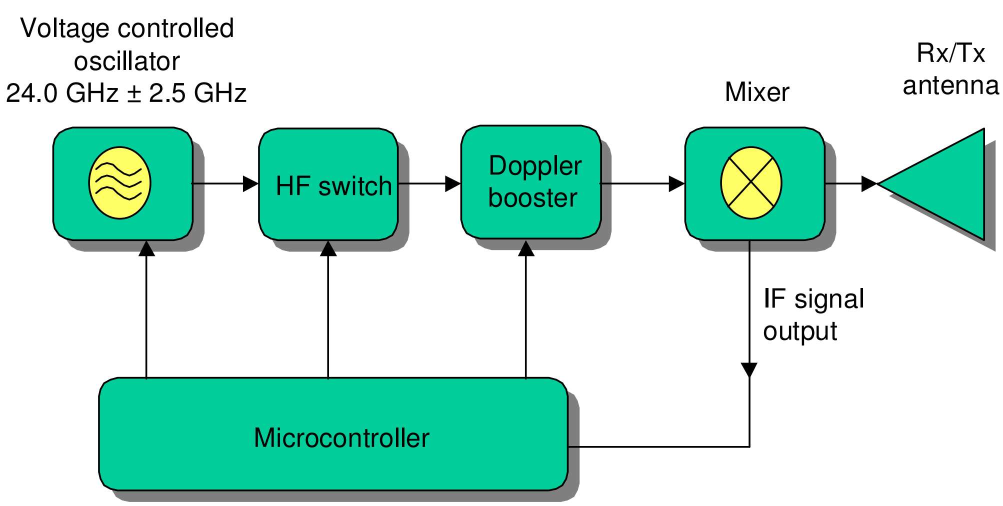

Figure 1: **Microwave front-end schematic diagram**

This design makes it possible for both the carrier and the frequency spread induced by the HF switch to be tuned independently according to the requirements of a

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particular vehicle application. The operating characteristics of the Siemens VDO vehicular radar, including its peak and mean power limits, are listed in Table 1. Table 2 shows the operating parameters for two different typical UWB operational modes of the Siemens VDO vehicular radar. For comparison, the parameters of a typical pulsed UWB vehicular radar are also added in Table 2.

PARAMETER	DEF	MIN	TYP	MAX	UNIT	REMARKS
Operating Characteristics						
Nominal operating frequency	F_{norm}	24.075	24.125	24.175	GHz	For Doppler in ISM Band
Frequency hopping bandwidth	B_{FHSS}	0.5	1	5	GHz	symmetrical or asymmetrical around F_{norm}
Avg. power EIRP	P_{AVG}	-40		20	dBm	depends on operational mode (Doppler, narrowband or B_{FH})
Peak power EIRP	P_{PK}	-10		20	dBm	depends on operational mode (Doppler, narrowband or B_{FH})
Power Spectral Density Mean	PSD_{mean}			-101.25	dBm/Hz	500 µV/m according to 47 CFR § 15.209
Power Spectral Density Peak	PSD_{peak}			0	dBm/50MHz	within B_{FH} @50 MHz RBW
Pulse Width	T_{pw}	5		300	ns	
Duty Factor	k_{duty}	0/13		30	dB	FH spreading not included 0 for Doppler in ISM Band
Pulse Repetition Frequency	f_{PRF}	10		1000	kHz	
Frame time period	T_{fr}	2	5	20	ms	
Blanking time period	T_{blk}	0		10	ms	used for ISM fixed carrier F_{norm} Doppler measurement
hopping channel carrier frequency separation	Δf_i	1	10	50	MHz	

Table 1: **Limiting values for Characteristic Parameters of the Siemens VDO pulsed FH vehicular radar.**

Design Parameters	Pulsed FH Example 1	Pulsed FH Example 2	Pure Pulse UWB-System	Remarks
Peak Power P_{peak}	6 dBm	-8 dBm	20 dBm	EIRP over entire BW
Pulse duration Δt	10 ns	50 ns	0.5 ns	Measured at 50% marks
Pulse Repetition PRF	1 MHz	1 MHz	2.5 MHz	
Pulse related Duty Cycle DC_{pulse}	0.01 -20 dB	0.05 -13 dB	0.00125 -29 dB	DC_{pulse} is the duty cycle issued by the pulsed on_off gating and is equivalent to peak to mean power ratio over entire bandwidth
$BW_{pulse\text{-}spread}$ [2]	100 MHz	20 MHz	2 GHz	Spreading of carrier due to pulse width; defined by first zero crossing of sinc envelope
$BW_{carrier\_hop}$	1 GHz	1 GHz	-	$BW_{carrier\_hop}$ is the total hopping frequency range for the carrier
BW_{occ}	1.1 GHz 90.4 dB_Hz	1.02 GHz 90.1 dB_Hz	2 GHz 93 dBm_Hz	overall occupied bandwidth for both frequency hopping and pulse spreading effects
Mean Power P_{mean}	- 14 dBm	- 21 dBm	-9 dBm	EIRP over entire BW
PSD	-104.4 dBm/Hz	- 111.1 dBm/Hz	-102 dBm/Hz	PSD = P_{mean} - $BW_{occ\_in\_dB}$
PSD	- 44.4 dBm/ MHz	- 51.1 dBm/ MHz	-42 dBm/ MHz	In 1 MHz RBW
$PDCF_{in\ 50\ MHz}$	6.0 dB	-	32 dB	20log(BW_{pulse_spread} / 50 MHz)
Peak Power $_{in\ 50\ MHz}$	0 dBm	-8 dBm	-12 dBm	P_{peak} – $PDCF_{in\ 50\ MHz}$
Mean Power $_{in\ 50\ MHz}$	- 27.4 dBm	- 34.1 dBm	-25 dBm	PSD+10log(50 MHz)
PDCF $_{in\ 3\ MHz}$	30.5 dB	16.5 dB	56.5 dB	20log(BW_{pulse_spread} 3 MHz)
Peak Power $_{in\ 3\ MHz}$	-24.5 dBm	-24.5 dBm	-36.5 d Bm	P_{peak} – $PDCF_{in\ 3\ MHz}$

Table 2: **Typical values for characteristic parameters of the Siemens VDO vehicular radar. For comparison purposes, the parameter values of a typical pure pulsed UWB vehicular radar are added. Green shaded values represent the peak and average power limits imposed by the FCC**

[2] For simplicity, a bandwidth of 1/ Δt is assumed.

As Table 2 makes clear, the operational parameters of the Siemens VDO vehicular radar are consistent with both the peak and the average power limits imposed for UWB vehicular radar transmitters operating in the 24 GHz band.

B. Frequency Bands – Transmitted Spectrum

As described above, the Siemens VDO vehicular radar is capable of operating in both pulsed FH (UWB) and Doppler mode. The discussion and analysis presented below focuses solely on the pulsed FH (UWB) mode.

The Siemens VDO vehicular radar emits signals with an instantaneous bandwidth of several MHz. Typically, within 4 milliseconds ("ms") the entire bandwidth of 1 GHz is filled up in its entirety, which is a characteristic feature of the spectrum emitted by the Siemens VDO system in pulsed FH operation mode. Moreover, the intentional emissions of the Siemens VDO vehicular radar are totally contained within the 22-29 GHz band allocated to vehicular radar systems in the FCC's UWB rules.

In the time domain the emissions of the Siemens VDO vehicular radar operating in the pulsed FH mode are burst-like. This burst-like character is depicted below in Figure 2, where the power emitted at a fixed frequency is plotted as a function of time (i.e., the spectrum analyzer is set in zero span mode).

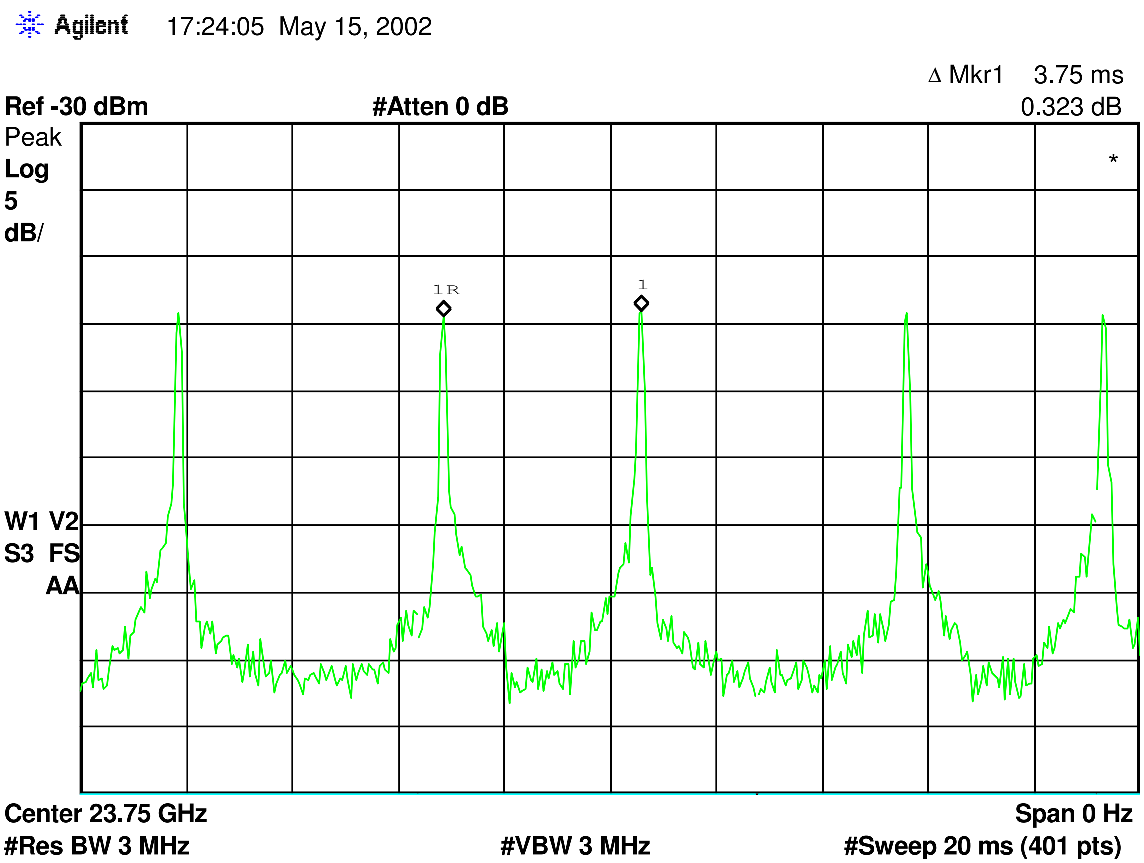

Figure 2: Emitted power at a fixed frequency plotted as function of time (spectrum analyzer in zero span mode)

Figure 3 below shows a zoom into a single burst. The individual short pulses every 10 µs, corresponding to a pulse repetition frequency of 100 kHz, are clearly resolved.

In the UWB Report and Order, the FCC indicated that no higher interference potential is expected due to an UWB device operating in a burst mode, as long as both the peak and average emission limits are not exceeded. *UWB Report Order* at ¶ 243. Therefore, since the Siemens VDO vehicular radar complies with both the peak and average power emission limits applicable to UWB vehicular radars, it has no greater interference potential than other UWB transmitters using a burst-like modulation technique.

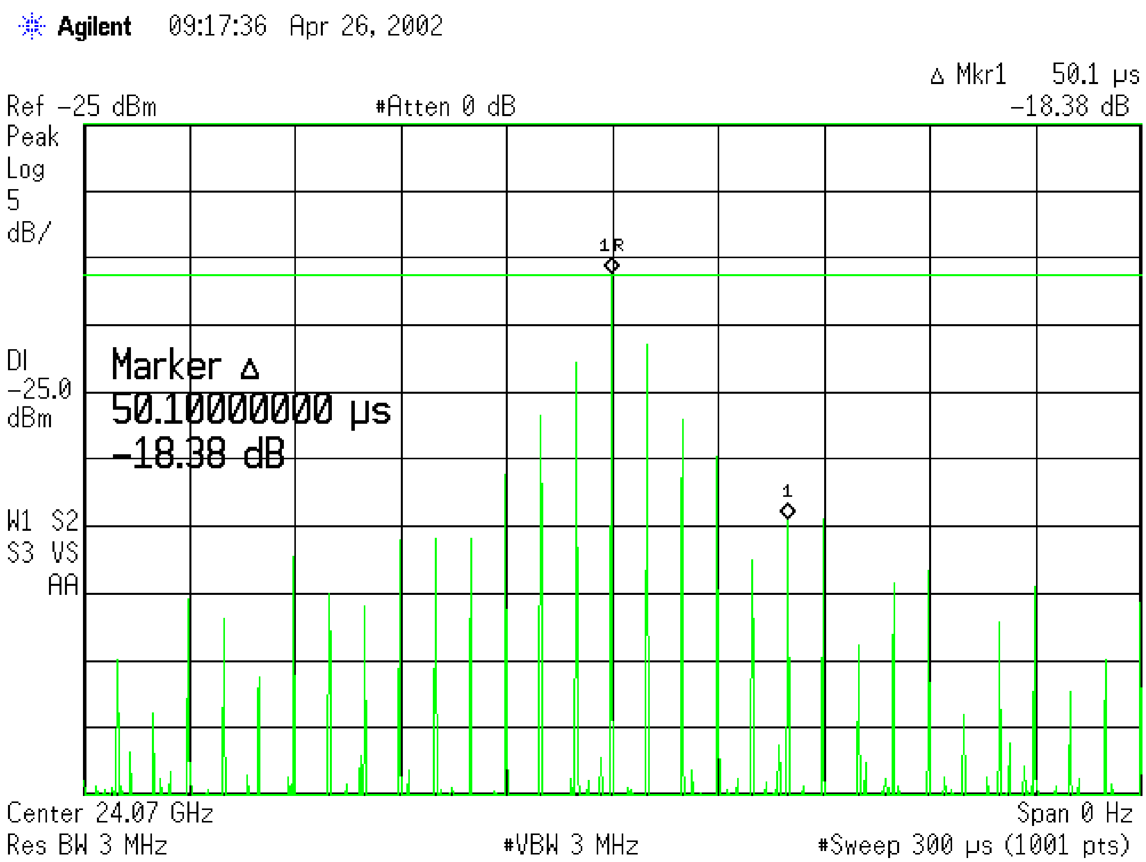

Figure 3: Time dependence of emissions from Siemens VDO vehicular radar (zoom into a single burst).

3. Power Measurement Procedure

As noted above, the main reason provided by the FCC for requiring that measurements of pulsed FH devices be taken with the hop stopped was that there were no proposals for measurement procedures with the frequency hop active. Although the FCC appears to be under the belief that no procedure has thus far been developed for measuring the average power emitted by a pulsed FH system with the hop active, the procedure presented in the UWB Report and Order for measuring the peak emission power is, in fact, also well suited for measuring pulsed FH systems with the hop active.

The FCC's UWB rules require the measurement of a device's true RMS average field strength over a bandwidth of 1 MHz for all frequencies above 960 MHz. *See* 47 C.F.R. § 15.521(d); Appendix F. Moreover the UWB Report & Order states:

> The RMS average measurement is based on the use of a spectrum analyzer with a resolution bandwidth of 1 MHz, an RMS detector, and a 1 millisecond or less averaging time. If pulse gating is employed where the transmitter is quiescent for intervals that are long compared to the nominal pulse repetition interval, measurements shall be made with the pulse train gated on. Alternative measurement procedures may be considered by the Commission. *Id.*[3]

The same procedure set forth in Section 15.521(d) can be used to measure pulsed FH devices such as the Siemens VDO vehicular radar with the frequency hop active. As demonstrated below, application of this procedure results in a true average PSD that coincides almost precisely with theoretically calculated values. Moreover, this measurement procedure shows that the emitted power of the Siemens VDO vehicular radar is spread out equally on average over the device's entire occupied bandwidth.

A. Measurement Procedure: Average Power Spectral Density

In the following measurements the average power results of a Siemens VDO pulsed FH vehicular radar sensor prototype will be presented. These results were obtained using a Rhode & Schwarz spectrum analyzer that incorporates a RMS detector. According to the system description provided by Rhode & Schwarz, the RMS detector always measures the signal power of the relevant device, independent of its signal type (CW-carrier, modulated carrier, noise or pulsed signal). [4]

Measurement Setup

- Distance between UWB-transmitter and receiver antenna: 1 m
- Height of transmitter and receiver antenna above metallic ground: 1 m
- Receiver antenna gain: 20 dB
- Receiver: Rhode & Schwartz spectrum analyzer type FSEM 30
- Cable losses (antenna to spectrum analyzer) ca. 3 dB

With the antenna gain of +20 dB, cable losses of 3 dB and a free space attenuation within 1 m of ca. 60 dB, the spectrum analyzer readings have to be corrected by a factor of 43 dB, i.e. a reading of –43 dBm corresponds to a emission value of 0 dBm.

Note About Measurement Procedures

The measurements presented below are intended to demonstrate that the procedure described in the UWB Report & Order for measuring the average power of UWB transmitters in general can also be used to accurately measure pulsed FH systems

[3] Siemens VDO notes that the spectrum analyzer operating manuals indicate that for RMS measurements the integration time for each frequency point (bucket) should be at least 3 to 5 times higher than the nominal repetition interval.

[4] In the annex to this report similar measurement results with another spectrum analyzer from Agilent that also incorporates a RMS detector are presented for comparison.

with the frequency hop active. However, because the average power emitted by a Siemens VDO vehicular radar is very low and no microwave amplifier was available, the emitted peak power EIRP was increased by approximately 20 dB above the limits imposed on UWB transmitters in order to conduct the measurements. Nevertheless, all relevant conclusions concerning the applicability of the measurement procedure can be drawn from the data obtained by these measurements.

B. Measurement Results

1. Pulsed FH with 1 GHz hopping bandwidth, 50 ns pulse width and 200 kHz PRF

Figure 4 depicts the spectrum analyzer readings obtained by measuring the Siemens VDO vehicular radar in a typical pulsed FH operation mode with a 1 GHz occupied bandwidth, a pulse width of 50 ns and a PRF of 200 kHz. The peak power reading measured in a RBW of 3 MHz is –46.8 dBm (magenta line). The measured RMS average PSD within a 1 MHz resolution bandwidth is approx. –84 dBm.
Starting with the measured peak power, the average power can be derived theoretically:

		Remark
Peak Power in 3 MHz	-46.8 dBm/3 MHz	Measured value
PDCF in 3 MHz	-13 dB	20log(1.5*50 ns*3 MHz)[5]
Peak power over entire BW: P_{Peak}	-33.8 dBm	$P_{Peak\ in\ 3\ MHz}$-$PDCF_{3\ MHz}$
DC_{pulse}	-20 dB	10log(Pulse width*PRF)
DC_{hop}	-30 dB	10log(1 MHz/1 GHz)
DC[6] $_{blanking}$	-1.3 dB	10log(3 ms/(3 ms+1 ms))
$PSD_{1\ MHz}$ (theoretically expected)	-85.1 dBm/1 MHz	$P_{Peak}+DC_{pulse}+DC_{hop}+DC_{blanking}$

The absolute readings, taking into account the antenna gain, free space losses and cable losses, can be calculated by adding the correction factor of 43 dB:

		Remark
Peak Power in 3MHz	-3.8 dBm/3MHz	Measured value
PDCF in 3MHz	-13dB	20log(1.5*50ns*3MHz)
Peak power over entire BW: P_{Peak}	+9.2dBm	$P_{Peak\ in\ 3MHz}$-$PDCF_{3MHz}$
DC_{pulse}	-20dB	10log(Pulse width*PRF)
DC_{hop}	-30dB	10log(1MHz/1GHz)
$DC_{blanking}$	-1.3dB	10log(3ms/(3ms+1ms))
PSD_{1MHz} (theoretically expected)	-42,1dBm/1MHz	$P_{Peak}+DC_{pulse}+DC_{hop}+DC_{blanking}$

[5] The factor 1.5 in the formula for the PDCF is required only if the RBW-filters of the spectrum analyzer are Gaussian filters.

[6] The frame time period (time interval for one complete spectrum coverage) is 3 ms followed by 1 ms quiescence (no emission at all). This leads to an additional duty cycle $DC_{blanking}$.

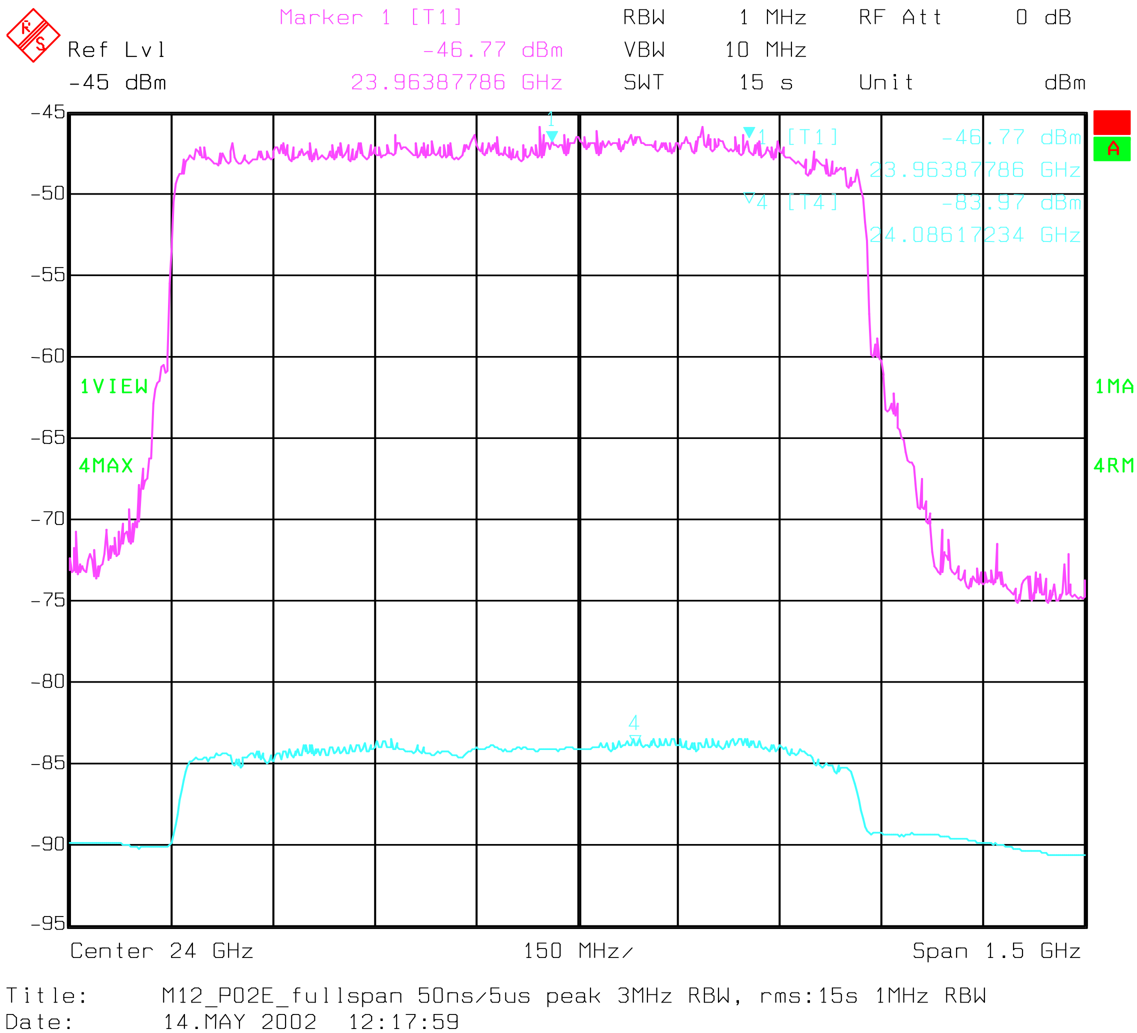

Figure 4: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 200 kHz PRF. Trace1 (magenta line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with max hold active, RBW=1 MHz and sweep time = 15 s for 1.5 GHz Span[7].

As Figure 4 makes clear, the average power as measured with the RMS detector with the frequency hop active exceeds the theoretical expected average PSD by only 1.1 dB.[8]

[7] The integration time for the RMS detector is not directly related to the span, but depends, instead, on the number of measurement points (so-called buckets). The number of points used was not available, so the integration time for a 1 MHz RBW is not known exactly (for 1500 points a integration time of 10 ms/ MHz would result).

[8] It should be noted that, the average power exceeds the noise floor by only 6 dB. By reducing the power emitted by the radar device to a value below the limits imposed in the UWB Report and Order (*i.e.,* 0 dBm/50 MHz or –24.4 dBm/3 MHz), a measurement of the average PSD without microwave amplifiers in the spectrum analyzer's reception path would be impossible, in particular for a distance between transmitter and receiver antenna of 3 meters.

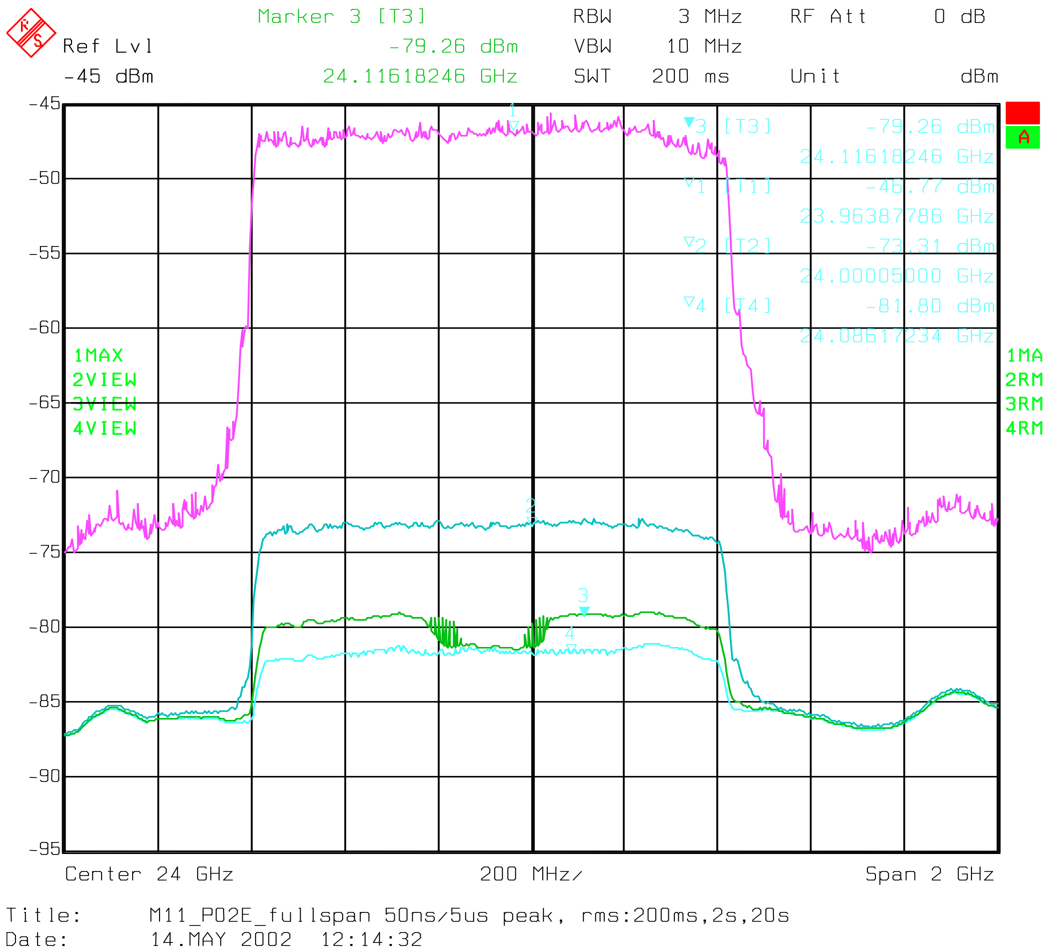

Figure 5: Full Span, 50 ns/5 µs, VBW=10 MHz, RBW = 3 MHz: Peak detector, max hold (magenta line); RMS detector, max hold, 200 ms/2 GHz (blue line); RMS detector, max hold, 2 s/2 GHz (green line); RMS detector, max hold, 20s/2 GHz (light blue line).

The green line shown in figure 5 corresponds to a 1 ms integration time for a 1 MHz bandwidth (if 2000 bucket points are assumed). The light blue line corresponds to an integration time for a 1 MHz bandwidth of 10 ms, whereas the blue line corresponds to an integration time for a 1 MHz bandwidth of only 0.1 ms.

The 0.1 ms integration time for a 1 MHz RBW is too short to provide true RMS readings. As the spectrum analyzer was set to peak max-hold mode, the reading becomes more like a sample or even peak detector measure.

Compared to Figure 4, the measurements presented in Figure 5 were taken with the RBW for the RMS detector set to 3 MHz. This explains the ca. 4.77 dB increase in the RMS readings and also in the noise floor.

2. Pulsed FH with 1 GHz hopping bandwidth, 50 ns pulse width and 2 MHz PRF

Figure 6 depicts the spectrum analyzer readings obtained by measuring the Siemens VDO vehicular radar in a typical pulsed FH operation mode with a 1 GHz bandwidth and a pulse width of 50 ns. In comparison to Figure 4, the PRF was changed from 200 kHz, to 2 MHz, thus changing the pulse related duty cycle DC_{pulse} to –10 dB. The peak power reading measured in a RBW of 3 MHz is –46.2 dBm (magenta line) and, therefore, approximately the same as in Figure 4. The measured RMS average PSD within a 1 MHz resolution bandwidth is approximately –75.3 dBm. Starting with the measured peak power, the average power can be derived theoretically:

		Remark
Peak Power in 3 MHz	-46.2 dBm/3 MHz	Measured value
PDCF in 3 MHz	-13 dB	20log(1.5*50 ns*3 MHz)
Peak power over entire BW: P_{Peak}	-33.2 dBm	$P_{Peak\ in\ 3\ MHz}$-$PDCF_{3\ MHz}$
DC_{pulse}	-10 dB	10log(Pulse width*PRF)
DC_{hop}	-30 dB	10log(1 MHz/1 GHz)
DC[9] $_{blanking}$	-1.3 dB	10log(3 ms/(3 ms+1 ms))
$PSD_{1\ MHz}$ (theoretically expected)	-74.5 dBm/1 MHz	P_{Peak}+DC_{pulse}+DC_{hop}+ $DC_{blanking}$

Again, the discrepancy between the theoretically expected and the actual measured PSD is less than 1 dB.

It is worth noting that if the sweep time per MHz RBW is too short relative to the time it takes for the occupied bandwidth to be filled up, the spectrum analyzer will produce measurement values that are slightly higher than the true average value (e.g. more sample detector like behavior). As the Siemens VDO pulsed FH radar is peak-power limited (in comparison to a pulse UWB systems, which are normally limited by the average power), the increase of the RMS average readings due to an overly short integration time does reduce the available margin of the mean power to the –41.25 dBm/MHz limit imposed by the FCC UWB Rule and Order. Although the margin of the Siemens VDO device is sufficient to compensate for the effect of this increased reading, an unnecessary limitation on the possible operation parameters occurs. The influence of the integration time used on measurements of the RMS average is shown above in Figure 5, and discussed in more detail in part 2 of the Annex to this paper.

[9] The frame time period (time interval for one complete spectrum coverage) is 3 ms followed by 1 ms quiescence (no emission at all). This leads to an additional duty cycle $DC_{blanking}$.

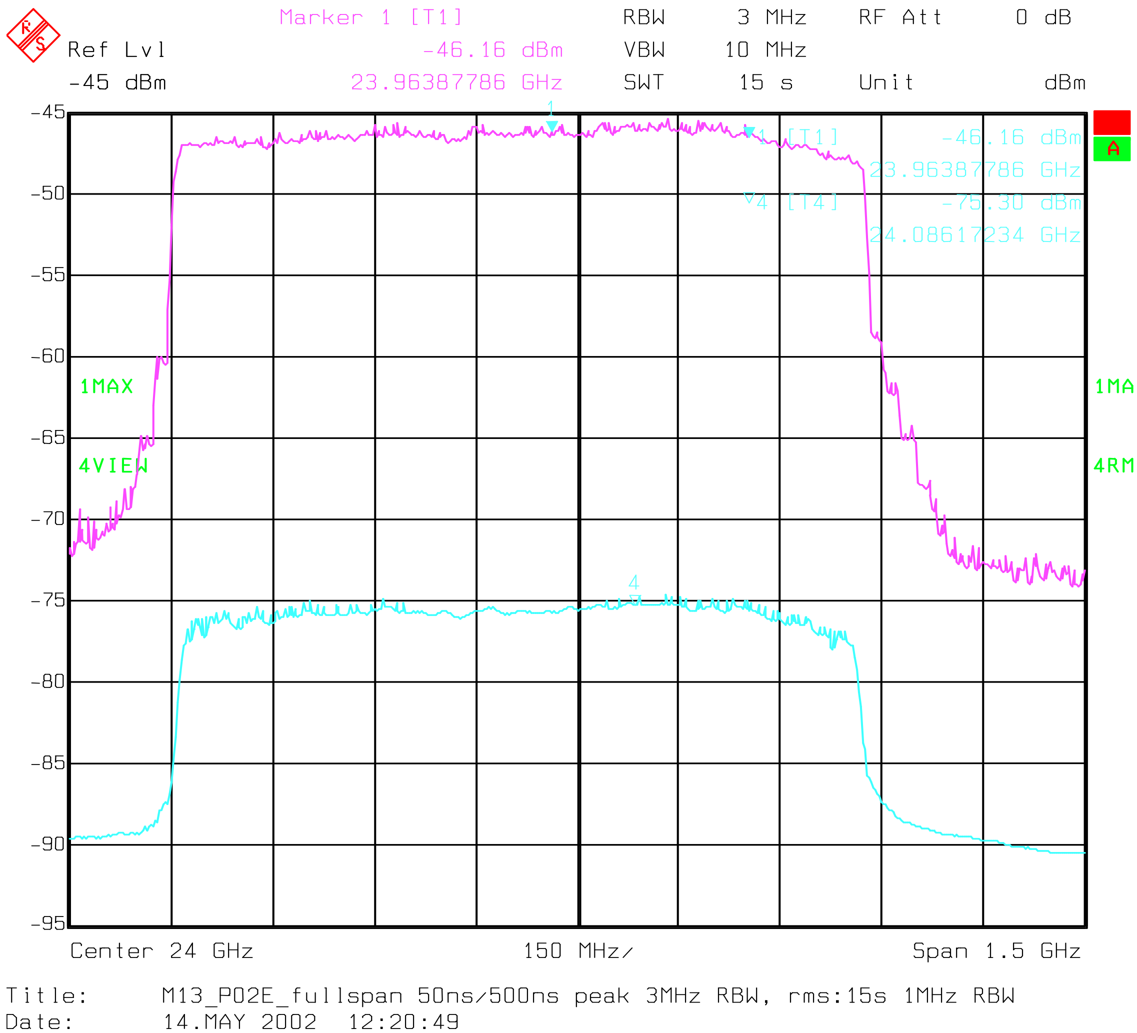

Figure 6: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 2 MHz PRF. Trace1 (magenta line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with max hold active, RBW=1 MHz and sweep time = 15 s/1.5 GHz.

3. Pulsed FH with 500 MHz hopping bandwidth, 50 ns pulse width and 200 kHz PRF

Figure 7 depicts a comparison of the spectrum analyzer readings obtained by measuring the Siemens VDO vehicular radar in two different pulsed FH operational modes: (1) with a 1 GHz bandwidth (blue and light blue line) and (2) with a 500 MHz bandwidth (magenta and green line). In both modes the pulse width is 50 ns with a PRF of 200 kHz, and the frame time period is 3 ms. The peak power reading measured in a RBW of 3 MHz is actually the same for both modes (-46.8 dBm/3 MHz) and, therefore, approximately the same as in Figure 5. The measured RMS average PSD within a 1 MHz resolution bandwidth is approximately –81.3 dBm for 500 MHz BW and –84.3 for 1 GHz BW. Theoretically, the following values are expected:

		Remark
Peak Power in 3 MHz	-46.8 dBm/3 MHz	
PDCF in 3 MHz	-16.5 dB	20log(1.5*50 ns*3 MHz)
Peak power over entire BW: P_{Peak}	-30.3 dBm	$P_{Peak\ in\ 3\ MHz}$-$PDCF_{3\ MHz}$
DC_{pulse}	-20 dB	10log(Pulse width*PRF)
DC_{hop} for 1 GHz bandwidth	-30 dB	10log(1 MHz/1 GHz)
DC_{hop} for 500 MHz bandwidth	-27 dB	10log(1 MHz/500 MHz)
DC[10] $_{blanking}$	-1.3 dB	10log(3 ms/(3 ms+1 ms))
$PSD_{1\ MHz}$ for 1 GHz bandwidth (theoretically expected)	-85.1 dBm/1 MHz	$P_{Peak}+DC_{pulse}+DC_{hop}^{1GHz}+DC_{blanking}$
$PSD_{1\ MHz}$ for 500 MHz bandwidth (theoretically expected)	-82.1 dBm/1 MHz	$P_{Peak}+DC_{pulse}+DC_{hop}^{500MHz}+ DC_{blanking}$

As would be expected based on theoretical calculations, actual measurements using the RMS detector show an increase in the average PSD of 3 dB as the occupied bandwidth is decreased from 1 GHz to 500 MHz. Again, the measured absolute values compare favorably with the theoretically calculated values.

C. Conclusions Regarding the Mean Power Measurement Results Using the Rhode & Schwartz Spectrum Analyzer with RMS Detector

The measurement results presented above show that the procedure set forth in the FCC's UWB Report & Order for measuring the average power of UWB devices in general is perfectly suited for measuring a pulsed frequency hopping device such as the Siemens VDO vehicular radar with frequency hop active. The average values obtained by measurements with a spectrum analyzer incorporating a RMS detector differ only slightly (≈1 dB) from the theoretically calculated PSD values, and importantly, show that the device complies with the FCC's limits for UWB vehicular radars. Moreover, the measurement procedure demonstrates that on average the power emitted by the Siemens VDO pulsed FH vehicular radar is distributed equally over its entire occupied bandwidth. In addition, from the measurement results it can be concluded that if the integration time of the RMS detector is set too short, the average power readings will become less accurate and will increase towards the readings that would be obtained with a sample or a peak detector.

[10] The frame time period (time interval for one complete spectrum coverage) is 3 ms followed by 1 ms quiescence (no emission at all). This leads to an additional duty cycle $DC_{blanking}$.

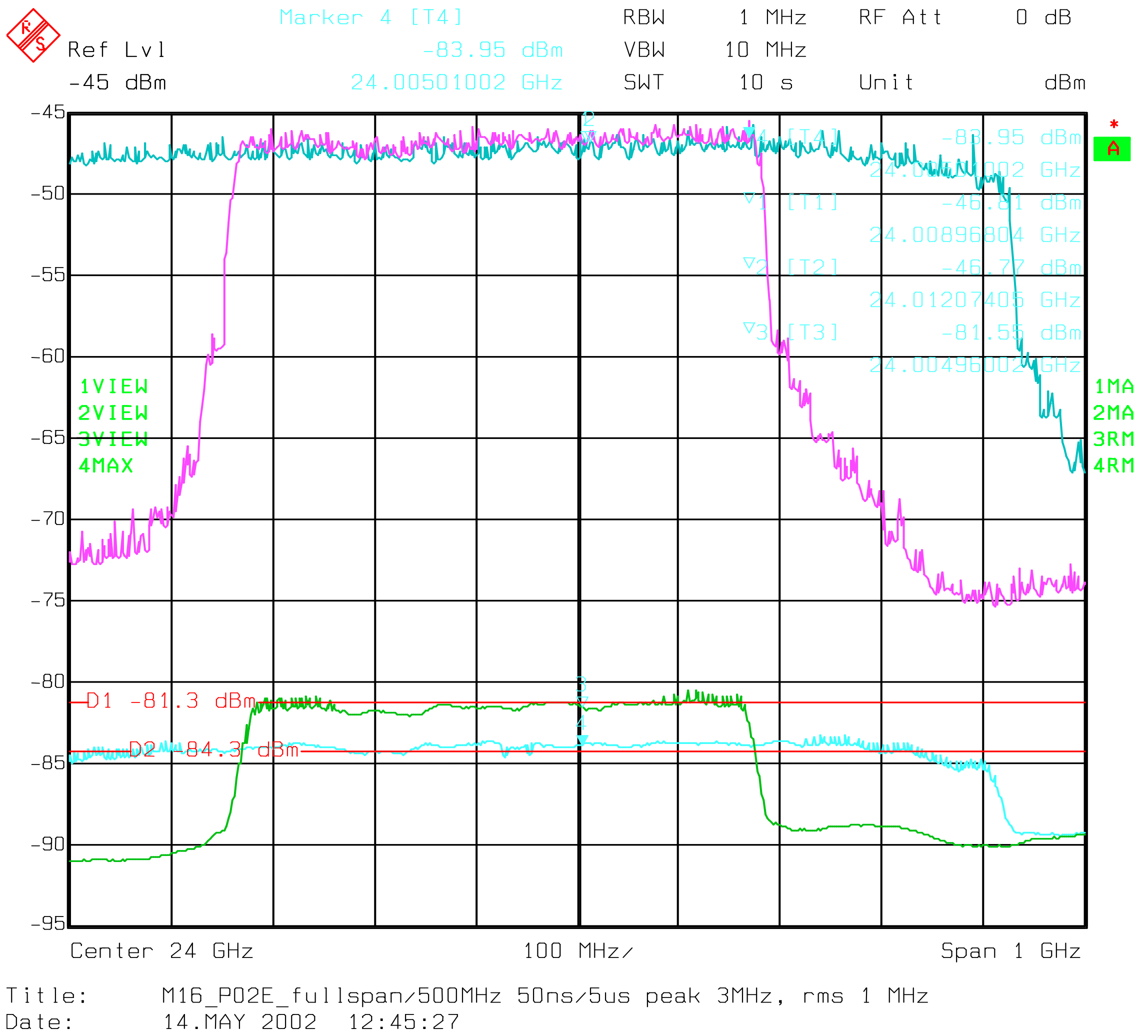

Figure 7: Pulsed FH with a pulse width of 50 ns and 200 kHz PRF. Trace1 (magenta line): Bandwidth = 500 MHz, max. peak detector with max hold active and RBW=3 MHz; Trace2 (green line): 500 MHz bandwidth, RMS detector with max hold active, RBW=1 MHz and sweep time = 10 s/1 GHz; Trace3 (blue line): Bandwidth = 1 GHz, max. peak detector with max hold active and RBW=3 MHz; Trace4 (light blue line): 1 GHz bandwidth, RMS detector with max hold active, RBW=1 MHz and sweep time = 10 s/1 GHz.

4. Bandwidth Measurement Procedure

Section 15.503(d) of the FCC's rules requires that a UWB transmitter satisfy the minimum 500 MHz UWB bandwidth "at any point in time," but the UWB Report and Order did not specify the length of an interval that would constitute "any point in time." Basic physics dictates that no frequency can be measured if the measurement time interval goes to zero. Thus, some measurement procedures with indirect frequency determination (*e.g*. via pulsewidth measure) must be established.

The Siemens VDO pulsed FH radar device has an instantaneous occupied bandwidth of typically 20 MHz (for a typical pulse width of 50 ns). The minimum UWB bandwidth of 500 MHz is filled up within the frame time period, which is typically on the order of a few milliseconds.

Siemens VDO should be permitted to measure its occupied frequency bandwidth during any 10 ms period using a spectrum analyzer. Two possible measurement methods are presented below:

Method A:

- Spectrum analyzer is set to zero span mode
- RBW is set to 3 MHz, VBW ≥ 3 MHz
- Detector mode is max. peak
- Sweep time of 10 ms
- Center frequency is set to several "test points" within the indicated occupied bandwidth

Notes:

For all selected frequency test points at least two burst signals should be within the required time period of 10 ms.

If the entire bandwidth of 500 MHz has to be verified (with a 1 MHz RBW), in total 500 frequency test points would have to be tested, which is very time consuming if measurement automation is not available.

Method B:

- The span of the spectrum analyzer is set to accommodate the occupied bandwidth of the DUT (device under test)
- RBW is set to 3 MHz, VBW ≥ 3 MHz
- Detector mode is max. peak
- The number of points of the spectrum analyzer is selected so that each point represents at maximum the RBW (example: Span = 1.8 GHz => minimum 600 points necessary)
- The sweep time is set to 10 ms multiplied by the number of points
- A single sweep is conducted

Notes:

The occupied spectrum should be flat without any holes in between, as for each frequency pixel (or bucket) within the 10 ms observation time at least one peak value should be detected, independent of the kind of modulation pattern applied. If the device doesn't fill up the minimum required bandwidth of 500 MHz within 10 ms, some holes will appear in the spectrum because no peak value occurred.

The shape of the RBW filter and the effective observation time per pixel (bucket) is spectrum analyzer-dependent. Thus, a correction factor for the sweep time will be necessary (to be defined and verified).

Annex

Measurement results with a second spectrum analyzer equipped with a RMS detector (for further validation and comparison)

The following measurements of the average power of a Siemens VDO pulsed FH vehicular radar sensor prototype were obtained by using an Agilent spectrum analyzer that incorporates a RMS-detector.

Measurement Setup

- Distance between UWB-transmitter and receiver antenna: ca. 0.34 m[11]
- Height of transmitter and receiver antenna above metallic ground: 1 m
- Receiver antenna gain: 20 dB
- Receiver: Agilent Spectrum Analyzer ESA-E4407B
- Cable losses (antenna to spectrum analyzer) ca. 3 dB

With the antenna gain of +20 dB, cable losses of 3 dB and a free space attenuation within 0.34 m of ca. 50.7 dB the spectrum analyzer readings have to be corrected by a factor of 33.7 dB, *i.e.* a reading of –33.7 dBm corresponds to an emission value of 0 dBm.

Measurement Results

1. Pulsed FH with 1 GHz hopping bandwidth, 50 ns pulse width and 200 kHz PRF

Figure 8 depicts the spectrum analyzer readings obtained by measuring the Siemens VDO vehicular radar in a typical pulsed FH operation mode with a 1 GHz bandwidth, a pulse width of 50 ns and a PRF of 200 kHz. The peak power reading as measured in a RBW of 3 MHz is –37.4 dBm (green line). The measured RMS average PSD within a 1 MHz resolution bandwidth is approx. –74 dBm. Starting with the measured peak power, the average power can be evaluated theoretically:

		Remark
Peak Power in 3 MHz	-37.4 dBm/3 MHz	Measured value
PDCF in 3 MHz	-13 dB	20log(1.5*50 ns*3 MHz)
Peak power over entire BW: P_{Peak}	-24.4 dBm	$P_{Peak\ in\ 3\ MHz}$-$PDCF_{3\ MHz}$
DC_{pulse}	-20 dB	10log(Pulse width*PRF)
DC_{hop}	-30 dB	10log(1 MHz/1 GHz)
DC[12] $_{blanking}$	-1.3 dB	10log(3 ms/(3 ms+1 ms))
$PSD_{1\ MHz}$ (theoretically expected)	-75.7 dBm/1 MHz	$P_{Peak}+DC_{pulse}+DC_{hop}+DC_{blanking}$

[11] The distance between the measurement antenna and radar device was reduced to 0.34 m because the sensitivity of the Agilent spectrum analyzer is about 10 dB lower than the Rhode & Schwartz type FSEM 30.

[12] The frame time period (time interval for one complete spectrum coverage) is 3 ms, followed by 1 ms quiescence (no emission at all). This leads to an additional duty cycle $DC_{blanking}$.

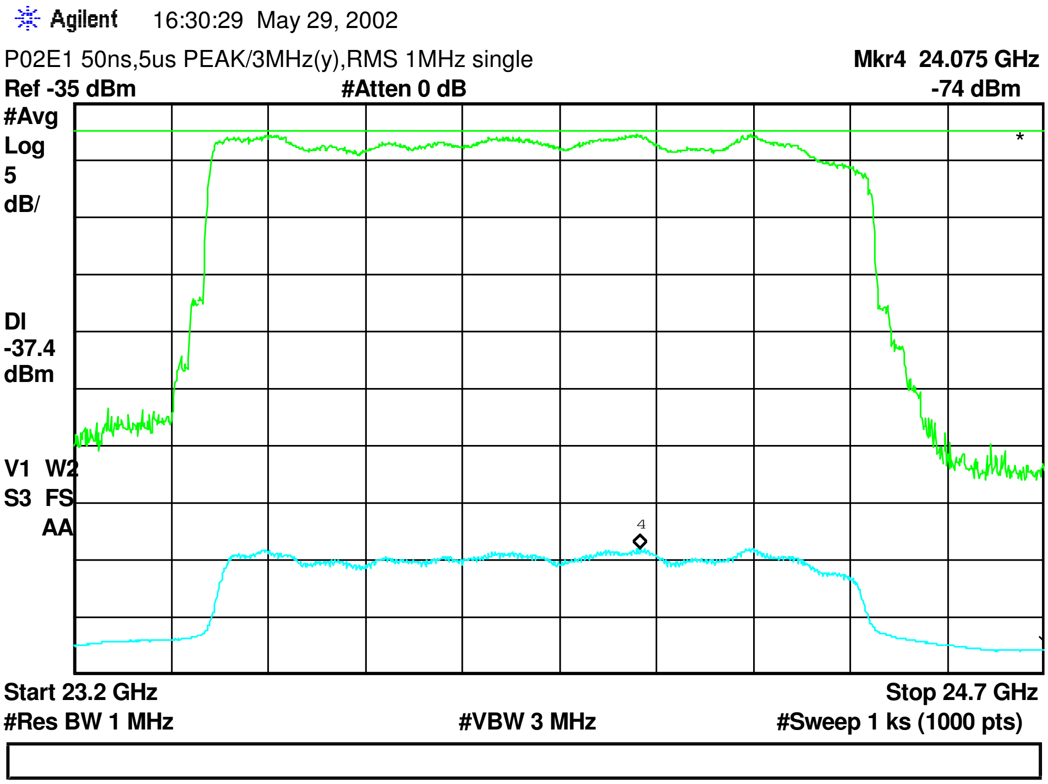

Figure 8: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 200 kHz PRF. Trace1 (green line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with max hold active, RBW=1 MHz and sweep time = 1000s for 1.5 GHz Span and 1000 pixels.[13]

As Figure 8 demonstrates, the average power measured with the RMS detector with hop active exceeds the theoretical expected average PSD by less than 1dB.[14]

2. Influence of Integration Time on RMS values

With the Agilent spectrum analyzer the exact relationship between integration time and the spectrum analyzer resolution bandwidth (RBW) could be evaluated.
In the following figures the integration time impact on the RMS readings for the pulsed FH operation mode is shown.

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[13] The integration time for the RMS detector is not directly related to the span, but depends on the number of measurement points (so-called buckets). The number of points used was 1000 and the sweep time was 1000 seconds (only single sweep mode was applied). Thus, the integration time for a 1 MHz RBW is 1 second, which is much greater than the transmitter repetition period of 4 ms and therefore yields the true RMS value.

[14] Note that the average power exceeds the noise floor by only 7 dB. By reducing the power emitted by the radar device to a value below the limits imposed by the UWB Report and Order (*i.e.*, 0 dBm/50 MHz or –24.4 dBm/3 MHz), a measurement of the average PSD without microwave amplifiers would be impossible, in particular for a distance between transmitter and receiver antenna of 3 meters (to conduct this measurement the actual distance was already reduced to 0.34 m)

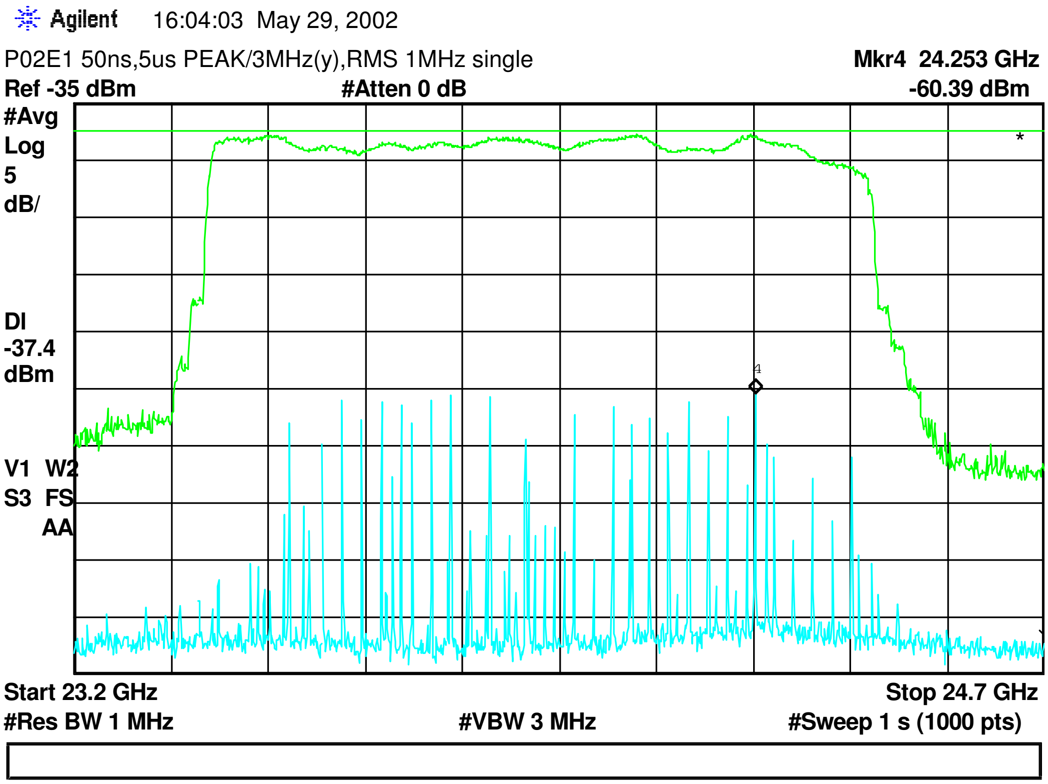

Figure 9: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 200 kHz PRF. Trace1 (green line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with RBW=1 MHz and sweep time = 1 s for 1.5 GHz Span and 1000 pixels (only one single sweep)

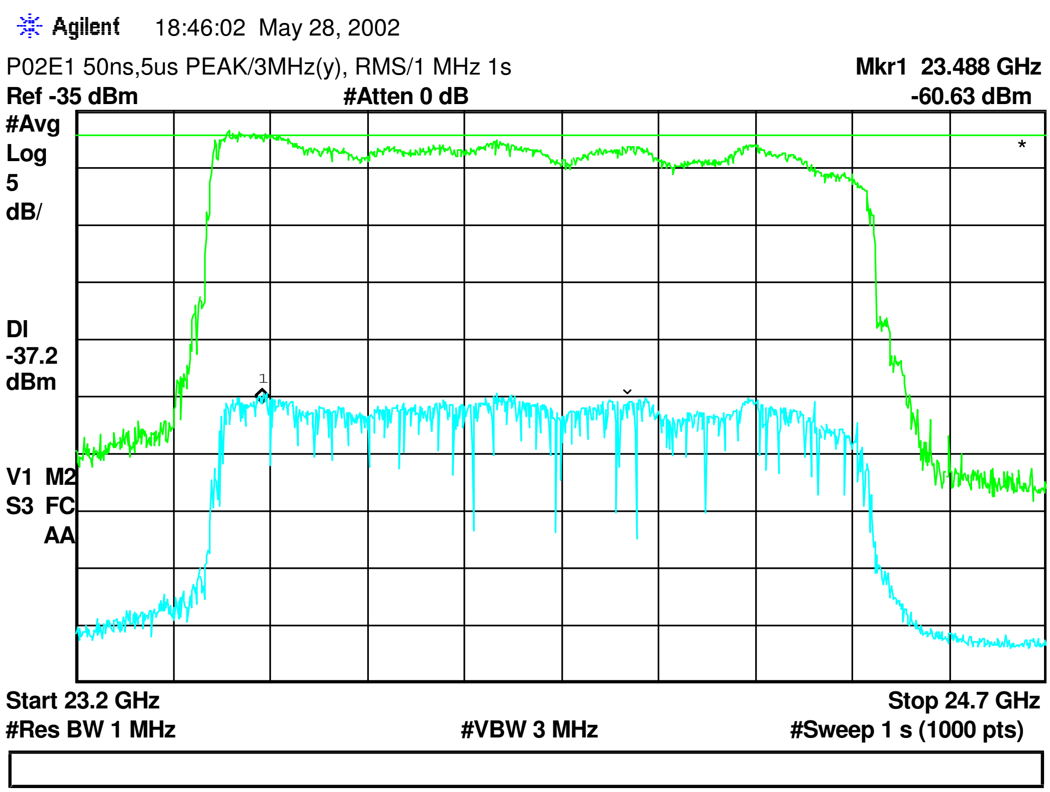

Figure 10: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 200 kHz PRF. Trace1 (green line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with max hold active, RBW=1 MHz and sweep time = 1 s for 1.5 GHz Span and 1000 pixels.

Compared to Figure 8, the RMS reading is about 15 dB higher. As the operating conditions of the pulsed FH radar are absolutely identical, the increasing effect stems from the fact that the sweep time was changed from 1 second per 1.5 MHz to 1 ms per 1.5 MHz.

In Figure 9 it can be seen that for each point (or pixel or bucket – i.e. 1.5 MHz) in the single sweep mode only 1 ms is available. This is below the pulsed FH repetition interval of 4 ms. Thus, the spectrum analyzer does not appear to be capable of capturing the signal correctly.

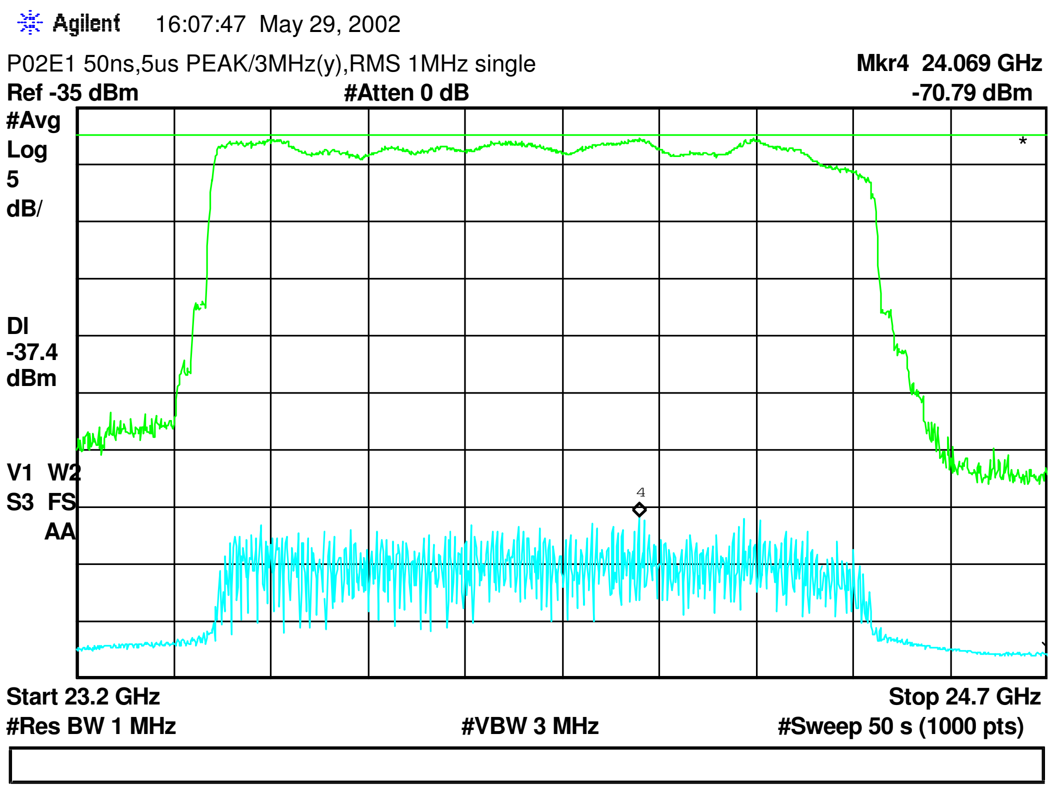

Figure 11: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 200 kHz PRF. Trace1 (green line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with RBW=1 MHz and a single sweep with sweep time = 50 s for 1.5 GHz Span and 1000 pixels (i.e. 50 ms for a 1.5 MHz bucket)

In Figure 11, the spectrum analyzer does appear to be capable of capturing the pulsed FH signal correctly within a single sweep, as the integration time for each bucket is 50 ms and, therefore, more than 10 times higher than the pulsed FH repetition interval of 4 ms.

Figures 12 and 13 show what happens under absolutely identical operating conditions to the RMS reading when the integration time for each bucket drops below 1 ms.

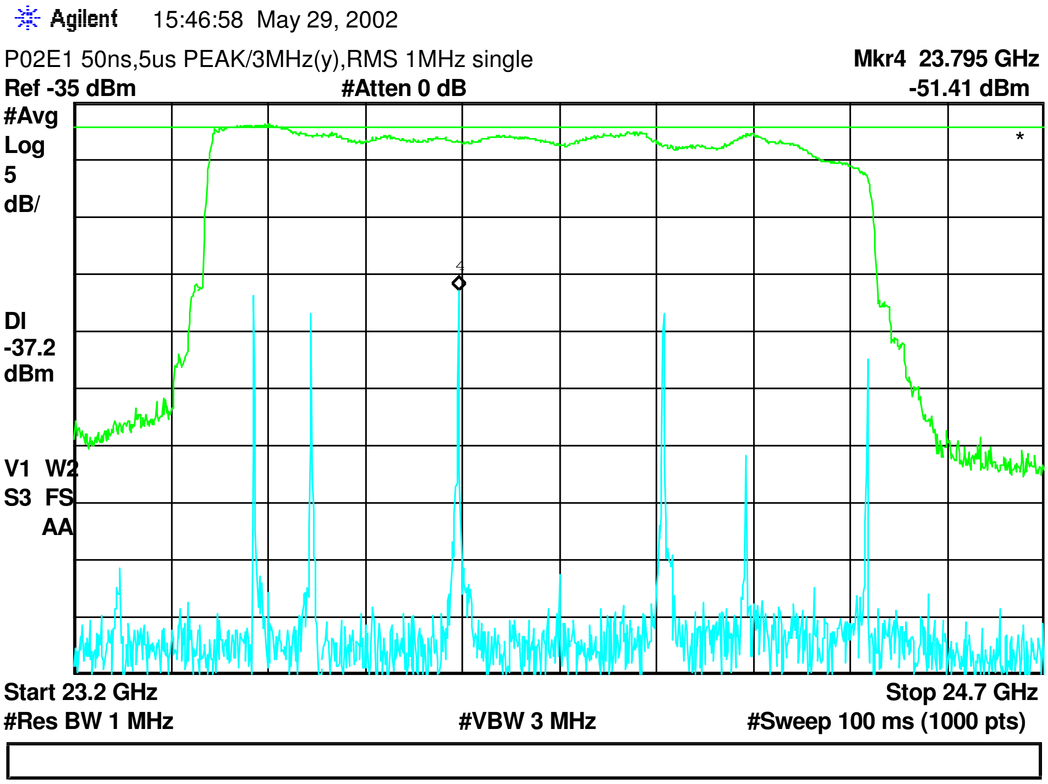

Figure 12: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 200 kHz PRF. Trace1 (green line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with RBW=1 MHz and a single sweep with sweep time = 100 ms for 1.5 GHz Span and 1000 pixels (i.e. 0.1 ms for a 1.5 MHz bucket)

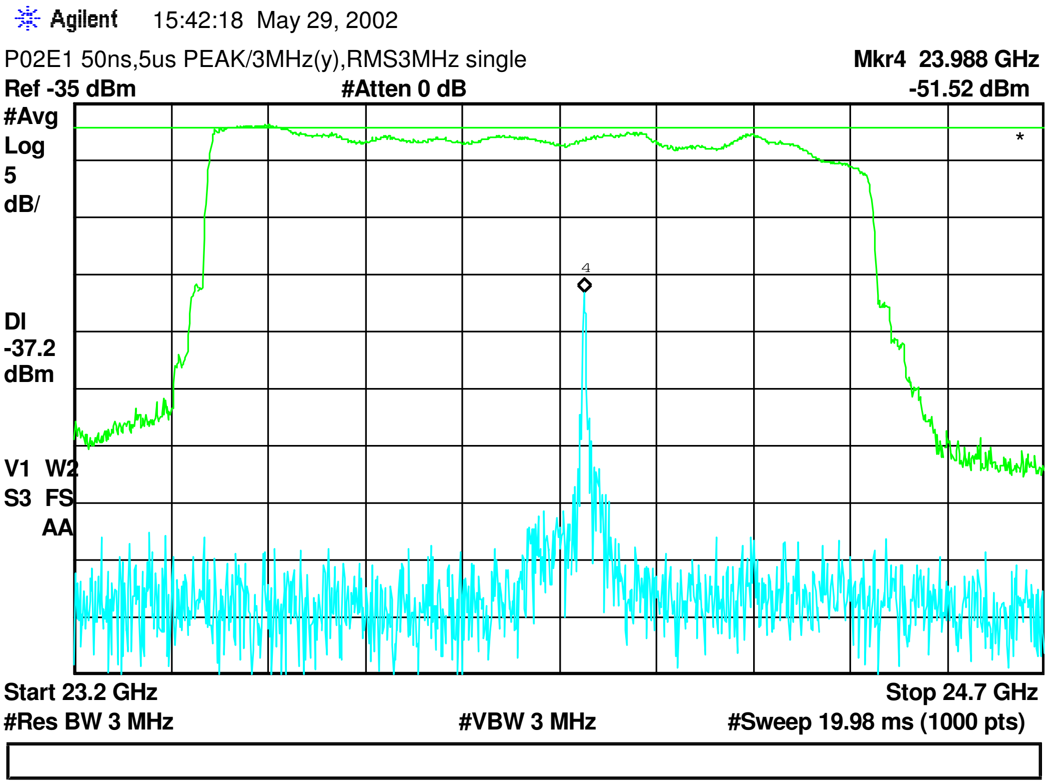

Figure 13: Pulsed FH with 1 GHz bandwidth, a pulse width of 50 ns and 200 kHz PRF. Trace1 (green line): Max. peak detector with max hold active and RBW=3 MHz; Trace2 (light blue line): RMS detector with RBW=1 MHz and a single sweep with sweep time = 20 ms for 1.5 GHz Span and 1000 pixels (i.e. 20 µs for a 1.5 MHz bucket)

Figure 12 and 13 illustrate that if the sweep time is too short it will not be possible to obtain enough samples of the signal within each bucket (which is required for an RMS detector to provide correct values). If this occurs, the RMS value will be transformed into a sample detector value with much higher readings.

Discussions with FCC and NTIA staff reveal that the 1 ms integration time was imposed to avoid excessive use of additional blanking or gating time in order to reduce the mean power measurement results.[15] In cases where no additional time gating is used, or where this blanking or time gating is switched off during the measurement procedure (as required by Section 15.521(d)), the rationale for a 1 ms integration time disappears.

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[15] In addition to the fixed or variable pulsewidth-to-PRF (pulse repetition frequency) ratio, the use additional blanking periods can further reduce the mean value. The frame time and accordingly the integration time increase with the blanking time. However, any blanking time can be accounted for and calculated into the pulsewidth-to-PRF ratio (*e.g.* a burst with a 1 ns pulsewidth with a PRF of 1 MHz for 1 ms followed by a blanking time of 9 ms is equal to a burst with a 1 ns pulsewidth with a PRF of 100 kHz for 10 ms followed by no blanking time at all) without changing the absolute mean power. The mean power distribution over time (a so-called instantaneously mean power) is the only thing that changes.

Because the analysis presently above demonstrates that a 1 ms integration time results in a distorted mean power reading of the Siemens VDO radar device, the Commission should permit an integration time of at least several milliseconds. This time period, although still shorter than that recommended by several spectrum analyzer manufacturers to achieve the most accurate reading, is suggested to correspond better with the integration time for EESS satellites, which is typically at least several milliseconds. A shorter integration time is superfluous as the EESS systems are not able to resolve any instantaneously mean power fluctuation below their integration time.

3. Influence of occupied bandwidth on RMS readings

In Figure 14 below the influence of the RMS readings with respect to the occupied bandwidth is shown. All operating parameters are identical except for the occupied bandwidth Bw_{occ}, which is 1GHz, 500 MHz and 250 MHz. The expected 3 dB difference (1 division = 3 dB) is clearly shown. The RMS spectra were recorded in single shot mode with a 1s integration time per bucket to achieve accurate readings.

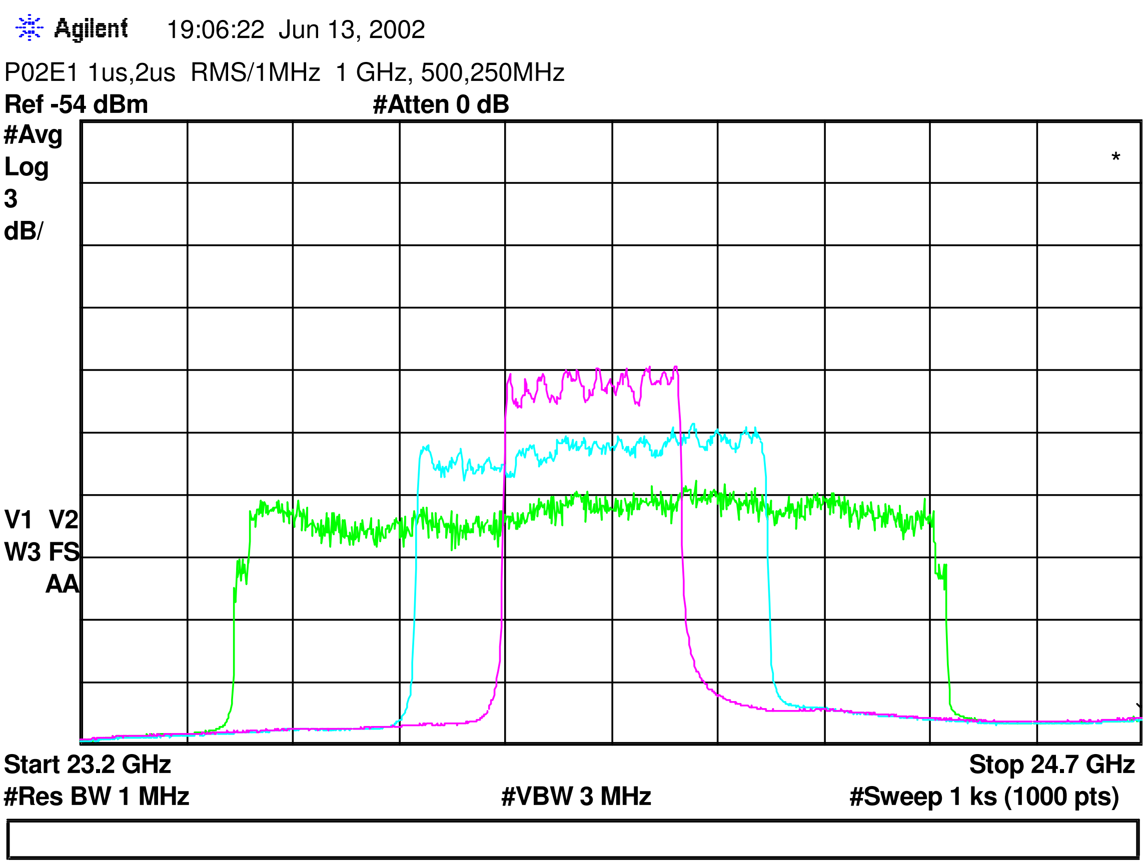

Figure 14: Pulsed FH with a pulse width of 1 µs and 500 kHz PRF and different occupied bandwidth. RMS detector with RBW=1 MHz and a single sweep with sweep time = 1000s for 1.5GHz Span and 1000 pixels (i.e. 1s for a 1.5 MHz bucket); Trace1 (green line): 1GHz BW_{occ}; Trace2 (light blue line): 500 MHz BW_{occ}; Trace3 (magenta line): 250 MHz BW_{occ}

4. Conclusions Based on Measurements Using the Agilent Spectrum Analyzer with RMS Detector

Like the Rhode & Schwartz spectrum analyzer, the Agilent spectrum analyzer with RMS detector also is well suited for measuring the average power of a pulsed FH radar with the frequency hop active, as the actual measurement values vary little from the theoretical expected average PSD. Due to spectrum analyzer performance limitations, however, the integration time for each measurement point (bucket) should be at least three to five times higher than the nominal hopping sequence.

If the integration time chosen is too short, the true RMS value will be increased up to the values normally obtained from a sample detector. If the 1 ms integration time per 1 MHz RBW established in the UWB Report & Order is used, the RMS reading of the Siemens VDO vehicular radar, when operating with a typical repetition interval in the order of 4 ms, will be increased by ca. 15 dB. But, even with this increase, the Siemens VDO radar still does not exceed the required UWB mean power limit of –41.25 dBm/MHz because the pulsed FH radar is mainly limited by the peak power value. With an allowed peak power value of –24.5 dBm in a 3 MHz RBW, the RMS reading (measured in a 1 MHz RBW with a 1 ms integration time) has to stay at least 16.75 dB below the peak reading. The Siemens VDO radar satisfies this requirement (see Figure 9, showing more than 20 dB margin between peak and RMS values).