RF and Microwave Wideband Power Sensors/Meters

GEM Microwave PM1890 Data Sheet

Features & Benefits

Key Performance Specifications

- Frequency range 50 MHz to 18 GHz, (50 MHz to 500 MHz with reduced video bandwidth)
- Model available with N Connector
- Peak power measurements of radar and mobile communications signals with up to 40 MHz RF video bandwidth; sensor rise time <10 ns
- Automatic burst detection and acquisition
- Ultra-fast statistical analysis (one-million point CCDF within <20 ms)
- Accurate continuous power measurements on modulated and unmodulated signals in the range from –63 dBm to +23 dBm
- High measurement repeatability due to very low zero drift of <125 nW for single-shot events and statistics, <1.5 nW for repetitive measurements
- Uncertainty as Low as 2%
- Operation via USB on a Laptop/PC
- Ideal for radar applications
- Readings Rates up to 15000 Readings/s (buffered mode)
- Automatic pulse analysis
- Statistical analysis
- High resolution mode
- Trigger master mode

Features

- Outstanding dynamic range and accuracy. Signal details can be analyzed in the range down to –50 dBm. Continuous average power measurements are even possible in a dynamic range of 86 dB (–63 dBm to +23 dBm). The PM1890 sensor fulfils practically any accuracy requirements. A complete sensor characterization over the entire temperature range produces excellent stability.
- High-speed data acquisition. Using a single-shot bandwidth of 100 Msample/s and a video bandwidth of 40 MHz, it is possible to measure pulses with a width of only 50 ns. The time resolution can be increased to up to 500 ps/div for repetitive pulse sequence. The fast rise time of typ. 10 ns enables accurate determination of the peak power both for the standard signals used in mobile communications nowadays and for the proprietary pulse sequences that are common in military applications, for example. Due to the high trigger sensitivity of typ. –25 dBm to +23 dBm (at 40 MHz video bandwidth), automatic recording of measured values is ensured for the usual signal levels.
- Average Power, Duty Cycle Corrected Pulse Power, and Measurement Logging
- Included Applications run under Microsoft Windows
  - Virtual Power Meter Application
  - LabVIEW Drivers and Programming Examples for Most Common Windows Programming Environments are Available for Automated System Support
- Max Hold and Relative Measurement Modes
- Offset, Frequency Response, and 75 Ohm Minimum Loss Pad Correction
- Flexible Averaging Modes for Quick, Stable Measurements
- TTL Trigger Input and Output allow Synchronization with External Instruments
- Pass/Fail Limit Mode
- Compact Size
- Full-trace and Gated Measurements including Pulse, Peak and Average Power, Overshoot, Crest Factor, Rise and Fall Time, Pulse Width, Pulse Repetition Frequency, Duty Cycle
- Statistical Measurements on the Trace Data, such as Complementary Cumulative Distribution Function (CCDF), and Probability Density Function (PDF)

Applications

- General-purpose RF and Microwave Average Power Measurements
- Characterization of Repetitive Pulsed Signals, such as Navigation, Weather, and other Radar
- Peak and Average Power Measurements on Modulated Signals such as GSM, CDMA, WCDMA, HSPA, WiMAX up to 40 MHz
- Peak and Average Power Measurements of Modulated Pulsed Communications Signals
- Level Control Feedback for Signal Sources
- Validation and Characterization of Power Amplifiers, Switches, and Other RF and Microwave Components
- Service, Maintenance, and Installation of DTV, Cellular, Microwave Radio Link, and Radio Broadcast Transmitters
- Verification and Calibration of Test Equipment and Systems

Capable, Compact Power Sensors/Meters

The PM1890 is compact power sensor/meter that deliver fast, accurate RF and microwave power measurements. A broad range of CW and pulse modulation measurements are available. The sensor comes with Virtual Power Meter application software for controlling the meter, displaying readings, and recording data. The combination of the sensor/meter and PC provides a complete solution, eliminating the need for a separate, dedicated meter mainframe.

By communicating with the Power Sensor the program covers a wide range of applications. Besides the basic continuous average measurement function, Virtual Power Meter application also includes the measurement modes timeslot, burst and scope measurement. The PM1890 sensor is highly accurate standalone measuring instrument. With its internal CPU the Power Sensor processes the measurement results and communicates directly with a PC via an USB connection. With a high dynamic range and automatic error correction the power sensors are suitable for nearly every measurement task. As an example, among other duties, the PM1890 is able to measure pulse parameters automatically, and the Virtual Power Meter software represents the results.For measurements of any number of GEM Microwave's USB power sensors the graphical user interface of the Virtual Power Meter application offers functionality and operation comparable to a multichannel oscilloscope.

No Meter Mainframe Required

With the included Virtual Power Meter software, familiar meter controls are available at the click of a mouse and readings are presented right on your PC screen. Familiar Windows pull-down menus provide additional controls. Data is immediately available on the PC for further analysis and documentation. The meters communicate with the PC using standard USB 2.0 protocols and cables for plug-and-play ease of use.

Integrate High-speed Power Measurements Into Your Testing

GEM Microwave PM1890 power sensor features fast measurement speed (15000 readings/s). This can significantly reduce test times and provide dynamic power measurement information that was previously unavailable. An included High-speed Logging Application provides a mechanism for getting this data into your PC for analysis. For custom test applications, you can communicate with the sensor using LabVIEW, or using a fully documented API. The communications library allows your program to communicate with any number of sensors, eliminating the need for costly switches. To allow synchronization with other measurement equipment the sensor includes Trigger In and Trigger Out TTL signals. High-speed measurements, extensive programming tools, and synchronization features make the PM1890 sensor versatile addition to your test setup.

Industry-leading Performance for Demanding Designs

The PM1890 power sensor/meter comes fully calibrated over the entire operating temperature range. Sensor zeroing and meter reference calibration have been eliminated, reducing setup time and helping to avoid inaccurate results. The meter provides accuracy you can count on for general-purpose CW, peak, pulse, and other modulated power measurements. Whether doing installation or maintenance on a wireless base station, production testing, or R&D for wireless components, the PM1890 sensor serves these needs with a wide dynamic range (–63 dBm to +23 dBm) and frequencies ranging from 50 MHz up to 18 GHz.

A Broad Range of Pulse Envelope Measurements

The PM1890 wideband power sensor is ideal for radar applications. In development or during installation and maintenance, pulse characteristics as well as output power have to be measured. Similar measurements are required in the production of radar systems and radar components. Thanks to a maximum video bandwidth of 40 MHz and a rise/fall time < 10 ns, the sensor can measure pulses with a pulse width as small as 50 ns. Key pulse parameters are determined automatically to simplify the measurement and prevent operating errors. GEM Microwave's USB power sensor features an easy-to-use, high performance, peak and CW power meter in one. It performs time domain pulse measurements such as rise/fall time, overshoot, and droop that have typically required costly signal analyzers.

Performance You Can Count On

Every GEM Microwave's USB power sensor/meter comes backed with a two-year standard warranty.

Specifications

Frequency range		50 MHz to 18 GHz
Impedance matching (VSWR)	50 MHz to 3 GHz	1.1
	> 3 GHz to 8 GHz	1.2
	> 8 GHz to 18 GHz	1.25
Power measurement range	Continuous Average	0.5 nW to 200 mW (-63 dBm to +23 dBm)
	Burst	
	full video bandwidth	10 µW to 200 mW (-20 dBm to +23 dBm)
	300 kHz	2 µW to 200 mW (-27 dBm to +23 dBm)
	Trace, Timeslot/Gate	10 nW to 200 mW (-50 dBm to +23 dBm)
	Statistics	2 µW to 200 mW (-27 dBm to +23 dBm) (Note 1)
Maximum power	Average power	200 mW (+23 dBm), continuous
	Peak envelope power	1000 mW (+30 dBm) for maximum 1µs
Dynamic response	Video bandwidth	≥ 40 MHz
	Single-shot bandwidth	≥ 40 MHz
	Video bandwidth setting	Full (≥ 40 MHz), 5 MHz, 1.5 MHz, 300 kHz
	Rise time 10 %/90 %	
	full video bandwidth	≤ 10 ns (f ≥ 500 MHz) ≤ 40 ns (f < 500 MHz)
	5 MHz	< 75 ns
	1.5 MHz	< 250 ns
	300 kHz	1.2 µs
	Detectable burst width	≥ 50 ns (f ≥ 500 MHz, full video bandwidth)
	Overshoot	≤ 3 %
Acquisition	Sample rate [period]	
	Full video bandwidth	100 Msps [10 ns]
	5 MHz	40 Msps [25 ns]
	1.5 MHz	10 Msps [100 ns]
	300 kHz	2.5 Msps [400 ns]
	Capture length	50 ns to 1 s (depending on meas. function)
	Time base accuracy	±50 ppm
	Time base jitter	< 1ns
Triggering	Internal	
	Threshold level range	-30 dBm to +20 dBm (usable from –25 dBm with full video bandwidth)
	Threshold level accuracy	Identical to uncertainty for absolute power measurements
	Threshold level hysteresis	0 dB to 10 dB
	Dropout (Note 2)	0 s to 10 s
	External	TTL
	Slope (external, internal)	positive/negative
	Delay	-100 µs to +10 s
	Hold-off	0 s 10 s
	Resolution (dropout, delay, hold-off)	Sample period
	Source	Internal, external

Note 1: With full video bandwidth. Reduce the specified minimum levels according to the reduction of sampling noise at lower bandwidths.

Note 2: Time span prior to triggering, where the trigger signal must be entirely below the threshold level in the case of a positive slope and vice versa in the case of a negative slope.

Specifications (continued)

Zero offset After external zeroing	Continuous Average	
	10 µs aperture time	< 100 pW
	other durations	< 1 nW
	Burst/Timeslot/Gate Average, Trace	
	with averaging	< 1 nW
	without averaging	< 50 nW
	Statistics	< 50 nW
Zero drift (Note 3)	Continuous Average	
	10 µs aperture time	< 100 pW
	other durations	< 200 pW
	Burst/Timeslot/Gate Average, Trace	
	with averaging	< 1 nW
	without averaging	< 50 nW
	Statistics	< 50 nW
Measurement noise (Note 4)	Continuous Average (Note 5)	< 100 pW
	Trace/Statistics (noise per sample)	
	Full video bandwidth	< 1 µW
	5 MHz	< 0.5 µW
	1.5 MHz	< 0.4 µW
	300 kHz	< 0.2 µW
	Burst/Timeslot/Gate Average, Trace	Multiply the noise-per-sample specifications for full video bandwidth with noise reduction factors from tables A and B. For gate lengths ≥ 2 µs, a noise value of 5 nW or better can be achived with adequate averaging.
Uncertainty for absolute power Measurements (Note 6)	50 MHz to < 100 MHz	2 %
	100 MHz to 8 GHz	1.5 %
	8 GHz to 18 GHz	2 %

Note 3: Within one hour after zeroing, permissible temperature change ±10 °C, following a fifteen minute warm-up of the power sensor.

Note 4: Measured over a one-minute interval, at constant temperature, two standard deviations.

Note 5: 512k averages taken with the aperture time set to default (10 µs). The measurement noise with other averaging numbers can be calculated by applying the multipliers indicated below:

Averaging number	512k	128k	32k	8k	2k	512	128	32	8
Integration time	10 s	4 s	1 s	250 ms	60 ms	15 ms	4 ms	1 ms	0.25 ms
Noise multiplier	1	2	4	8	16	32	64	128	256

Integration time is defined as the total time used for signal acquisition,i.e. the product of twice the aperture time and the averaging number. The measurement noise is always minimal for the default aperture time. Increasing the aperture time above this value is only useful for suppressing modulation-induced fluctuations of the measurement result, e.g. by matching the aperture time to the modulation period.

Note 6: From 0 °C to +50 °C. Expanded uncertainty (k = 2) for absolute power measurements on CW signals. Specifications include calibration uncertainty, linearity, reflection of sensor-induced harmonics on the DUT, and temperature effect. Zero offset, zero drift and measurement noise must additionally be taken into account when measuring low powers. As a rule of thumb, the contribution of zero offset and zero drift can be neglected for power levels above –35 dBm if external zeroing has been applied. The contribution of measurement noise can be neglected below 0.02 dB. Example: The power to be measured is 50 nW (–43 dBm) at 12 GHz in the Continuous Average mode; averaging number set to 32k with an aperture time of 10 µs (1 s integration time). The typical absolute uncertainty due to zero offset is 100 pW. The corresponding relative measurement uncertainty can be calculated as follows: $10 \cdot \log((50nW + 100pW)/50nW) = 0.0087dB$. Using the noise multiplier (4) from note 5, the absolute noise contribution is typically 100 pW × 4 = 400 pW, which corresponds to a relative measurement uncertainty of $10 \cdot \log((50nW + 400pW)/50nW) = 0.035dB$ .Combined with the value of 0.086 dB (2 %) specified for the uncertainty of absolute power measurements at 12 GHz, the total expanded uncertainty is $\sqrt{0.086^2 + 0.0087^2 + 0.035^2}\,dB = 0.093dB$ .The contribution of zero drift has been neglected in this case. It must be treated like zero offset if it is relevant for total uncertainty.

Table A Noise reduction factors for averaging

Averaging number	2	4	8	16	32	64	128	256	512	1k	2k	4k	8k
Reduction factor	0.7	0.5	0.35	0.25	0.18	0.13	0.09	0.063	0.044	0.031	0.022	0.016	0.011

Example: A power measurement on a radar pulse is carried out by means of the Timeslot/Gate function. The gate length is set to 1 µs, and the averaging number to 32. The pulse repetition rate is 100 Hz, and the pulse power is about –10 dBm. From the specifications, a 2σ noise-per-sample value of 1 µW (typical) can be derived for reference conditions. Gating reduces noise by a factor of 0.15 (table B), and averaging further reduces noise by a factor of 0.18 (table A). The residual 2σ noise of mean power within the gate can then be calculated as follows: 1 µW · 0.15 · 0.18 = 27 nW (0.03 % of measured value).

Table B Noise reduction factors for gating and smoothing

The noise reduction factors in this table describe how measurement noise is reduced if the mean value of adjacent samples is taken over a time interval. The time interval can be the length of a gate, timeslot, or pixel in trace mode. Without averaging or for single events, use the leftmost column. If averaging is activated, use the columns for the individual repetition rates and additionally apply multipliers from table A. The repetition rate is identical to the frequency of the measurement being carried out, i.e. the inverse of the trigger period.

<table>
<tr><th>Repetition rate / Gate length</th><th>0 Hz</th><th>10 Hz</th><th>100 Hz</th><th>1 kHz</th><th>10 kHz</th><th>50 kHz</th><th>100 kHz</th></tr>
<tr><td>20 ns</td><td colspan="7">0.7</td></tr>
<tr><td>50 ns</td><td colspan="7">0.5</td></tr>
<tr><td>100 ns</td><td colspan="7">0.4</td></tr>
<tr><td>200 ns</td><td colspan="7">0.3</td></tr>
<tr><td>500 ns</td><td colspan="7">0.2</td></tr>
<tr><td>1 µs</td><td>0.16</td><td colspan="2">0.15</td><td colspan="4">0.14</td></tr>
<tr><td>2 µs</td><td>0.14</td><td>0.16</td><td>0.12</td><td>0.11</td><td colspan="2">0.1</td><td></td></tr>
<tr><td>10 µs</td><td>0.11</td><td>0.1</td><td>0.09</td><td>0.08</td><td>0.07</td><td>0.06</td><td></td></tr>
<tr><td>100 µs</td><td>0.1</td><td>0.09</td><td>0.07</td><td>0.06</td><td>0.04</td><td></td><td></td></tr>
<tr><td>1 ms</td><td>0.1</td><td>0.07</td><td>0.06</td><td>0.035</td><td></td><td></td><td></td></tr>
<tr><td>10 ms</td><td>0.1</td><td>0.06</td><td>0.035</td><td></td><td></td><td></td><td></td></tr>
</table>

Additional characteristics

Sensor type		Wideband multi-path diode power sensor
Measurand		Power of incident wawe
		Power of source (DUT) into 50 Ω (Note 7)
RF connector		N male
Measurement functions	Stationary and recurring waveforms	Continuous Average
		Burst
		Timeslot/Gate
		Trace, Statistics
	Single events	Trace, Statistics
Continuous Average function	Measurand	Mean power over recuring acquisition interval
	Aperture	1 µs to 1 s (10 µs default)
	Window function	Uniform, von Hann (Note 8)
	Duty cycle corection (Note 9)	0.001 % to 99.999 %
	Capacity of measurement buffer (Note 10)	1 to 8192 results
Burst Average function	Measurand	Mean power over burst portion of recurring signal (trigger settings required)
	Detectable burst width	50 ns to 0.1 s
	Minimum gap between bursts	40 ns
	Dropout period for burst end detection (Note 11)	0 s to 0.1 s
	Exclusion periods (Note 12)	
	Start	0 to burst width
	End	0 s to 81.92 µs
	Resolution of dropout and exclusion periods	Sample period

Note 7: With gamma correction.

Note 8: Preferably used with determined modulation when the aperture time cannot be matched to the modulation period. Compared to a uniform window, measurement noise is about 22 % higher.

Note 9: For measuring the power of periodic bursts based on an average power measurement.

Note 10: To increase measurement speed, the power sensor can be operated in buffered mode. In this mode, measurement results are stored in a buffer of user-definable size and then output as a block of data when the buffer is full. To enhance measurement speed even further, the sensor can be set to record the entire series of measurements when triggered by a single event. In this case, the power sensor automatically starts a new measurement as soon as it has completed the previous one.

Note 11: This parameter enables power measurements on modulated bursts. The parameter must be longer in duration than modulation-induced power drops within the burst.

Note 12: To exclude unwanted portions of the signal from the measurement result.

Additional characteristics (continued)

Timeslot/Gate function	Measurand	Mean, maximum and minimum power over individual timeslots/gates of recurring signal
	Number of timeslots/gates	1 to 16 (consecutive)
	Nominal length	50 ns to 0.1 s
	Start offirst timeslot/gate	At delayed trigger event
	Exclusion periods (Note 12)	
	start	0 to nominal length
	fence	0 s to 0.1 s (anywhere within the timeslot)
	end	0 s to 81.92 µs
	Resolution of nominal lengths and exclusion periods	10 ns
Trace function	Measurand	Mean, random, maximum and minimum power over pixel length
	Acquisition	
	Length (*Δ*)	50 ns to 1 s
	Start (referenced to delayed trigger)	-4096 × *Δ*/*M* to +10 s
	Result	
	Pixels (*M*)	3 to 8192
	Resolution (*Δ*/*M*)	
	Normal	≥ sample period
	Equivalent time	≥ 100 ps
Statistics function	Measurand	CCDF or PDF over accumulated records
	Acquisition	
	Mode	Recurring or triggered
	Length (aperture)	10 µs to 0.3 s
	Start (referenced to delayed trigger)	0 s to +10 s
	Exclusion period (fence)	0 s to 0.3 s (anywhere within aperture)
	Number of accumulated records	1 to 65536 (set by averaging number)
	Result	
	Number of histogram classes (*C*)	3 to 8192
	Power span (*S*)	0.01 dB to 100 dB
	Minimum class width (*S*/*C*)	0.006 dB
Averaging filter	Modes	Auto off (fixed averaging number)
		Auto on (continuosly aotu-adapted)
		Auto once (automatically fixed once)
	Auto off	
	Supported measurement functions	All
	Averaging number	2^N ,N = 0 to 20 (16 for Trace/Statistics)
	Auto on/once	
	Supported measurement functions	Continuous Average, Burst Average, Timeslot/Gate Average
	Normal operating mode	Averaging number adapted to resolution settings and power to be measured
	Fixed noise operating mode	Averaging number adapted to specified noise content
	Result output	
	Moving mode	Continuous, independent of averaging number
	Rate	Can be limited to 0.1 s^{-1}
	Repeat mode	Only final result
Attenuation correction	function	Corrects the measurement result by means of a fixed factor (dB offset)
	range	±200 dB
Embedding	function	Incoporates a two-port device at the sensor input so that the measurement plane is shifted to the input of the device
	parameters	S_{11}, S_{21}, S_{12} and S_{22} of device
	Number of devices	User-definable
	Frequencies (sum of all devices)	≤ 32k
Gamma correction	function	Removes the infulence of impedance mismatch from the measurement result so that the power of source (DUT) into 50 Ω can be read
	parameters	Magnitude and phase of reflection coefficent of source (DUT)

Additional characteristics (continued)

Frequency response corection	Function	Takes the frequency response of the power meter into account		
	parameter	Center frequency of test signal		
	Residual uncertainty	See specification of calibration uncertainty and uncertainty for absolute power measurements		
Measurement times (Note 13) 2^N: averaging number *T*: number of timeslots *w*: nominal length of timeslot	Continuous Average	$2 \times$ (aperture + 5 µs) $\times 2^N + t_z$		
	Buffered without averaging (Note 14)	$2 \times$ (aperture + 50 µs) $\times$ buffer size + t_z t_z:1.6 ms (typical)		
	Timeslot/Gate Average			
	(signal period – $T \times w$) > 6 µs	$\leq 2 \times$ signal period $\times (2^N + 1/2) + t_t$		
	All other cases	$\leq 4 \times$ signal period $\times (2^N + 1/4) + t_t$ t_t: 3 ms (typical)		
Zeroing (duration)	Including all functions, entire frequency range	5 s		
	Restricted to < 500 MHz, all functions	2 s		
	Restricted to ≥ 500 MHz, all functions	2 s		
	Restricted to Trace and Statistics function, entire frequency range	20 ms		
Measurement error due to harmonics (Note 15) *n*: multiple of carrier frequency	*n* = 3	≤ 4 GHz	4 GHz to 12 GHz	>12 GHz
	-60 dBc	< 0.004 dB	< 0.003 dB	< 0.003 dB
	-40 dBc	< 0.035 dB	< 0.030 dB	< 0.250 dB
	-20 dBc	< 0.350 dB	< 0.300 dB	< 0.250 dB
	n = 2	≤ 4 GHz	4 GHz to 8 GHz	>8 GHz
	-60 dBc	< 0.001 dB	< 0.002 dB	< 0.003 dB
	-40 dBc	< 0.010 dB	< 0.015 dB	< 0.025 dB
	-20 dBc	< 0.100 dB	< 0.150 dB	< 0.250 dB
Change of input reflection coefficient with respect to power	-70 dBm to –10 dBm	< 0.001		
	-10 dBm to 0 dBm	< 0.004		
	-10 dBm to +10 dBm	< 0.005		
	-10 dBm to +23 dBm	< 0.010		
Calibration uncertainty (Note 16)	50 MHz to 100 MHz	0.07 dB (1.5 %)		
	> 100 MHz to 3 GHz	0.06 dB (1.3 %)		
	> 3 GHz to 8 GHz	0.07 dB (1.5 %)		
	> 8 GHz to 13 GHz	0.08 dB (1.8 %)		
	> 13 GHz to 18 GHz	0.09 dB (2.1 %)		
Interface to host	Power supply	+5V DC @ max. 2A Via 2.1mm I.D. (+), 5.5mm O.D. (-)		
	Remote control	As a USB device (function) in full-speed mode, compatible with USB 1.0/1.1/2.0 specifications		
	Trigger input/output	TTL compatible		
	Connector type	six-pole cylindrical straight plug (remote), SMB (trigger)		
	Permissible total cable length	≤ 5 m		
Dimensions	W × H × L	60 mm × 60 mm × 150 mm		
	Lenght including connecting cable	1.6 m		
Weight		< 0.45 kg		

Note 13: Valid for Repeat mode, extending from the beginning to the end of all transfers via the USB interface of the power sensor.

Note 14: To increase measurement speed, the power sensor can be operated in buffered mode. In this mode, measurement results are stored in a buffer of user-definable size and then output as a block of data when the buffer is full. To enhance measurement speed even further, the sensor can be set to record the entire series of measurements when triggered by a single event. In this case, the power sensor automatically starts a new measurement as soon as it has completed the previous one.

Note 15: Magnitude of measurement error referenced to an ideal thermal power sensor that measures the sum power of carrier and harmonics. For power levels below –10 dBm, the specifications for $2 \cdot f_0$ ($3 \cdot f_0$) can be lowered by a factor of $\sqrt{10}$ (10) per 10 dB below –10 dBm. Example: At 12 GHz/–30 dBm, the influence of the second harmonic, suppressed by 20 dBc, will cause an error of max. 0.25 dB / 10 = 0.025 dB. Standard uncertainties can be assumed to be half the values.

Note 16: Expanded uncertainty (k = 2) for absolute power measurements on CW signals at the calibration level (–10 dBm) within a temperature range from +10 °C to +30 °C and at the calibration frequencies (50/55/60/68/80/100/200/300/400/499.99/500/600/720/850/1000/1500 MHz), from 2 GHz to the upper frequency limit in steps of 0.5 GHz. Specifications include zero offset and measurement noise (up to a 2σ value of 0.01 dB).

18 Dec 2012 201216