

## ComScire QNG Model: PQ4000KS Validation Tests of Randomness

### ComScire QNGmeter: Continuous Random Number Tester

The ComScire QNGmeter is a continuous statistical tester (Real-Time) that uses five powerful and fundamentally different tests on the input data. Unlike other statistical test suites it is designed to measure the quality of randomness of a continuous sequence of bits up to tens of Terabits in length. The QNGmeter automatically performs metatests of subsequences, which would have to be done manually by other popular test suites. Every QNG Model PQ4000KS is tested extensively after production and finally just before shipment using the QNGmeter test suite.

The five tests are:

- 1) 1/0 Balance – nominal expected value is  $p(0) = p(1) = 0.5$ ,
- 2) Auto Correlation - orders 1 up to 32, nominal expected value is 0.0 for all orders,
- 3) Entropy Test – nominal expected value is  $H = 1.0$ , an update of U. Maurer's "Universal Test" (J-S Coron, *LNCS*, Vol. 1560, pp29-42, 1999),
- 4) Serial Test - (Good, I. J, The serial test for sampling numbers and other tests for randomness, *Proc. Camb. Philos. Soc.* Vol. 49, 1953),
- 5) OQSO – Overlapping-Quadruples-Sparse-Occupancy test, nominal expected value for the mean = 141909.47 and standard deviation (by simulation) = 294.63 (G. Marsaglia and A. Zaman, *Computers Math. Applic.*, Vol. 26, No. 9, pp 1-10, 1993).

The z-scores, p-values, and chi-square (metatest) p-values are presented for each test. In addition, current test run time information, such as *Bits Tested*, *Elapsed Time*, *Throughput*, and *Bits Tested %*, is displayed by the tester. *Bits Tested* is the total number of bits tested. *Elapsed Time* is the time from the start of the current test run. *Throughput* is the input data rate in bits per second. *Bits Tested %* is the percent of the total bits tested. This value might be less than 100% due to limited CPU resources.

Each test uses blocks of data of varying lengths, depending on the specific test. The 1/0 Balance and Auto Correlation tests use a block size of 65536 bits. The Serial test has a block size of 262144 bits. The Entropy test has 4194304 bits in a block. The OQSO test uses 10485775 bits per block.

A z-score is calculated for every test for each data-block. The z-scores are converted to probabilities with the assumption they are normally distributed. The z-scores of the 1/0 Balance, Auto Correlation and Serial tests and their associated p-values displayed are cumulative for all blocks. The z-scores of the Entropy and OQSO tests are combined by

summing the z-scores of all blocks and dividing by the square root of the number of blocks, respectively.

A second level of testing is applied to the p-values calculated from the z-scores for each block of data. The z-scores are expected to be normally distributed and hence their associated p-values are expected to be uniformly distributed. A chi-square test is applied to the individual p-values from each of the five tests. The chi-square tests are cumulative and their results are displayed as probabilities. If these chi-square p-values converge to 0.0 or 1.0 for any test, the assumption of randomness fails, indicating non-random patterns in the data being tested.

A third level of testing is applied to all of the individual chi-squared tests. A Kolmogorov-Smirnov (KS) test is first applied to the probabilities of chi-squared results of all orders of auto correlation being tested to reduce the auto correlation results to a single number. A meta KS test is finally calculated using the auto correlation KS result and the probabilities of the chi-squared results of the remaining tests. The meta KS(+) and KS(-) probabilities are displayed. Convergence toward 1.0 or 0.0 indicates failure.

If any cumulative z-score exceeds  $\pm 4.265$  standard deviations the generator will be determined as failed. Failure is also pronounced if the probability of any chi squared test is less than 0.00001 or greater than 0.99999, or if the probability of either of the Meta KS results is less than 0.0001 or greater than 0.9999.

For the hardware validation report, the QNGmeter tests were completed on a QNG Model PQ4000KS for approximately 5.18 trillion random bits. All metatest results for the device are recorded in the following table.

ComScire QNGmeter 5.18 Trillion Bits Test			
Testing QNG Device S/N QWR600X1			
Run Time Information		Autocorrelation	
Bits Tested	5.18E+12	Order	p ( $\chi^2 \leq x$ )
Time Elapsed	15:00:00:00	1	0.173
Throughput	4.00E+06	2	0.833
Meter	40.2+	3	0.171
1/0 Balance		4	0.396
p ( $z \leq x$ )	0.687	5	0.326
p ( $\chi^2 \leq x$ )	0.576	6	0.462
Entropy Test		7	0.281
p ( $z \leq x$ )	0.405	8	0.720
p ( $\chi^2 \leq x$ )	0.600	9	0.225
Serial Test		10	0.048
p ( $z \leq x$ )	0.369	11	0.115
p ( $\chi^2 \leq x$ )	0.520	12	0.894
OQSO (Monkey Test)		13	0.810
p ( $z \leq x$ )	0.239	14	0.865
p ( $\chi^2 \leq x$ )	0.072	15	0.663
AC Meta KS- Test		16	0.018
KS-	0.375	17	0.597
Meta KS Test		18	0.021
KS+	0.846	19	0.736
KS-	0.332	20	0.031
		21	0.882
		22	0.159
		23	0.236
		24	0.988
		25	0.300
		26	0.231
		27	0.013
		28	0.896
		29	0.568
		30	0.771
		31	0.787
		32	0.876