Modeling the Raspberry Shake Analog Circuit with LTSpice

The following pages detail the results of noise modeling the analog circuitry and geophone of the Raspberry Shake Seismometer using LTSpice. They include graphs of geophone and circuit noise referenced to both the input and output and plotted vs. frequency and period. There is also a plot of the Analog instrument gain, which is ~85 V per m/s in the center of its response band. That analog output goes to a 24-bit A/D which has a total input span of ±1.5V, providing a resolution of ~1.788E-8 V per count and giving an overall instrument resolution of 2.09E-10 m/s per count.

The principal noise contribution of the geophone is from the Johnson noise of its 380Ω coil resistance. It contributes less noise than the electronics, tracking at long periods 8.3dB below the total circuit noise. Its Brownian noise will be about -163dB, which is 11dB below the lowest point on the circuit noise curve, at ~2Hz. The geophone will contribute less than 1/2 dB to the total instrument noise. We can see that the theoretical electrical noise is within 16dB of the New Low Noise Model at 2 Hz and within 8dB at 1/2 Hz.

Not included here are the effects of varying temperature on the geophone spring, noise introduced by associated circuits, thermal EMF variation or digitizer noise. These could be significant.

The plots are of Acceleration power spectral density. The input-referred plots show the amount of ground noise which would be equivalent to the Shake's internal analog noise. The output-referred plots show the power spectral density of the signal provided to the input of the A/D, assuming zero ground noise.

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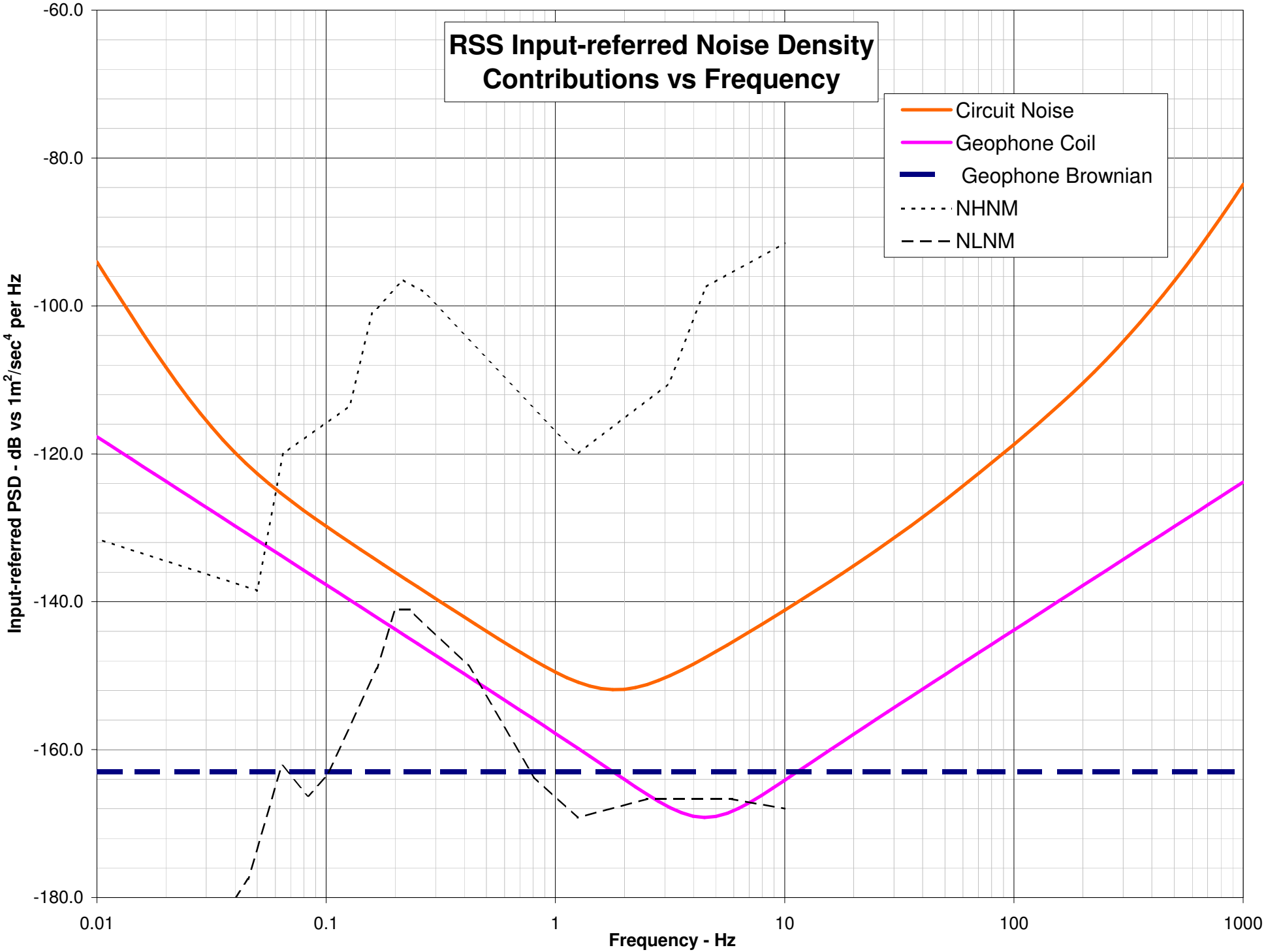
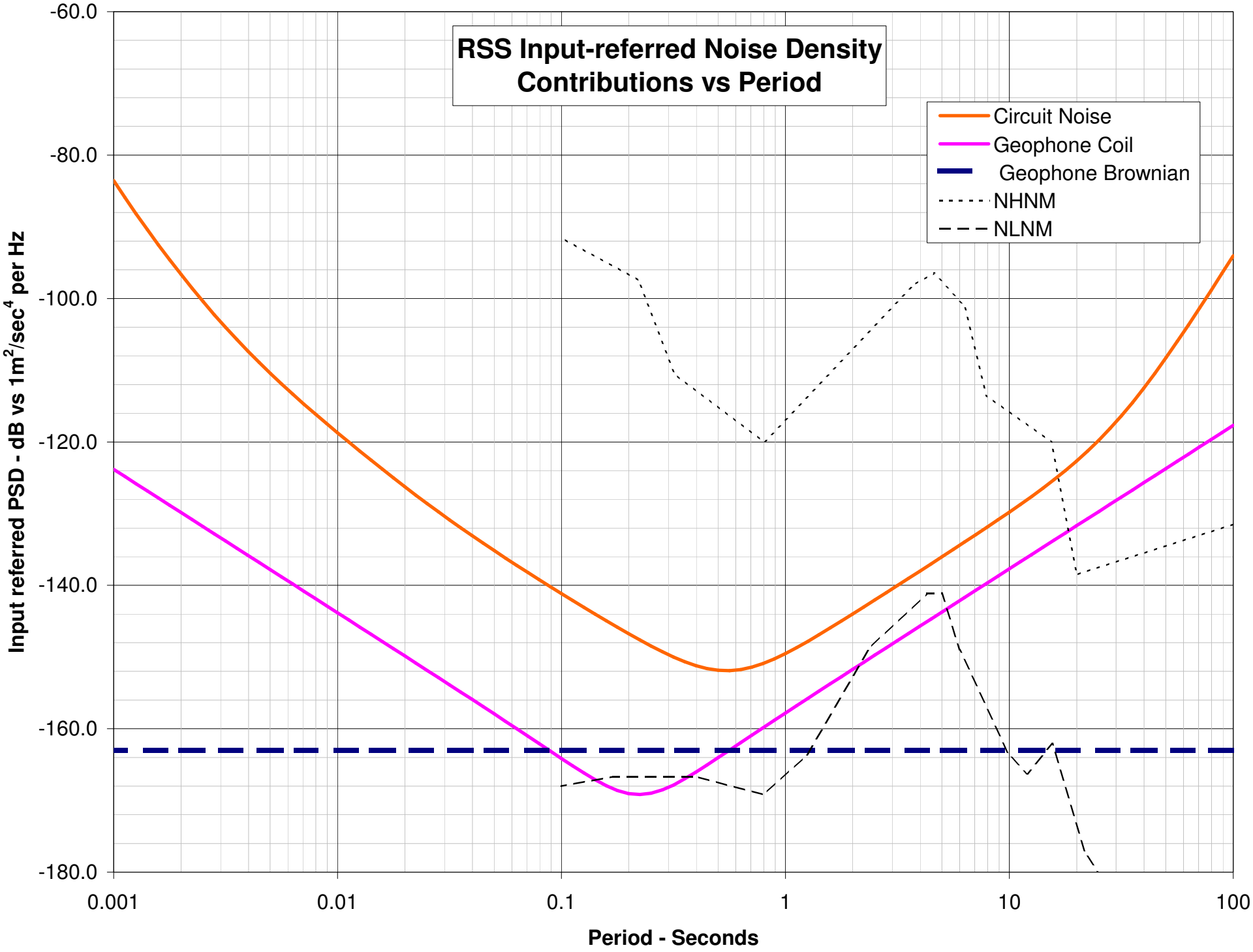
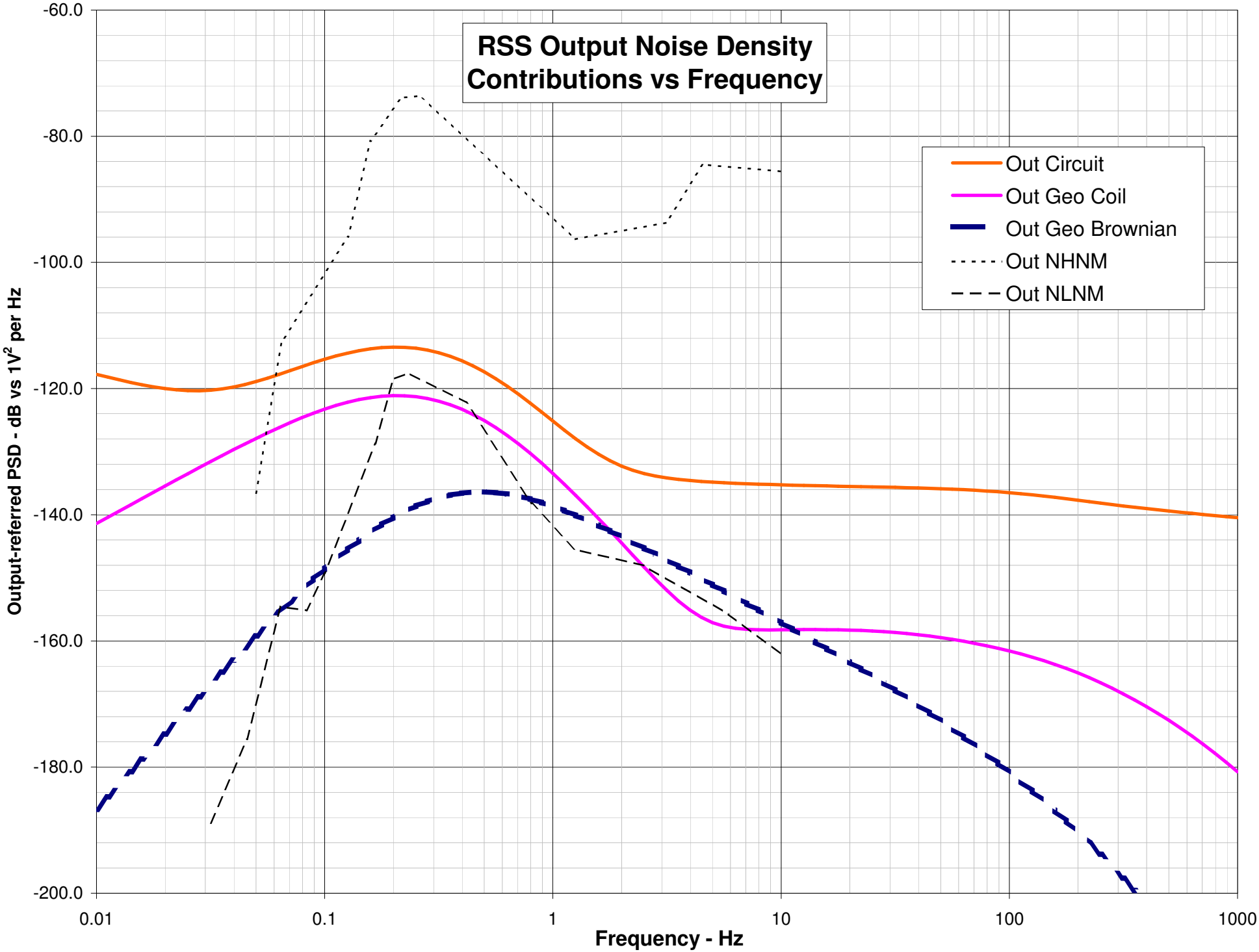
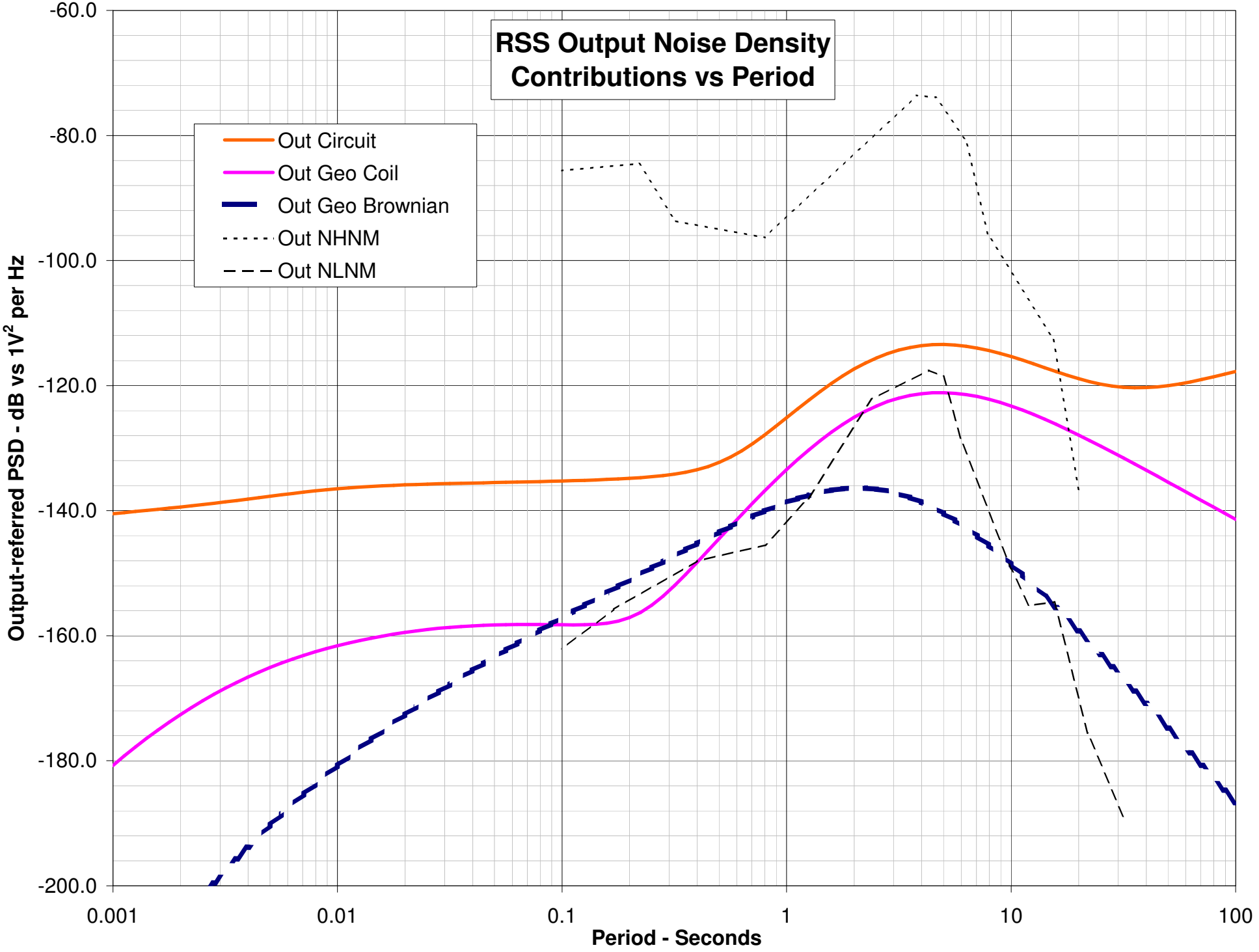
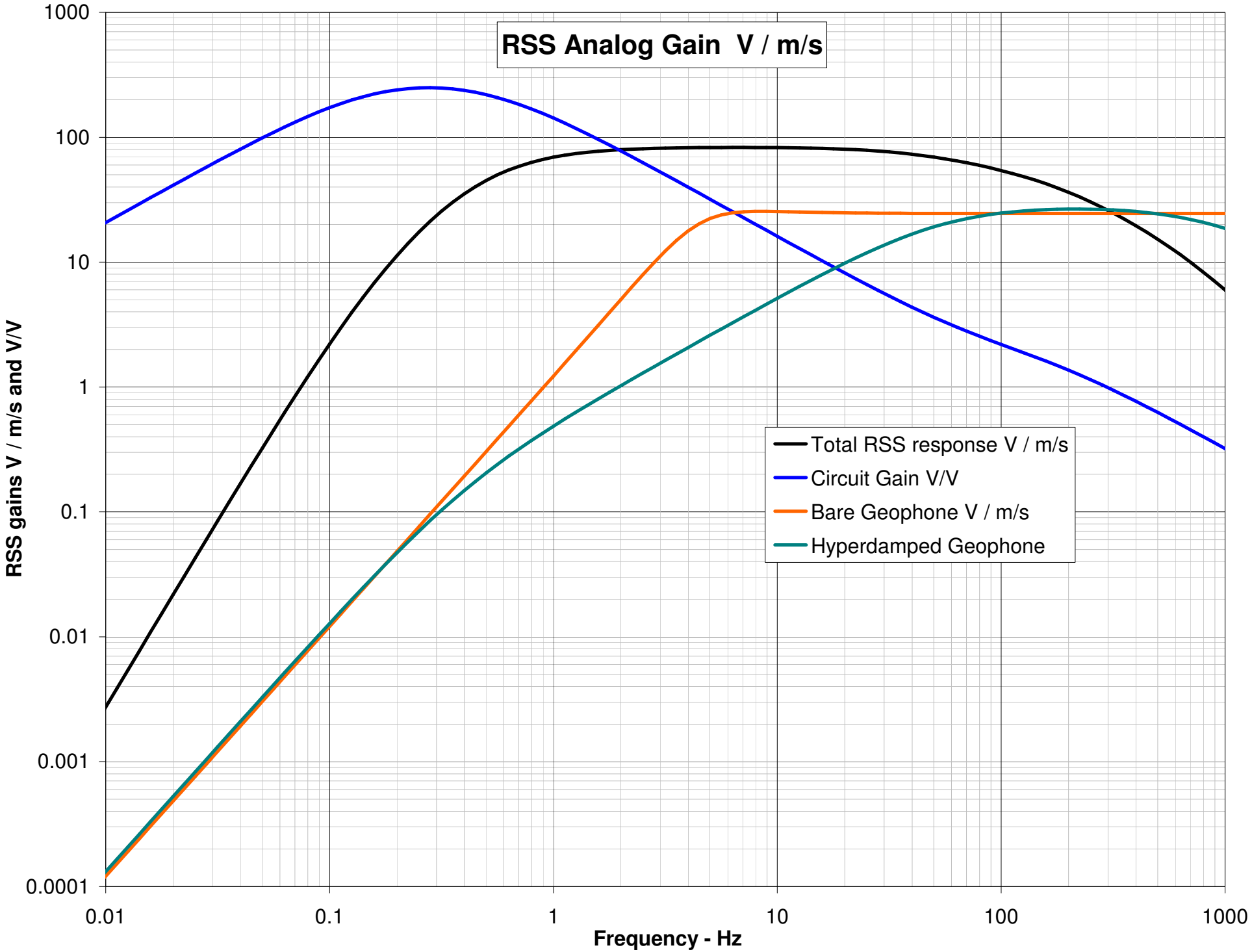
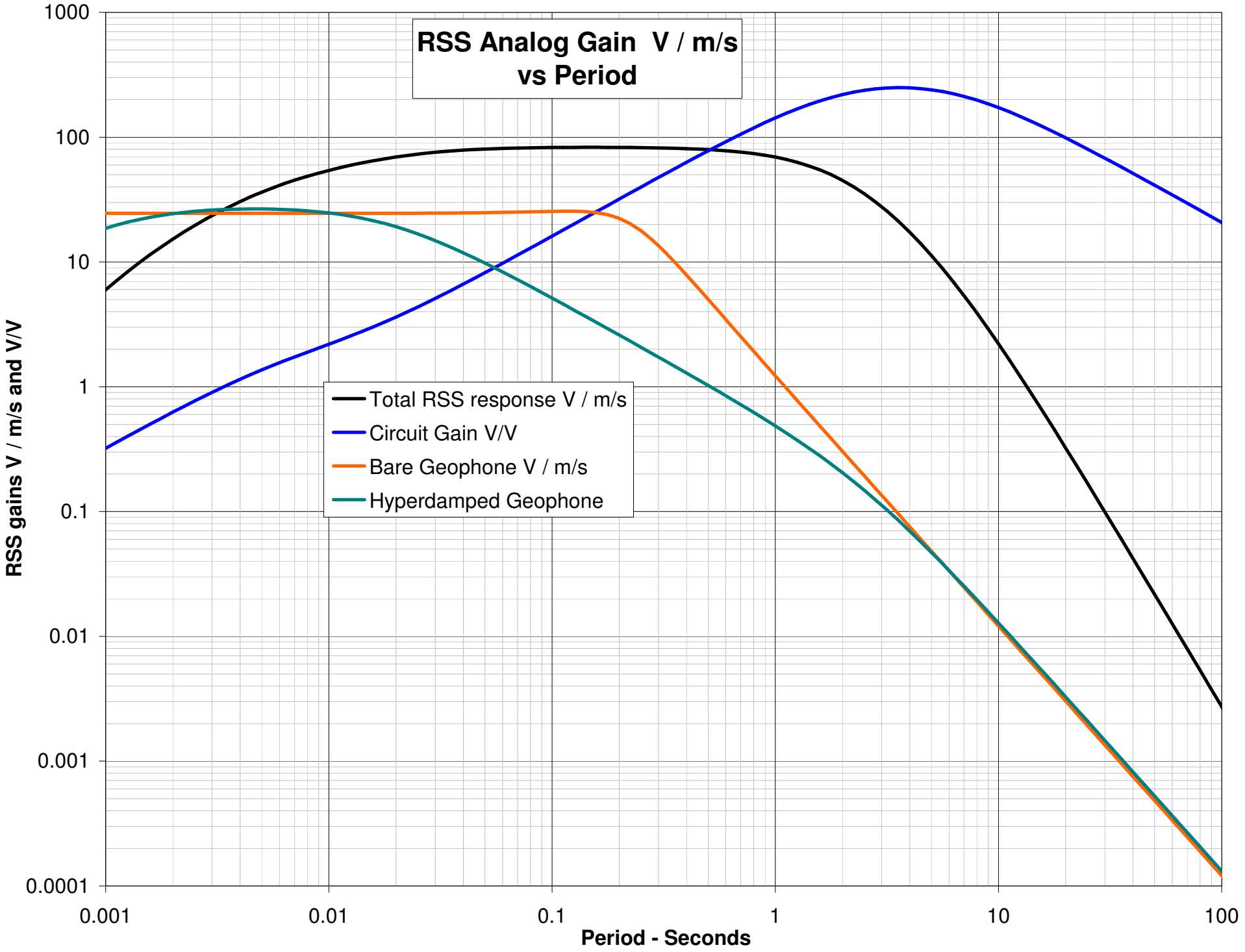

RSS Input-referred Noise Density Contributions vs Frequency
Circuit Noise
Geophone Coil
Geophone Brownian
NHNM
NLNM
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
Input-referred PSD - dB vs 1m²/sec⁴ per Hz
0.01
0.1
1
10
100
1000
Frequency - Hz


RSS Input-referred Noise Density
Contributions vs Period
Circuit Noise
Geophone Coil
Geophone Brownian
NHNM
NLNM
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
0.001
0.01
0.1
1
10
100
Input referred PSD - dB vs 1m²/sec⁴ per Hz
Period - Seconds


RSS Output Noise Density
Contributions vs Frequency
Out Circuit
Out Geo Coil
Out Geo Brownian
Out NHNM
Out NLNM
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
-200.0
0.01
0.1
1
10
100
1000
Output-referred PSD - dB vs 1V² per Hz
Frequency - Hz


RSS Output Noise Density
Contributions vs Period
Out Circuit
Out Geo Coil
Out Geo Brownian
Out NHNM
Out NLNM
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
-200.0
Output-referred PSD - dB vs 1V2 per Hz
0.001
0.01
0.1
1
10
100
Period - Seconds


RSS Analog Gain V / m/s
RSS gains V / m/s and V/V
1000
100
10
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
100
1000
Frequency - Hz
Total RSS response V / m/s
Circuit Gain V/V
Bare Geophone V / m/s
Hyperdamped Geophone


RSS Analog Gain V / m/s
vs Period
1000
100
10
1
0.1
0.01
0.001
0.0001
RSS gains V / m/s and V/V
0.001
0.01
0.1
1
10
100
Period - Seconds
Total RSS response V / m/s
Circuit Gain V/V
Bare Geophone V / m/s
Hyperdamped Geophone