Kit Review

TESTING THE NORTH CREEK BOREALIS LOUDSPEAKER KIT

By Joseph D'Appolito

I ran a series of impedance, frequency-response, and distortion tests on the North Creek Borealis loudspeaker kit constructed by Mark Florian (*SB* 6/00). *Figure 1* is a plot of system-impedance magnitude and phase. At low frequencies the plot displays the double-peaked curve of a vented system. The impedance minimum of 9.28Ω at 30Hz indicates the vented-box resonant frequency. At 170Hz there is a second local minimum impedance of 5.95Ω.

In addition to the two impedance peaks at low frequencies, a third peak occurs at 1kHz, where the woofer and tweeter crossover networks interact to form a parallel resonance. Impedance phase lies between +36° and –63° over the full audio range.

The impedance difference of 3.3Ω between the two minima just mentioned indicates a problem with vented system efficiency and low-frequency cone control. I'll discuss this point further shortly.

FREQUENCY RESPONSE

Figure 2 shows the Borealis's far-field frequency response with the microphone placed along the front-baffle axial centerline on a level with the bottom of the tweeter flange at a distance of 1.2m. This is a quasi-anechoic response,[1] which is valid above 200Hz. The plotted response has been normalized to 1m to obtain system sensitivity.

Near-field woofer and port responses (*Fig. 3*) are summed by the MLSSA system, giving proper weighting to the difference between the woofer and port areas, to obtain the complete near-field system response.[1] The validity of this approach is somewhat compromised in this instance by the straws filling the vent tube. These straws take up room and decrease the effective area of the port. I assumed that the port area is reduced by 40%. Fortunately, the final result is not too sensitive to this assumption.

In a typical vented system, woofer response will dip sharply at the box-tuning frequency. The dip, typically on the order of 15–20dB, indicates that woofer cone motion is greatly reduced and that response at this point is coming predominantly from the port. The reduction of cone motion at low frequencies is one of the advantages in using a vented alignment.

In the Borealis the woofer near-field response dip is much shallower than in other systems I have tested. The port is contributing only about 8dB to system output at the box-tuning frequency. Furthermore, woofer cone motion at this frequency will be two to four times greater than that of a more typical vented system at the same SPL level. The straws in the vent tube appear to increase port flow resistance, which lowers port Q and appears as an elevated resistive component in the measured impedance at the f_B. All things being equal, increased cone motion should result in higher low-frequency distortion, but as you will see, the superior linearity of the Scan-Speak woofer motor and suspension produce rather low distortion products.

The system near-field response (*Fig. 3*) is spliced to the quasi-anechoic response (*Fig. 2*) at 234Hz to get the full-range response without the use of an anechoic chamber. This result is shown in *Fig. 4*. Average sensitivity over the two octaves centered on 1kHz is 84.2dB/2.83V/1m. Relative to this level, the –3dB points fall at 39Hz and 20kHz. Response slopes gently downward by 2.5dB between 100Hz and 15kHz.

CUMULATIVE SPECTRAL DECAY

The cumulative spectral decay (CSD) response (*Fig. 5*) shows the frequency content of the system response following a sharp impulsive input at time zero. On the CSD plot, frequency increases from left to right and time moves forward from the rear. Each slice represents a 0.11ms increment of time. The total vertical scale covers a dynamic 30dB range.

Ideally the response should decay to zero instantaneously. Inertia and stored energy that take a finite amount of time to die away, however, characterize real loudspeakers. A prominent ridge parallel to the time axis indicates the presence of a strong system resonance.

The first time slice in *Fig. 5* (0.00ms) represents the system frequency re-

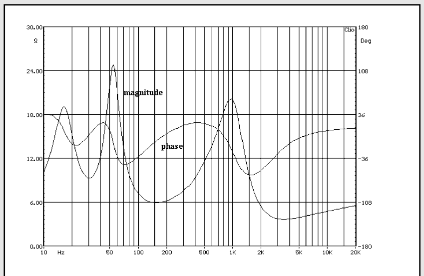

FIGURE 1: North Creek Borealis system impedance.

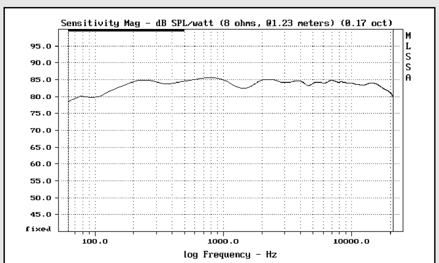

FIGURE 2: Borealis far-field quasi-anechoic response.

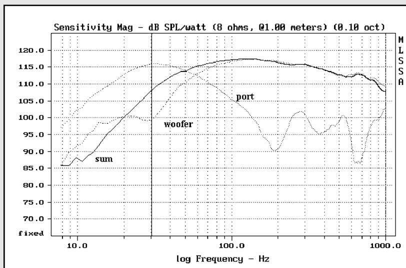

FIGURE 3: Near-field response of port, woofer, and their sum.

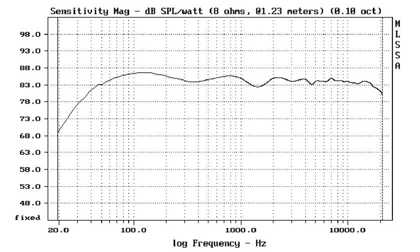

FIGURE 4: Borealis full-range frequency response.

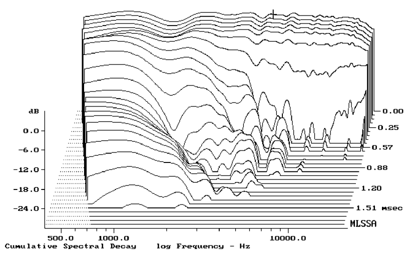

FIGURE 5: Borealis cumulative spectral decay.

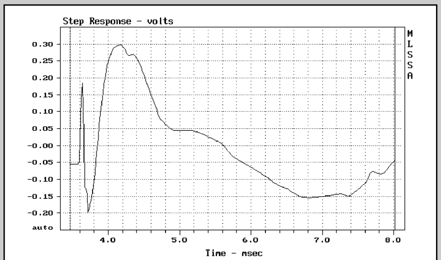

FIGURE 6: Borealis step response.

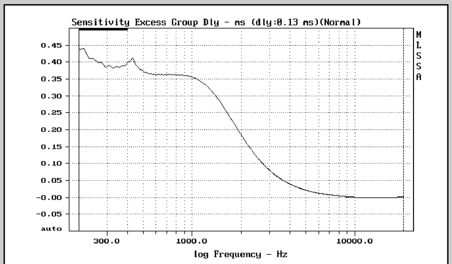

FIGURE 7: Borealis excess group delay.

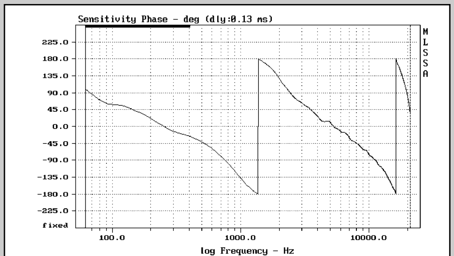

FIGURE 8: Borealis phase response referenced to the tweeter.

sponse. There are no strong ridges in the CSD. Tweeter decay is rapid and well controlled. The woofer and its crossover network control decay response below 3kHz. The overall decay performance is quite good.

SYSTEM STEP RESPONSE

A plot of system step response (*Fig. 6*) is obtained by a numerical integration of the system impulse response. The ideal step response should be a single rapid rise followed by a smooth decay through the 0.00 level. *Figure 6* shows two separate arrivals of acoustic energy. The initial, sharper positive spike is the tweeter arrival, followed by the woofer arrival, peaking about 0.4ms later. Both drivers are connected with positive polarity, but the system is not time coherent.

A better view of this behavior is a plot of excess group delay versus frequency referenced to the tweeter's acoustic phase center (*Fig. 7*). This is a plot of delay in milliseconds versus frequency. (See a detailed description of excess group delay in reference 1.) In a time-coherent system this plot would be a flat line.

Above 10kHz excess group delay is essentially zero, as it should be since it is referenced to the tweeter in this frequency range. The curve rises gradually below 10kHz, reaching a plateau below 1kHz of roughly 360µs, or 0.36ms. This plot shows that over its operating frequency range, the woofer is 360µs behind the tweeter. System phase response referenced to the tweeter's acoustic phase center is plotted in *Fig. 8*.

POLAR RESPONSE

Polar response is examined in *Figs. 9* through *12*. *Figure 9* is a waterfall plot of horizontal polar response in 10° increments from 60° left to 60° right when facing the speaker. All off-axis plots are referenced to the on-axis response, which appears as a straight line at 0.00°. For good stereo imaging, the off-axis curves should be smooth replicas of the on-axis response, with the possible exception of some tweeter rolloff at higher frequencies and larger off-axis angles.

You can see the expected rolloff of tweeter response at higher frequencies and larger off-axis angles. This performance is fairly typical of 28mm dome tweeters, which are deliberately mounted off center on the Borealis front baffle. At higher frequencies you should expect left/right differences in polar response.

Table 1 lists the left and right off-axis responses at 15kHz and all angles up to ±60°. This table is for the tweeter mounted to the right of the baffle centerline. *Figure 10* compares horizontal response at 30° left and right. The two responses track closely out to about 4kHz. Above 4kHz, however, response to the left averages 2dB above response to the right.

There is a broad dip in horizontal polar response centered on 1k4Hz at larger off-axis angles. This dip reaches 5.3dB at ±60°. This may cause some subtle changes in spectral balance with position due to changes between direct and reverberant sound levels.

The average response over a 60° horizontal angle (±30°) in the forward direction is shown in *Fig. 11*, where you can clearly see the broad dip centered on 1k4Hz. The general downward trend in response above 2kHz is also apparent. Notwithstanding these small problems, this is excellent horizontal coverage and suggests good direct-field coverage in the primary listening area with only small changes in timbre with position. Image stability should be very good.

Figure 12 is the waterfall plot of vertical polar response. Responses are shown in 5° increments from 20° below (–20°) the tweeter axis to 20° above it. Response between +10 and –5° is within 1dB of the on-axis response over the entire frequency range. The smoothest response, however, is at 0° and –5°. At larger angles you see broad dips forming around 1k7Hz, due to the selected crossover frequency.

HARMONIC DISTORTION

I ran harmonic-distortion tests at an average SPL of 90dB at 1m. Ideally, these tests should occur in an anechoic environment. In practice, it is important to minimize reflections at the microphone during these tests. Out-of-phase reflections can produce false readings by reducing the level of the fundamental while boosting the amplitude of the harmonic. In order to reduce the impact of reflections, I placed the microphone at 0.5m from the loudspeaker.

Figures 13 and *14* show second and third harmonic-distortion levels in dB SPL versus frequency plotted in one-sixth octave steps. System frequency response is also plotted on these figures.

The second and third harmonic-distortion levels at 50Hz are 3.5% and 1.8%, respectively. All system harmonic distortion is well below 1% above 105Hz. Tweeter harmonic distortion is below 0.2% at all frequencies. This is excellent performance.

INTERMODULATION DISTORTION

I next measured intermodulation distortion. In this test two nearby frequencies are input to the speaker. Intermodulation distortion produces output frequencies that are not harmonically related to the input. These frequencies are much more audible and annoying than harmonic distortion.

Let the symbols f_1 and f_2 represent the two frequencies used in the test. Then a second-order nonlinearity will produce intermods at frequencies of $f_1 \pm f_2$. A third-order nonlinearity generates intermods at $2f_1 \pm f_2$ and $f_1 \pm 2f_2$.

I first examined woofer intermods by inputting 900Hz and 1kHz signals at equal levels. These frequencies should appear predominantly in the woofer output. I adjusted total SPL with the two signals to 90dB at 1m. The Borealis system output spectrum for this test is shown in *Fig. 15*. The two largest spectral lines represent the input signals.

The largest distortion product—second order at 1k9Hz—is 59.5dB below the main output, which is equivalent to 0.105% distortion. This is better than many solid-state amps and most tube amps! The lines each side of the 1k9Hz line at 1k8 and 2kHz are harmonic-distortion components.

I measured tweeter intermods with a 10 and 11kHz input pair also adjusted to produce 90dB SPL at 1m (*Fig. 16*). A number of intermodulation-distortion products appear at 1kHz intervals on the plot. The largest intermods are at 9 and 12kHz. Total IM distortion is 0.27%.

The last IM test examines cross intermodulation between the woofer and tweeter using frequencies of 900Hz and 10kHz. (A 1kHz signal would produce intermods that fall on harmonic-distortion lines, confusing the results.) Ideally, the crossover should prevent high-frequency energy from entering the woofer and low-frequency energy from entering the tweeter.

This spectrum resulting from this test is shown in *Fig. 17*. The largest IM product at 10.9kHz is 64.9dB below the main output. Total distortion is only 0.06%. This is the lowest level of cross IM I have ever measured.

ADDITIONAL TESTS

I conducted all of these tests with the grille off. *Figure 18* shows the response of the Borealis system with the grille on, but referenced to the response with the grille off. That is, it plots the difference in response under the two conditions.

Below 1kHz the grille has little effect. Above 1kHz, however, it causes ragged response deviations of 4.5dB peak-to-peak. There isn't much point in fabricating a grille for this system unless for cosmetic reasons.

Two samples of the Borealis system were available for testing. The two units were arbitrarily labeled 1 and 2. I conducted all of the tests described so far with the 2 sample.

One question of interest is, "How well do the two samples match?" *Figure 19* provides the answer. It is a plot of the response difference between the 1 and 2 samples. The two systems match by better than 1dB over most of the frequency range. The discrepancy does rise to 1.2dB for a brief interval around 17kHz.

MARK FLORIAN'S COMMENTS ON MEASUREMENT RESULTS

The impedance plot of the Borealis *(Fig. 1)* shows a difference of resistance in the troughs of about 3.3Ω, evidently due to the straws inserted into the port.

To further explore this, I removed the straws from one port and listened to the difference when feeding the speaker a sine wave between 18 and 40Hz. The difference is very noticeable. The port with the straws is much quieter and exhibits very little "chuffing" or "whistling," even at large excursions. The unstuffed port is much noisier at normal levels and becomes even more so at large excursions.

Using a calibrated Mitey-Mike and a Loftech TS-2 dB meter, I measured the output of the ports. These measurements (*Fig. 6*) correspond well to what I heard. Perhaps a port with a flared collar would also reduce the noise without incurring the impedance penalty.

The frequency-response plot (*Fig. 4*) is quite smooth, save for the −2.5dB dip around 1500Hz. The distortion curves are very low, particularly IM distortion, no doubt due to the excellent motor design and construction of the Scan-Speak drivers. *Figure 18* proves that putting a wooden-frame grille on the Borealis is a mistake.

Following NC's instructions, I used black window screen instead of the more common cloth. But the main problem with grilles is not the fabric or screen, it's the frames, which cause diffraction problems. As always, the best frame is no frame. Finally, *Fig. 19* proves that matched drivers and crossover components are worth the effort and additional expense.

TABLE 1
LEFT/RIGHT POLAR RESPONSE AT 15KHZ

ANGLE	LEFT (DB)	RIGHT (DB)
10	-0.3	-1.4
20	-1.8	-3.8
30	-4.7	-6.6
40	-7.8	-10.1
50	-11.6	-14.2
60	-14.3	-16.7

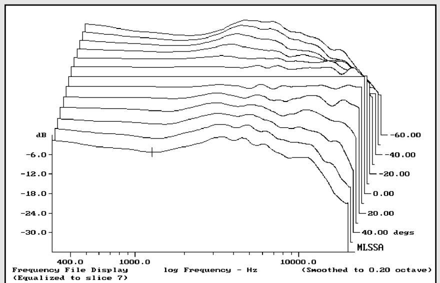

FIGURE 9: Borealis horizontal polar response.

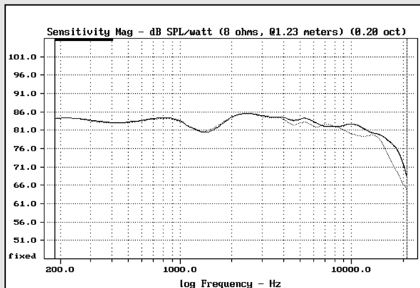

FIGURE 10: Borealis off-axis response: 30° left (solid), 30° right (dotted).

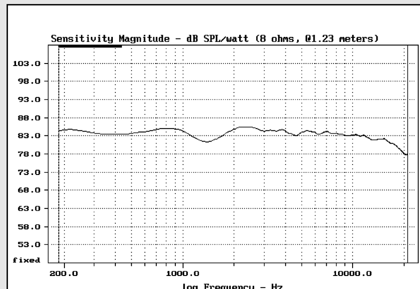

FIGURE 11: Borealis horizontal response averaged over ±30°.

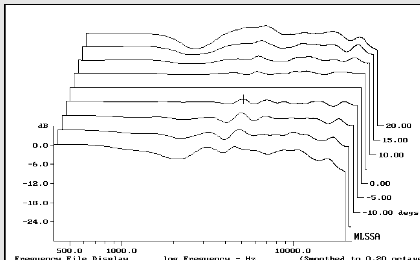

FIGURE 12: Borealis vertical polar response.

Manufacturer's response:

We would like to thank Mark Florian, Dr. Joseph D'Appolito, and *Speaker Builder* for their thorough review of the North Creek Borealis loudspeaker, and also for this opportunity to comment.

The North Creek Borealis is the least expensive North Creek-designed loudspeaker we offer.

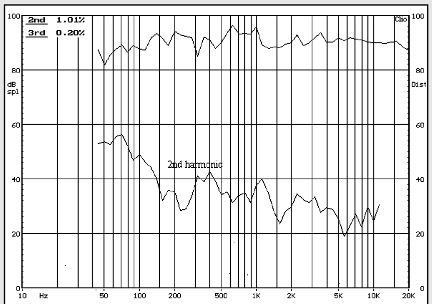

FIGURE 13: Borealis second harmonic distortion at 90dB.

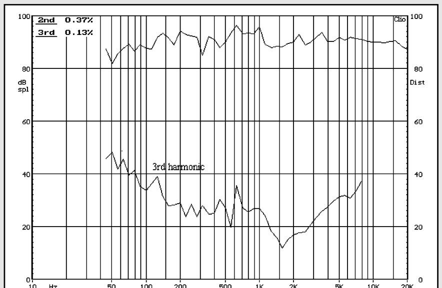

FIGURE 14: Borealis third harmonic distortion at 90dB.

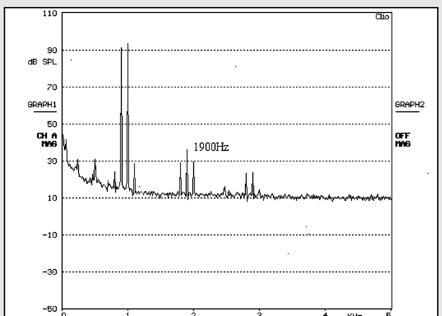

FIGURE 15: Woofer intermod distortion spectrum.

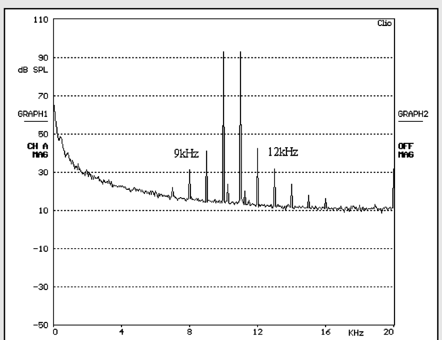

FIGURE 16: Tweeter IM distortion spectrum.

The price for the loudspeaker system, single wired and with "soft matched" drivers, is $695 per pair. As provided to Mark Florian, bi-wired and with broken-in, hand-matched "perfect pair" drivers, is $782 per pair. The cabinets are available separately, factory direct from Lee Taylor and Co. for $675 per pair.

This is a fair amount of money for a loudspeaker kit, but still represents an excellent value. The Scan-Speak drivers are beautifully made units that offer both subjective and objective performance that is far superior to most other drivers. They are hand-made using the latest technology, they are very expensive, and they are worth it. Likewise, the North Creek crossover components were developed by ear to match the Scan-Speak drivers, and, together with our construction techniques and extensive subjective design process, they allow the drivers to perform to their full potential. The retail cost of this loudspeaker would be three to five times the kit price.

Mr. Florian and Dr. D'Appolito brought up a few aspects of the loudspeaker which we feel deserve further discussion. First of all, the crossover.

The tweeter network is a simple attenuated second-order network with a resonance trap. The purpose of the trap is to minimize dome excursion around the tweeter's fundamental resonance by creating a frequency-specific short circuit across the tweeter leads. In essence, this trap is a frequency-specific electrodynamic "brake." A side benefit of the trap is that it also flattens the impedance the rest of the crossover network sees, so tweeter high-pass electrical slope will remain a smooth second-order throughout the stop band. The combination of the crossover's electrical slope, the driver's natural rolloff, and the boundary conditions created by the cabinet front result in a smooth high-pass transfer function that is approximately third-order.

The woofer crossover is a damped third-order topology, but is more precisely viewed as two cascaded first-order networks with a shelving function. This is possible because the Scan-Speak 18W/8545 has a perfect L+R impedance at high frequencies. L2 then acts as a simple first-order low pass, but the impedance the network sees before L2 on is still a simple L+R. C1 and R1 then become an impedance compensation "Zobel" of sorts. The combination of L1 and the C1, R1 "Zobel" become another first-order low pass, but by correctly tuning the C1 and R1, the transfer function is actually initially second order, shelving to first-order higher in frequency. The resulting acoustic transfer function of the entire network, combined with the baffle diffraction step and the 18W/8545's rising response before roll-off, is approximately third-order.

One can view the individual slopes of the drivers as well as the combined response on our web site—www.NorthCreekMusic.com. We will no longer provide component values, however.

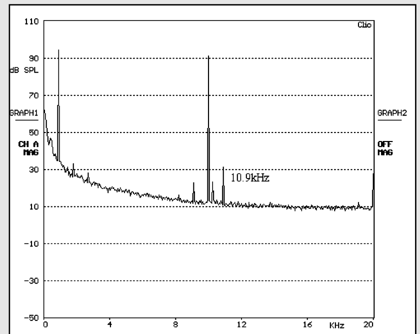

FIGURE 17: Cross intermodulation distortion spectrum.

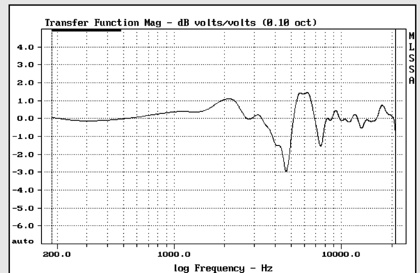

FIGURE 18: Effect of grille on Borealis system frequency response.

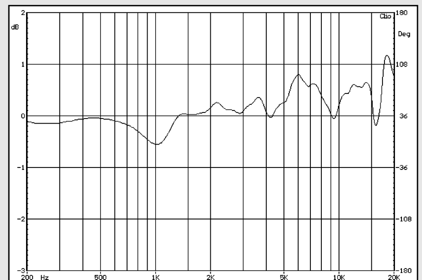

FIGURE 19: Borealis pair match.

A note on testing: The North Creek Borealis kit was tested in the laboratories of Audio and Acoustics, Ltd., using the MLSSA and CLIO PC-based acoustic data-acquisition and analysis systems with an ACO 7012 ½″ laboratory-grade condenser microphone and a custom-designed wideband, low-noise preamp. Polar response tests were conducted with the aid of a computer-controlled OUTLINE turntable on loan from the Old Colony Division of the Audio Amateur Corporation.

REFERENCES

1. J. D'Appolito, *Testing Loudspeakers*, Audio Amateur Corporation, Peterborough, NH, 1998.

A second area that requires more discussion is our method of port tuning, or "the straws."

It would be nice to say that it was invented here, but it was actually discussed first in writing by Dr. Neville Thiele himself, in an ASA journal in the late 1950s. The purpose of the straws in the port tube is to force laminar air flow through the port at high volume levels. Dr. Thiele found this to be more effective than flaring the port's egress, a method used by many manufacturers at the time and recently reinvented. The method we developed of tuning the port—by keeping the port tube length constant while changing the length of the straws in the port—allows the builder to control both the tuning frequency and port Q. This in turn allows the Borealis' low-frequency response to be precisely tuned to the builder's listening room and electronics.

Adding straws to the port will not work with most woofers because the additional flow resistance lowers Q1 and can cause the woofer to go into over-excursion, as Dr. D'Appolito points out. It works with the Borealis because the Scan-Speak 18W/8545 motor is constructed in such a way that over-excursion is not an issue. The benefit of forcing laminar flow through the port is the elimination of port noise, particularly at high volume levels, which Mr. Florian confirmed.

George E. Short III, President
North Creek Music Systems