EQUIPMENT **PROFILE**

D. B. KEELE, JR.

SUNFIRE TRUE SUBWOOFER MARK II POWERED SUBWOOFER

Honey," my wife asked, "is there a big truck in the driveway? Or are you making that rumbling noise?" It was just me, doing ground-plane tests of the Sunfire True Subwoofer Mark II in our driveway, about 20 feet from the room where she was. I was running a sine-wave sweep and had accidentally turned the woofer's gain up to maximum. The Sunfire's limiter was properly protecting the driver against overload, but the speaker was nevertheless generating its designed maximum low-frequency output—which obviously was quite substantial.

The True Subwoofer's rated response goes down to a low 18 Hz. Yet the whole package, including a very efficient, very high-powered, built-in amplifier, fits into an 11-inch cube, which is minuscule for a subwoofer of its output and frequency range.

When I first read Sunfire's spec sheet on this subwoofer, in late 1995, I was immediately excited about the possibility of a super-small subwoofer capable of producing real output down to 20 Hz and below. (I was also quite skeptical about Sunfire's seemingly extravagant performance claims, but I knew that Sunfire's founder, Bob Carver, has a strong track record for making good on his assertions.) I grew even more excited when I first saw and heard a demonstration of the True Subwoofer, at the 1996 Winter Consumer Electronics Show. (The Mark II is an updated version of the 1996 model, with improvements in the woofer and slight changes in the electronics.) A couple of times during the demonstrations, the high air velocities generated by the subwoofer actually sucked the draperies against the system's driver!

Bob is known for his expertise in electronics, not speakers. But he has long been known for devising novel solutions to knotty audio problems. So, coming relatively fresh to speaker design may actually have helped, by letting him look at its problems with a fresh eye. He is to be commended for a very challenging design that a more experienced speaker designer might not have even attempted.

Sunfire's 13-page white paper, written by Bob Carver, goes into great detail on the True Subwoofer's operation, in ways that depart significantly from conventional engineering explanations. He discusses speakers as electric motors (which they are, albeit motors whose loads go back and forth instead of rotating), using an electric-motor concept called the stall ratio (see "The Stall Ratio and Back-EMF").

Sunfire claims that the True Subwoofer is significantly more efficient than conventional subwoofers of comparable performance. Bob cites the difference in power drawn from the AC line by his subwoofer and the draw of a conventional amp driving a much larger, conventional subwoofer to the same sound pressure levels. He says the True Subwoofer's high efficiency results both from its exceptionally efficient ampli-

Rated Frequency Response: 18 to 80 Hz, +0, –3 dB.
Rated Output: Greater than 110 dB SPL from 18 to 80 Hz.
Rated THD: Typically less than 10% at rated output.
Low-Pass Crossover Adjustment Range: 35 to 75 Hz.
Dimensions: 11 in. H x 11 in. W x 11 in. D (27.9 cm x 27.9 cm x 27.9 cm).
Weight: 48 lbs. (21.8 kg).
Price: $1,299.
Company Address: P.O. Box 1589, Snohomish, Wash. 98290; 425/335-4748.
For literature, circle No. 90

Photos: Michael Groen

fier and from the design of the subwoofer itself. (However, he does not claim that the subwoofer is more efficient than large conventional woofers, only that it's a lot less inefficient than Thiele-Small parameters say a woofer its size should be.)

At each end of the True Subwoofer's cabinet is a 10-inch diaphragm with a large, protruding surround. However, the system has only one woofer; the other diaphragm is a passive radiator. The woofer and passive radiator have identical frames, cones, surrounds, and spiders and are each said to deliver very long excursions of 2.5 inches, peak to peak. But where the Sunfire's woofer has a voice coil and an extremely large magnet, its passive radiator has a 1.7-pound mass attached. The passive radiator's movement is governed solely by mass, compliance, and the air pressure in the enclosure. In effect, it is coupled to the woofer through the springiness of the air in the enclosure.

THE TRUE SUBWOOFER MANAGES TO GET 18-Hz RESPONSE FROM AN 11-INCH CUBE.

Passive radiators are sometimes referred to as drone cones or vent substitutes. (Bob prefers to call the one in the True Subwoofer a "mass-driven driver.") Essentially, a passive-radiator system is a vented-box enclosure, with the passive radiator replacing the port. The passive radiator enables large amounts of low-frequency acoustic power to be generated from small enclosures. A real vent small enough to fit such an enclosure would not have the same bass effect, nor would it have enough vent area to avoid turbulence. (Turbulence causes not only wind noise but also vent compression, a limiting effect that occurs when the vent's output stops rising as input power is increased.) The area of the Sunfire's passive radiator is quite large, however. And the passive radiator's mass helps tune the Sunfire's enclosure, whose volume is less than 1 cubic foot, to 20 Hz. For an 8-inch vent to have the same effect, it would have to be about 60 feet long—which means the vent tube's volume would be about 21 times that of the enclosure!

In a box this small, two large diaphragms making very large excursions generate extremely high air pressure—about 3 pounds per square inch, according to Sunfire (10 to 20 times the pressure in conventional enclosures)—and a total force of about 150 pounds on each cone. To supply such force requires a high-current woofer with a big voice coil and a strong magnetic field. The True Subwoofer's magnet, about twice the size of any I've seen on a production woofer, weighs 14 pounds. The beefy, four-layer, high-power voice coil is 3 inches in diameter and 2 inches long.

To deal with the large forces involved requires heavy-duty construction of the woofer and passive radiator. The surround and spider must be very stiff and strong, so that they do not deform in normal operation. The True Subwoofer's surround is therefore ⅛ inch thick and is composed of five separate layers of foam, compressed by heat and pressure.

The high current is supplied by one of Sunfire's very efficient Tracking Downconverter amplifiers, rated at an impressive 2,700 watts. The amplifier is operated directly from the AC power line, without an isolating power transformer. There's no shock hazard because the amp is in the same enclosure as the woofer, so you can't touch the amp's output connections, and its inputs are isolated via optocouplers, eliminating any direct connection between the input jacks and the power line. The Tracking Downconverter amplifier is extremely efficient because its power supply tracks the audio signal, thus limiting dissipation in the output transistors. (For further details, see *Audio*'s January 1997 review of the Sunfire Cinema Grand power amp or get Sunfire's white paper describing it.)

All of the True Subwoofer's electronics, controls, and input connections are mounted on an anodized aluminum plate, 0.2 inch thick and 10 inches square, that forms the subwoofer's rear panel. The complete rear-panel assembly (including input connections, controls, preamplifier, power amplifier, and power cord) weighs only 4½ pounds!

The controls on that panel include adjustments for bass level, crossover frequency, and phase, as well as a switch whose positions are labeled "Flat" and "Video Contour." (The latter position raises the cutoff from 20 to 30 Hz, which increases ex-

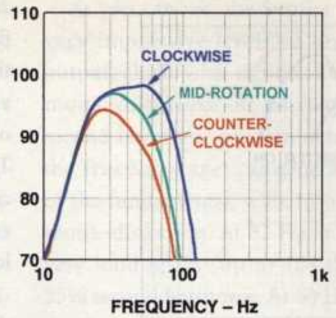

Fig. 1—Frequency response at crossover settings of 33, 55, and 75 Hz.

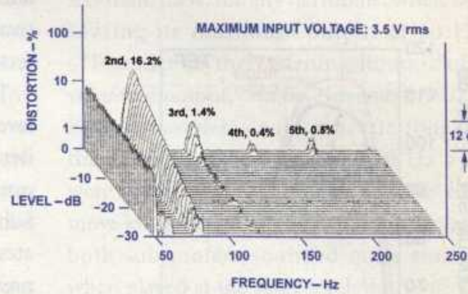

Fig. 2—Harmonic distortion spectrum for E_1 (41.2 Hz); 0 dB equals 3.5 volts rms.

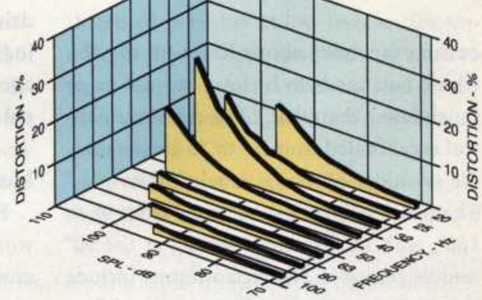

Fig. 3—Harmonic distortion vs. SPL and frequency.

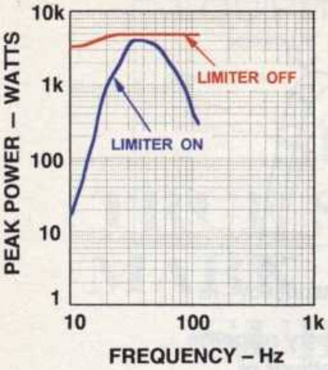

Fig. 4—Amp peak power, 4-ohm load.

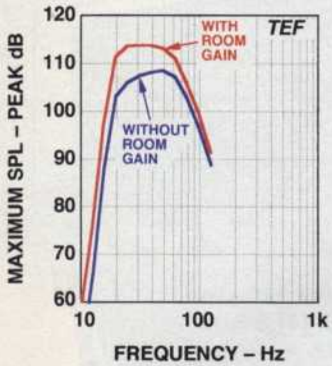

Fig. 5—Maximum peak sound output.

cursion capability above 30 Hz for movies, whose bass tends to be loud but not to go much lower than that.) The crossover control is calibrated from 35 to 75 Hz; its middle position, 55 Hz, is labeled "Normal." The phase control's range runs from 0° to 180°, with its "Normal" setting at the 90° middle position. The stereo inputs include line-level RCA jacks and speaker-level five-way binding posts spaced to accept double banana plugs. Stereo line-level outputs, passively high-passed via capacitors, are also provided.

Most subwoofers have stereo inputs that sum to mono. The True Subwoofer does, too, but instead of mixing the left and right signals equally, it mixes in 7.6 dB more of the left channel than of the right, to preserve some of whatever bass difference signals may be in a recording. This weighted summing takes place on the preamp board, which also holds the crossover and several types of filter and dynamic protection circuits. The filters include the switchable 20/30-Hz cutoff filter and equalization to flatten the woofer's response. To safeguard the amplifier and the woofer from overload and to prevent the system from generating objectionable noises when overdriven, the True Subwoofer has a thermal-protection circuit, a clipping eliminator (limiter), an excursion limiter, and a circuit that detects low back-EMF.

The thermal-protection circuit allows the amplifier to feed full sine-wave power into the woofer for up to about 2 minutes; it then reduces the power to prevent overheating. If the input level is reduced, the circuit resets automatically after a time. Sunfire claims that the circuit will never activate on any rational music or special-effects signal.

The True Subwoofer's maximum output level is set by the clipping eliminator, a limiter placed after the volume control to keep overly loud signals from driving the True Subwoofer to excessive distortion; it operates at all frequencies. The excursion limiter prevents the woofer from being overdriven below 25 Hz, by momentarily attenuating loud signals below that frequency by about 4 dB for several seconds, even if the input level drops during that period. Tied into the excursion limiter is the circuit that detects low back-EMF; it is designed to reduce the drive level at the woofer's vented-box tuning frequency, where the driver's impedance is lowest, in order to protect the internal amplifier.

Measurements

Figure 1 shows the Sunfire True Subwoofer's frequency response for three crossover settings. These are ground-plane measurements, the ones I was making on my driveway. The test microphone was on the concrete, 1 meter in front of the subwoofer (i.e., on the side opposite the rear panel), equidistant from the woofer and the passive radiator. To compensate for ground-plane gain, which doubles the pressure, I subtracted 6 dB from the measurements. The 2.83-volt rms input level used in testing passive speakers was above the Sunfire's excursion-limiting threshold, so I used an input signal of 0.5 volt rms (about 6 dB below that threshold) and raised the curves by 15.1 dB to compensate. The bass level control was set approximately midway, at its indicated 0-dB position. The cutoff switch was in its "Flat" position, and the phase control was set to "Normal/90°," its middle position. With these settings and a 20-Hz, 0.5-volt input signal, the excursion of the passive radiator was about 0.6 inch, peak to peak, and its driver's peak-to-peak excursion was about 0.1 inch.

With the crossover control fully clockwise, at its 75-Hz position, the response curve is fairly flat and covers a range of about 23 to 71 Hz between its –3 dB points. Set fully counterclockwise, at an indicated 35 Hz, the curve peaks at 28 Hz and covers the range of 20 to 42 Hz. The passbands between –6 dB points are roughly 20 to 80 Hz with the control fully clockwise, 19 to 59 Hz with the control at mid-rotation, and 18 to 52 Hz with the control at its lowest position. The highest crossover setting is significantly lower in the Mark II than it was in the first True Subwoofer, whose crossover control was calibrated from 40 to 120 Hz.

I had originally expected that the True Subwoofer would be somewhat delicate and that I'd have to be careful not to feed it a signal that would drive it to damaging excursion levels or overheat it. These concerns were unfounded; the Sunfire is very robust. I couldn't even get it to sound bad. Its limiters efficiently ensured that overload was always graceful, with only lower harmonics evident when the woofer was driven to extremes, no matter the frequency, the level, or how fast I applied the signal. The cabinet is so solid that its walls didn't vibrate at all

THE CONE EXCURSIONS, AND THE FORCES THEY PRODUCE, ARE DOWNRIGHT SCARY!

during my high-level sine-wave sweep. (The cabinet did move a bit, however, about which more later.) And when driven by high-level sine waves, the True Subwoofer's excursion and the forces it produces are downright scary! If you happen to touch the passive radiator's flat center when its excursion is large, you'll get a hard rap on your knuckles.

I measured excursions of about 1.4 to 1.5 inches, peak to peak—the greatest of any driver I've tested. (Sunfire quotes a still larger excursion, 2.5 inches, peak to peak, but says that's for a driver in free air, not in the enclosure.)

The woofer and passive radiator reached their maximum excursions at different frequencies, of course. The woofer's excursion peaked at 31 Hz, a frequency at which the passive radiator's excursion was fairly small. At 25 Hz, both moved equal distances. At 20 Hz, just about the True Subwoofer's resonant frequency, the woofer's excursion reached its minimum, while the passive radiator's extension was very large. Going lower, the excursion of both diaphragms increased again, with the passive radiator's maximum excursion at about 17 Hz and the woofer's at about 15 Hz. Below 15 Hz, the excursion of both elements dropped off rapidly. No dynamic offset was evident in the woofer's excursion (passive radiators don't exhibit offset).

The True Subwoofer's E_1 (41.2-Hz) harmonic distortion is seen in Fig. 2. Signal voltages up to 3.5 volts rms were applied to the left-channel speaker-level input and the volume control set at its midpoint. (At 41 Hz, this input signal and volume setting kept the level just below the threshold of the Sunfire's protection limiters and caused a woofer excursion of about 1.1 inches, peak to peak.) The second harmonic rises to a significant 16.2%, but the third harmonic reaches only a low 1.4% and higher harmonics are 0.5% or less. The Sunfire sounded quite effortless and powerful at this frequency. Total harmonic distortion was somewhat high, but because most of it was the comparatively benign second harmonic, it wasn't bothersome.

Table I shows the Sunfire's 20-Hz harmonic distortion at input levels ranging from 18 dB below the limiter's threshold of 0.25 volt rms to 30 dB above it. When this threshold was reached, the woofer's output was reduced by about 4 dB. At higher levels, the excursion increased somewhat but then reached a limit. Test conditions were the same as for Figs. 1 and 2, except that the volume control was turned up to maximum. The 20-Hz output levels do not include the effects of room gain. The "Total" distortion column lists the sum of the powers in the second through fifth harmonics. The data in the Table is referenced to the level of the fundamental alone, rather than to the total output of fundamental plus harmonics. This change from standard practice enables me to give distortion percentages greater than 100% where the harmonic's level exceeds the fundamental's.

As in Fig. 2, the second and third harmonics predominate in the tabulated measurements, even exceeding the speaker's output of the fundamental at levels 24 dB or more above the limiter's threshold—significantly so, at +30 dB. According to Bob Carver, this is no accident. At levels more than 12 dB above the limiting threshold, the electronic drive to the woofer is deliberately distorted to raise low-order (second- and third-) harmonic distortion; this makes the True Subwoofer sound louder when severely overdriven, although the fundamental does not get louder. At the 20-Hz test frequency, the additional distortion comes from the woofer (whose excursion is quite small) rather than from the passive radiator (whose excursion is very large at this point).

Figure 3 shows distortion for frequencies from 20 to 100 Hz at levels of 70 to 110 dB SPL, room gain included. The distortion percentages are for the sum of the powers of the first 10 harmonics, referenced to the power of the fundamental; this is not quite identical to total harmonic distortion, which includes the power in all harmonics. (Note that the SPL scale reflects the level of the fundamental alone, not counting harmonics.) The end point of each curve marks the level where output of the fundamental stopped increasing as the input level was raised.

As you can see, the Sunfire can generate very impressive levels of low-frequency output, albeit with significant second-harmonic distortion. At all frequencies, the second harmonic predominates. At 20 Hz, the True Subwoofer can generate 97 dB SPL of the fundamental, with 13% second-harmonic distortion. At 32 Hz, it can generate very loud levels (up to 104 dB) but with 25% second harmonic. At 50 Hz and above, the distortion does not exceed 3%.

How audible is this distortion? To check, I compared the True Subwoofer's sound to that of a Velodyne F-1500B subwoofer, whose distortion I've measured as being less than 1.5%, for any harmonic, when delivering its maximum output at 20 Hz ("Thunder in the Listening Room: Subwoofer Shootout," *Audio*, November 1992). Both subwoofers could generate roughly the same maximum levels at 20 Hz and were equally able to rattle the windows and move knickknacks on the wall. Surprisingly, both subwoofers sounded quite similar when played at the same level; the Sunfire's second-harmonic distortion was not very noticeable or objectionable. That's because the human ear is very forgiving of low-frequency distortion (especially of the second harmonic, which is musically harmonious). One reason for this is that the ear's hearing threshold is higher at low frequencies; another is that a tone's fundamental tends to mask its harmonics. Wideband music signals will also mask harmonic distortion components.

My distortion measurements are higher than those reported by Sunfire because of

Table I—*Harmonic distortion at 20 Hz versus input level, in dB re limiting threshold (0.25 volt rms) and in volts rms. Distortion is given as a percentage of the level of the fundamental rather than of the total output, and the output levels do not include room gain.*

Input Level		Output SPL	Harmonics, % 2nd	3rd	4th	5th	Total
−18 dB	0.03125 V	76.3 dB	1.6	0.3	0.3	0.3	1.7
−12 dB	0.0625 V	83.1 dB	6.1	2.5	0.3	0.4	6.6
−6 dB	0.125 V	88.9 dB	8.9	1.4	0.4	0.7	9.0
−1 dB	0.225 V	93.3 dB	11.3	3.1	0.7	0.6	11.8
0 dB	0.25 V	91.5 dB	8.9	2.2	0.3	0.4	9.2
+6 dB	0.5 V	95.6 dB	10.7	16.2	5.2	4.8	20.7
+12 dB	1 V	95.4 dB	11.3	18.2	6.6	7.7	23.7
+18 dB	2 V	95.2 dB	11.1	26.6	8.6	9.0	31.4
+24 dB	4 V	95.8 dB	53.7	101.2	12.7	8.7	115.6
+30 dB	8 V	95.9 dB	53.1	124.5	14.5	21.6	137.8

differences in our testing methods. Bob uses a two-microphone near-field technique, with one mike close to the center of the driver and the other near the center of the passive radiator, and then sends the summed signal from the mikes to a distortion analyzer. I made ground-plane measurements, with a single mike, at various distances. I verified that the distortion was indeed lower when the mike was placed close to the cones and that it increased significantly when moved farther away, to positions more representative of normal listening distances. At these distances, you hear not just the output from the cones but all sounds radiated by the system, including side-wall radiation and noises caused by cabinet rocking. When measured by the near-field method, distortion was typically less than half that shown in Fig. 3 and within Sunfire's specification.

Figure 4 shows the results of short-term peak-power measurements on the Sunfire subwoofer's internal amplifier, measured using tone bursts, with the amplifier disconnected from the speaker and connected to a 4-ohm resistive load. The amp was powered by an isolation transformer and an adjustable voltage source set to 120 volts rms. These measurements were made at the Sunfire factory by Bob Carver himself, under my direction and supervision.

With the amp's internal clipping eliminator on, the output curve is shaped like a haystack, peaking at about 4 kilowatts(!) from 30 to nearly 50 Hz, but the limiter reduces the power at higher and lower frequencies. At 20 Hz, for example, the power is limited to a little over 1 kilowatt. With the limiter defeated (by removing an internal connection), the peak power rises into the 5-kilowatt range above 20 Hz, smoothly rolling off below that to a still hefty 3.2 kilowatts at 10 Hz. Since a sine wave's peak-to-average ratio (crest factor) is 3 dB, the subwoofer's built-in amplifier is clearly capable of generating roughly 2.5 kilowatts of continuous sine-wave power, at least for intervals of about 2 minutes.

The Sunfire True Subwoofer's short-term peak sound output versus frequency, measured using the same tone burst as in the previous test, is shown in Fig. 5. The crossover control was set to its highest frequency, 75 Hz. As before, the input to the system was raised until the output was objectionably distorted, as judged by ear and by monitoring the output waveshape with an oscilloscope.

Note the levels in Fig. 5. The Sunfire's low-frequency output equals or surpasses that of most subwoofers and large full-range speakers I have measured. The only systems that can compete with it are much bigger. Only above 30 Hz do a few other speakers deliver more output than the Sunfire, some attaining levels of 120 dB or greater above 40 Hz. Two Sunfires used together could easily outperform any other speaker used singly and still take up much less space.

Use and Listening Tests

I'd seen the Sunfire True Subwoofer at trade shows, but it wasn't until I got it home that I realized how amazingly compact it is. You can actually hold it under one arm (though not for long—it's very heavy for its size).

When I first get a speaker system, I like to feel it with my fingers and see how it reacts when I push its diaphragm. When I tried this on the Sunfire subwoofer, nothing seemed to move. The cone didn't budge, and the surround, very flexible on other speakers, felt like a hard surface. I wondered if a speaker this stiff could actually work. But when I

THE STALL RATIO AND BACK-EMF

Electric motors and generators are essentially the same, coils that can move within magnetic fields. Move the coil, and it's a generator, putting out a voltage, or electromotive force (EMF). Apply a voltage to it, and it moves—a motor. But since a motor's coil is being moved within a field, it also generates back-EMF, a voltage that opposes the one being applied to it.

Back-EMF sounds like a bad thing, but it isn't necessarily. If it becomes too low relative to the applied EMF, the motor stalls, i.e., it runs inefficiently, turning more and more of its electrical input into heat instead of motion. When it gets hot enough, it burns out and stops—or vice versa, depending on its heat resistance.

A motor's back-EMF will vary with its speed. It stalls under load because the load slows it down to the point where it can no longer generate enough back-EMF to properly oppose the incoming voltage. When that happens, current flow through the coil becomes excessive, causing the heat.

Stalling is defined by the ratio:

$$\frac{EMF_b}{V_f - EMF_b},$$

where V_f is the applied voltage and EMF_b is the back-EMF. When this ratio falls below 1 (that is, when the back-EMF is less than half the applied voltage), the motor is "in stall." The further into stall it gets, the more its heat output rises and its efficiency drops. Sunfire's Bob Carver says conventional speakers normally operate in stall, making them dissipate about 95% of their input power as heat and radiate little of that input power as sound.

The stronger the magnetic field and the more the coil is moved within it, the greater the back-EMF. The Sunfire True Subwoofer moves its voice coil vigorously within a very strong magnetic field; according to Sunfire, it generates a back-EMF of 47.3 volts rms when delivering 104 dB SPL at 27 Hz. Under those conditions, its amplifier is delivering 50 volts rms (yielding a generous stall ratio of 17.5), for a nominal output of 625 watts into the driver's rated 4 ohms. Because the driver is well out of stall, it operates efficiently.

What about electrical efficiency? The nominal power sounds high. Sunfire says that because of impedance variations, power factor (the phase relationship between voltage and current), slip angle (the phase relationship between the driving voltage and back-EMF), and the current-limiting effects of back-EMF, the effective power delivered to the True Subwoofer's driver is actually far less than the internal amplifier's rated 2,700 watts. So electrical efficiency, as measured by power draw at your AC wall socket, is high, too. *Ivan Berger* fired the Sunfire up, everything moved—in spades! As I said earlier, the diaphragm excursion during full-power operation at low frequencies was somewhat scary.

So was the motion of the cabinet. The motions of the woofer and passive radiator generate significant unbalanced forces when high-level signals are played. These forces rock the cabinet and can make it creep along the floor, especially if the floor isn't carpeted. The True Subwoofer comes with small rubber feet attached, and Sunfire provides an extra set, about ½ inch deep, which encourage rocking rather than creeping on most surfaces. When I used the larger feet and put the subwoofer on the carpet, it would rock significantly at high levels but would not creep. The rocking is greatest at about 16 to 17 Hz, where the woofer and passive radiator are essentially 180° out of phase (when one is moving inward, the other is moving out).

Half of the True Subwoofer's manual is devoted to safety issues, placement, connections and controls, crossover frequency adjustment, and troubleshooting. (The manual's other half lists specs and describes how the system works.) You are warned not to remove the rear panel because of potentially lethal voltages in the amplifier circuits behind it, some of which operate directly from the power line without the isolation normally provided by power transformers. As for placement, Sunfire recommends locating the True Subwoofer in a corner, which I did for most of my listening tests.

I added the Sunfire to the music system in my listening room. Ancillary equipment included a pair of KEF Reference Series Model Two speakers, driven by a Crown Macro Reference power amplifier and a Krell KRC preamp. My signal source was an Onkyo Integra DX-7711 CD player. To roll off the lows being fed to the main speakers, I inserted a passive 90-Hz high-pass filter with a 6-dB/octave slope into the preamp's tape loop; I then put a passive shelving network in series with the subwoofer so that its input signal would not be rolled off. The shelving filter provided a 6-dB/octave lift below 90 Hz but bevelled off below 10 Hz. Although I used the Sunfire's line inputs, the signal I fed to it was derived from the amplifier's speaker outputs so that I would not need long runs of unbalanced line-level cables between the preamp and subwoofer.

I COULDN'T OVERLOAD THE SUNFIRE SUB ENOUGH TO MAKE IT SOUND BAD, LET ALONE DAMAGE IT.

The Sunfire was driven through its left line-level input.

I placed the Sunfire diagonally in the corner, so that the woofer and passive radiator were equidistant from the intersecting walls. However, later tests revealed that as long as the True Subwoofer was within 6 inches of the corner, orientation was quite unimportant. The subwoofer's small size encourages you to move it around to see what placement yields the best bass. The crossover control was set to its clockwise, 75-Hz, position and the phase control to its middle position, 90°.

The first selection I listened to was Little Feat's "Hangin' on to the Good Times," on the *Brüel & Kjaer Pro Audio* test CD (Brüel & Kjaer CD-4090). The robust and extended bass on this track gave the music plenty of punch.

With the Sunfire's volume control slightly above its middle, 0-dB, position, I got somewhat more bass than I would from my B&W 801 Matrix Series 3 speakers, which are essentially flat to 20 Hz at my listening position in this room. A subwoofer with its own amp and level controls, operating below 80 Hz, lets you boost the low bass without overemphasizing the upper bass and lower midrange; that additional degree of control over your listening setup's sound is usually very desirable. The Sunfire's rapid, 36-dB/octave rolloff above 70 Hz ensures it won't add energy to frequencies above its passband.

I listened to the True Subwoofer with classical, jazz, country, rock, pipe-organ, and synthesizer music, as well as sound effects and test signals. On all this material, the Sunfire's bass output kept up with or exceeded that of most speakers and subwoofers I have tested.

The Sunfire's bass extension equalled that of any speaker I have tested. Very few speakers (subwoofers included) can reproduce the 18-Hz pedal note in the second movement of Saint-Saëns' Symphony No. 3 in C Minor, the "Organ" Symphony (Philips 412 619, track 2, 9:04 to 9:20). Among those I've tested, the Sunfire, the Velodyne F-1500B, and the Hsu Research HRSW 10V subwoofers all can, but the Sunfire is much smaller than the other two.

The True Subwoofer's excursion limiter and clipping eliminator did a very good job of preventing overload. It was a pleasure not having to worry about overload when listening at high volume levels to recordings with lots of low bass. One such recording, track 1 of *The Digital Domain: A Demonstration* (Electra 9 60303), starts very low, with forest and brook sounds, and then hits you with a jet flyover at full level. Sunfire's trick of increasing the subwoofer's low-order harmonic distortion when the sub is severely overdriven did a good job of making the woofer sound louder, even though the level of the fundamental didn't increase. On other subwoofers with limiters, when the volume of the program material reaches the limiter's threshold, there's no further apparent increase in bass level.

The Sunfire's strength is in the low bass; at 40 Hz and above, many speakers have higher output capability and are often cleaner. This might be one reason to use main speakers that have solid output down to 40 Hz and use the Sunfire to fill in at lower frequencies. Don't get me wrong, as the Sunfire's bass is already *loud* by the point where the limiter kicks in at higher bass frequencies. It's only a limitation with rock, whose bass power is greatest above 40 Hz, and then only if you're listening at true concert levels. But two True Subwoofers, operated close together, would have 6 dB more output and could keep up with virtually anything—and still wouldn't take up more room than one ordinary subwoofer!

For direct comparisons between the Sunfire True Subwoofer and the Velodyne

F-1500B, I placed both in the same room corner. (The Sunfire's edges were parallel to the walls and about 2 inches away from them; the Velodyne was in front of the Sunfire, with its woofer facing toward the rear wall.) On most recordings, it was hard to tell the difference between the two subs. Bass quality and quantity were equally impressive, and both shook the room equally well when reproducing the Saint-Saëns 18-Hz pedal note.

In low bass, the Sunfire had slightly greater maximum output, but the Velodyne could play slightly louder in the upper bass. Slight differences did exist in voicing and frequency balance, but I had no clear preference. The Velodyne reproduced more of the upper bass, in the crossover region, presumably because it rolled off less steeply than the Sunfire above the crossover point.

From my normal listening position, both sounded equally clean on low-frequency sine waves. Only when I walked up to the front wall, near the corner, and listened directly to the two subwoofers' outputs, could I hear a change in the character of the Sunfire's output, which was caused by its higher-level low-order harmonics.

FEW SPEAKERS OR SUBS I'VE TESTED PRODUCED LOUDER BASS THAN THE SUNFIRE, AND NONE WENT DEEPER.

I also found it hard to tell the two subs apart when listening at a high level to Ron Tutt's kick drum on *The Sheffield Track Record/The Sheffield Drum Record* (Sheffield CD/14/20). As with the sine wave, it was only when I listened in the corner that I could hear differences: The Velodyne sounded a little tighter, and the Sunfire went slightly lower and could play a bit louder at those low frequencies. On the helicopter track of the *Digital Domain* CD, the Sunfire reproduced the high-level low-frequency sounds of the helicopter's blade slapping air more realistically and louder than the Velodyne.

On third-octave band-limited pink noise, the Sunfire could deliver slightly more output than the Velodyne at 32 Hz and below, but at 40 Hz and above, the Velodyne's output was greater. The Velodyne sounded somewhat cleaner than the Sunfire at 40 Hz and below at equally loud levels. On alternating-level tone bursts, the Sunfire could play 20- to 32-Hz bands louder than the Velodyne. The Velodyne's limiters made every burst sound the same, whereas the alternate bursts played by the Sunfire were louder but had a slightly higher-pitched quality.

I also compared the Sunfire with a Boston Acoustics VR2000 powered sub. The Sunfire walked all over the Boston below 32 Hz but came in behind the Boston at 40 Hz and above. At 50 Hz and above, the Boston could play significantly louder and cleaner than the Sunfire.

Despite its efficiency, the Sunfire draws a lot of power from the AC line. When I listened at high levels to material with heavy bass, the lights in my listening room fluctuated in sync with the bass. When I listened to the kick drum on the title track of AC/DC's *Highway to Hell* (ATCO 92419), it was like having my own light show!

Does the Sunfire True Subwoofer live up to its name? Yes! A true subwoofer should be able to rattle the walls at 25 Hz and below, which the Sunfire accomplishes easily. Admittedly, the True Subwoofer has somewhat higher distortion than some of its competitors. But the difference between the Sunfire's distortion and the superlow distortion of the Velodyne was not clearly discernible on most program material at normal listening distances. From a psychoacoustic standpoint, it may be better to allow higher maximum output with higher distortion, as Sunfire has.

The Sunfire True Subwoofer is a truly innovative product with a number of unusual characteristics, including extremely small size, high output even below 20 Hz, a very powerful, high-efficiency internal amplifier, and excellent self-protection systems. I doubt that the True Subwoofer would have seen the light of day at any large speaker manufacturer. Even to attempt designing a subwoofer with its very small size, high output, and response to below 20 Hz takes guts that large companies seldom have. The Sunfire True Subwoofer is a groundbreaking design that embodies some very innovative thinking and creative problem-solving. I'm impressed! A