

SHIVA WHITE PAPER

A technical paper related to the Shiva subwoofer



REVISIONS

REV	AUTHOR	SECTIONS	DATE	WHY
2.1	DCW	ALL	2000-10-01	Reflect new Mark II Shiva
2.0	DCW/DEH	4.0 and on	2000-02-12	Removed apps; in separate documents
1.3	DCW	1.2;2.10; 4.9.4	1999-06-30	Added displacement of Shiva; entered correct magnet weight; fixed sensitivity calculations; added efficiency/sensitivity calculations
1.2	DCW	1.2;4.9.3;ALL	1999-06-03	Fix rotated text in physical drawing; fixed reference to sealed section; repaginated
1.1	DCW	ALL	1999-05-31	Added more graphs; added physical dimensions; repaginated
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0.99	DCW/DEH	ALL	1999-05-21	Initial Release

TABLE OF CONTENTS

1	GENERAL DESCRIPTION.....	3
1.1	WHAT IS SHIVA?	3
1.2	PHYSICAL DIMENSIONS	3
1.2.1	<i>Mechanical Drawing</i>	3
1.2.2	<i>Driver Displacement</i>	3
1.3	THIELE SMALL PARAMETERS	4
1.4	FREQUENCY RESPONSE	5
1.5	IMPEDANCE	6
2	PHYSICAL CONSTRUCTION	7
2.1	CONE.....	7
2.2	SURROUND	7
2.3	SPIDER.....	7
2.4	BASKET	7
2.5	FORMER.....	7
2.6	VOICE COILS	7
2.7	TINSEL LEADS	7
2.8	POLE PIECE.....	8
2.9	TOP PLATE.....	8
2.10	MAGNET.....	8
2.11	BACK PLATE.....	8
2.12	GAP	8
3	THEORY OF DESIGN	9
3.1	WHY THESE T/S PARAMETERS?.....	9
3.2	WHY DUAL VOICE COILS?.....	10
3.3	WHY A STEEL BASKET?	11
3.4	WHY A FOAM SURROUND?.....	11
3.5	HOW DO MULTIPLE SHIVA SUBS ADD UP?	12

TABLE OF TABLES

TABLE 1- T/S PARAMETERS	4
TABLE 2 - MULTIPLE SHIVA IMPEDANCE AND SENSITIVITY CHART	12

TABLE OF FIGURES

FIGURE 1 - SHIVA PHYSICAL DIMENSIONS	3
FIGURE 2 - NEAR FIELD FREQUENCY RESPONSE	5
FIGURE 3 - IMPEDANCE OF Q=0.6 BOX.....	6

1 General Description

1.1 What Is Shiva?

Shiva is a 12" subwoofer driver from Adire Audio. It features an extremely long Xmax, high power handling, and parameters suited for use in a variety of enclosures. It is designed to give low-distortion, high-SPL bass down to infrasonic frequencies in modest-sized enclosures.

1.2 Physical Dimensions

1.2.1 Mechanical Drawing

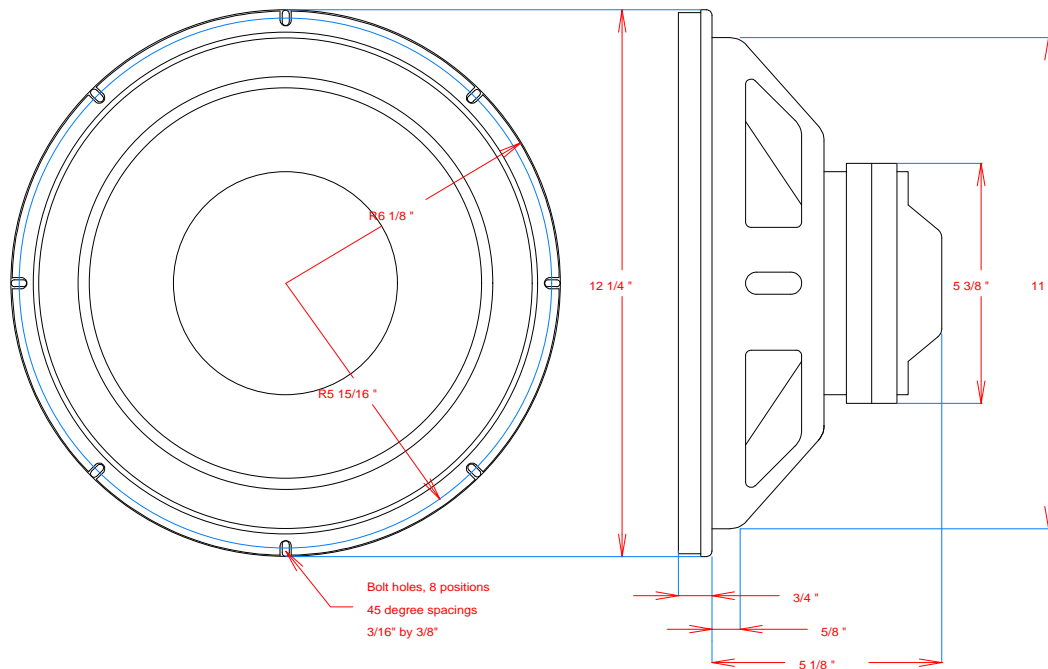


Figure 1 - Shiva Physical Dimensions

Shiva measures 12.25" (31.1 cm) in diameter. It requires a cutout of 11" (28 cm). It has a front-mount height of 3/4" (1.9 cm). It has a front-mount rear-depth of 5.125" (13 cm). There are 8 bolt-holes oriented at 45° increments around the driver. These holes are oval in shape, with a width of 3/16" (4.75 mm) and a length of 3/8" (9.5 mm).

1.2.2 Driver Displacement

For enclosure calculations, Shiva displaces 3 liters (183 cubic inches).

1.3 Thiele Small Parameters

Thiele-Small parameters were defined by A. N. Thiele and R. H. Small. These parameters describe the small-signal behavior of a dynamic (moving cone) driver, and can be used to design and predict the small-signal response of the driver in a multitude of enclosures.

The T/S parameters of the Shiva driver are specified in the first three columns, depending upon the connection scheme used.

Parameter	Parallel Connected Voice Coils	Series Connected Voice Coils	Single Voice Coil (other shorted)
Fs	21 Hz	21 Hz	21 Hz
Qts	.39	.39	0.39
Vas	151 liters	151 liters	151 liters
Re	2.9 Ω	11.6 Ω	5.8 Ω
Le	2.1 mH	8.4 mH	4.2 mH
Znom	4 Ω	16 Ω	8 Ω
Qes	0.41	0.41	0.82
Qms	6.7	6.7	0.82 [*]
Mms	125 grams	125 grams	125 grams
Cms	0.47 mm/N	0.47 mm/N	0.50mm/N
Rms	2.54 N*s/m	2.54 N*s/m	21.63 N*s/m
Sd	481 cm ²	481 cm ²	481 cm ²
BL	10.8 N/A	21.6 N/A	10.8 N/A
EBP	51.2	51.2	25.1
No	0.37%	0.37%	0.20%
SPL	87.2 dB@1W,1m 90.2 dB@2.83 Vrms	87.2 dB@1W,1m 84.2 dB@2.83 Vrms	84.2 dB@1W,1m 84.2 dB@2.83 Vrms
Xmax	±15.8mm	±15.8mm	±15.8mm
Pmax	375W/coil; 650W total	650W total	375W total

Table 1- T/S parameters

* This change in Qms indicates the effectiveness of electromechanical braking caused by the shorted second coil.

[†] Xmax as defined by the minimum throw to one side of center where the BL product drops by 3 dB. Total linear throw is 31.6mm.

[‡] Xsus as defined by the suspension restoring force increasing beyond four times its center value. Total linear throw is 43.6mm.

1.4 Frequency Response

The Shiva frequency response was measured in a $Q=0.6$ (88.5 liter) enclosure. Frequency response was measured via the close-mic technique, in absolute SPL. Drive level was $2V_{RMS}$ (1W delivered to a nominal 4Ω load) for a nominal 87.2 dB SPL level. The measured frequency response is:

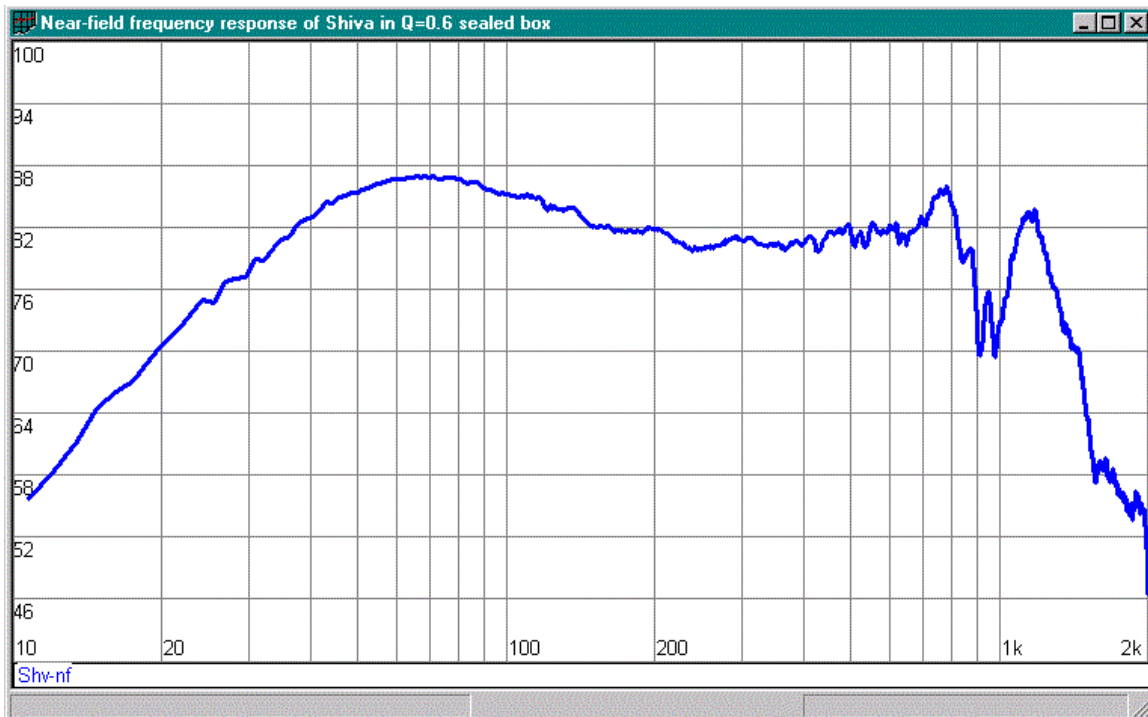


Figure 2 - Near field frequency response

As can be seen, the low frequency response exhibits a typical $Q=0.6$ curve; realize that the low-frequency end of the response is completely determined by the alignment used for the driver. Additionally, the “bump” in the low end of the response (from 40 Hz to 150 Hz) is an artifact of the near-field response measurement, and is expected.

The high frequency response of the driver shows a peak at 780 Hz. This is the primary breakup mode of the driver. Additional breakup modes are seen at 900 and 990 Hz (destructive), and 960 and 1150 Hz (constructive).

Based upon the measured frequency response, we recommend that the bandwidth of Shiva be limited to below 450 Hz. This will keep the breakup modes greater than 20 dB down, assuming use of a 4th order lowpass filter at 450 Hz, with $Q = 0.707$. Note that a lower-order crossover can be successfully used, provided the crossover frequency is lowered as well (for example, a first order electrical network will provide the recommended amount of attenuation if set to roughly 75 Hz).

1.5 Impedance

The Shiva impedance was measured in a $Q=0.6$ (88.5 liter) enclosure. Impedance was measured for a single coil. This measurement is fairly representative of the impedance of a sealed-box Shiva system, and is a good indicator of the type of load such a system will place on either a passive crossover or high-output-impedance amplifier. The measured impedance is:

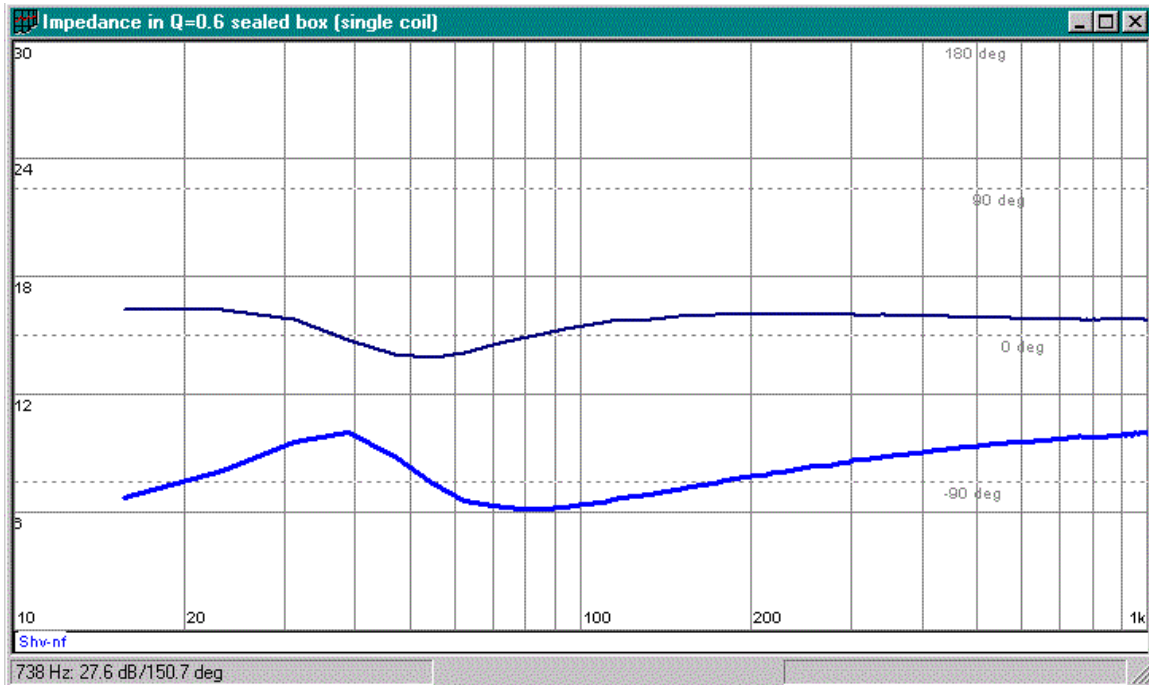


Figure 3 - Impedance of $Q=0.6$ box

The impedance presented by the in-box Shiva is quite benign; the minimum (per coil) is 6Ω , while the maximum level is 10Ω . This impedance curve is well-suited to approximation as an 8Ω load. Additionally, the phase exhibits less than 30 degrees of phase shift throughout the passband.

2 Physical Construction

2.1 Cone

The cone of Shiva is made from Kevlar™-impregnated paper, and is treated with a stiffening epoxy. This combination creates a very stiff material with good internal damping. It is formed into a woofer diaphragm having the optimal cone angle to maintain piston motion up into the midrange, making it easy to cross over to the next driver.

2.2 Surround

The surround is a thick (1.6mm) compressed foam unit, with a diameter of 25.4mm. The surround is UV treated for longevity. The roll is designed to allow extreme excursions with minimal distress. In combination with the sturdy foam, this prevents the "suck-back" seen in other loose or soft surrounds used in other designs. In addition, this heavy foam provides improved, long-lasting centering and proper termination for the stiff cone.

2.3 Spider

The spider is a flat progressive cloth unit. The spider is gapped from the basket with a custom plastic spacer ring. This arrangement makes for perfectly symmetrical properties, thus linearizing motion over that of common cupped spiders. The progressive design retains a nearly constant compliance until it approaches maximum excursion, at which point it decreases progressively to control excursion beyond Xmax.

2.4 Basket

The driver basket is a thick (15 AWG/B&S) stamped steel unit, with integral ribs to stiffen it. It has a surface area of 760 cm², compared to 500 cm² for a typical "Venezuelan style" cast basket. Thus, it can transfer and radiate heat nearly as effectively as the cast basket, without being as brittle. It is painted with a satin black enamel.

2.5 Former

The former is 2" in diameter. It is made of Kapton™, a heat-resistant, high-strength, non-conductive polymer.

2.6 Voice Coils

The voice coils are 2" in diameter. They are wound with 27 gauge round enamel coated solid core copper wire. Each voice coil is two layers; this yields a total of four layers on the former. The voice coil windings cover 39mm of the former.

2.7 Tinsel Leads

The Tinsel Leads are fashioned from low-resistance braided tinned copper and cotton. They are designed to eliminate cone slap while still allowing a full 22mm excursion each side of center.

2.8 Pole Piece

The pole piece is machined from steel. It features a 6.35mm extension past the top plate. This increases the BL linearity and reduces inductance modulation over the specified excursion, yielding the large Xmax of the driver.

The extended pole piece is also drilled through with a 25.4mm diameter axial vent. This vent, along with the top extension, significantly increases heat conduction away from the voice coil, thus improving power handling and reducing heat-induced power compression.

2.9 Top Plate

The top plate forms the gap of the magnetic circuit. It is machined from steel and is 7.94mm thick.

2.10 Magnet

The magnet consists of one ring of a high-energy ceramic material with a total height of 28.58mm. Total weight is 60 ounces.

2.11 Back Plate

The back plate is stamped from 6.35mm thick steel. It features a rearward-extended bump of 26mm height for increased excursion capability. This thick plate serves both to conduct magnetic flux from the magnets to the pole piece and as a heatsink to radiate heat from the voice coil conducted back down the pole piece.

2.12 Gap

The gap height is set by the thickness of the top plate and is thus 7.94mm thick. The gap width is 1.05mm. The materials and dimensions of the parts that form the gap (pole piece and top plate) were designed through advanced finite-element analysis to create as saturated a gap and as focused and symmetric a field as are possible without sacrificing other important features.

Gap saturation is important to minimize modulation of the magnetic field caused by currents through the voicecoil. Measurements indicate that this was essentially achieved in the Shiva design. Decreased stray field and greatly increased symmetry maximize driver linearity and thus reduce distortion.

3 Theory of Design

Shiva was designed to produce awesome, clean bass in small boxes at a great price. Design choices were made to optimize function over form; if a design change had no positive impact on the performance of the driver, then it was dropped. The result is a high-performance woofer with superior performance at a cost-conscious price.

3.1 Why these T/S parameters?

The T/S parameters of Shiva are quite different from most high-end subwoofers. Most immediately notice the mid-value Qes and the much smaller Vas, then ask the question “why these parameters?”

We wanted a driver with great performance in a small sealed box (57 liters [2 ft³] or smaller), or a medium-sized vented box (less than 120 liters [4.3 ft³]). To determine how to achieve this, we created a simulation/generation program. This program would generate T/S parameter combinations, calculate sealed box (Q = 0.7) and vented box (Adire) alignments, analyze the results, and iteratively optimize the parameters for best performance.

Then we judged the “ranking” of the T/S parameter combinations with the following criteria:

1. Bass extension. Lower is better, calculated so that halving the F3 will quadruple the score.
2. Box size. Smaller is better. 120 liters is as big as we wanted to go, as that's about as big as you can get from a single 4'x8' sheet of wood, so there was a penalty for boxes >120 l.
3. Reference SPL. Higher is better.
4. Max SPL output versus frequency (summed 1/3rd octave from 10 Hz to 100 Hz).

These were weighted as 30% extension, 25% SPL, 25% max SPL, 20% box size. We calculated these values for the driver in the sealed and vented boxes. Then the total score of the driver was 55% of the sealed score plus 45% of the vented score.

We ran this simulation for 500,000 T/S parameter combinations. The top 0.05% combinations were surprisingly close to how Shiva turned out: low Fs, middle-value Qes, small Vas. Going with a lower Fs at the given Qes only reduced sensitivity, and didn't give much bass extension; lower Qes values increased SPL, but also increased F3 for the boxes; smaller Vas just reduced SPL as expected.

In the end, the target was an Fs around 20 Hz, Qes around 0.4, Qms around 5.0, and a Vas around 150 liters. A Qms of 5.0 or higher had little impact on the Qts, and it's easier to get a higher Qms than a lower one, so if something had to give, it would be Qms.

Then Xmax and power handling came up. Our driver engineer had already discussed with us a possible way to create a design capable of over ±14mm Xmax, so we asked for it. Power handling was spec'd as “high as possible”.

We ended up with Shiva: very good performance in a variety of alignments (the Qts of 0.4 looks promising for TL use, too). Small mid-Q sealed boxes (45 liters stuffed for Q=0.7 F3 = 42.2 Hz, F8 = 17.8 Hz). TINY medium-high-Q sealed boxes (25 liters stuffed for Q=0.9, F3 = 39.8 Hz, F8 = 20 Hz). Medium to large vented boxes (anywhere from 80 liters to 180 liters).

3.2 *Why dual voice coils?*

After asking about the T/S parameters, the next most common question is “why dual voice coils?” Most high-end subwoofers have a single voice coil; so why dual?

Simply put, dual voice coils dramatically increase the flexibility of the driver. Most obviously, the total impedance of the driver can be changed. As each voice coils is nominally 8Ω , one can run a single voice coil and have a nominal 8 ohm woofer. But wiring the voice coils in parallel will yield a nominal 4Ω woofer. And wiring the voice coils in series will yield a nominal 16Ω woofer. All in all, these configurations allow easy use in low-voltage applications (4Ω woofer, for use in apps such as car audio), or multiple driver systems (16Ω drivers allow one to parallel 2 to 4 drivers in a single system, and still maintain an acceptable impedance without series connecting any drivers).

Note that the connection flexibility afforded by dual voice coils is equally great. For example, to use a single channel of an amplifier (or a monoblock amplifier), one can connect the voice coils in parallel or series (or just hook up a single voice coil) to meet the load requirements of the amplifier.

But, to use a stereo amp, one can connect a single voice coil to each channel. This allows the driver to act as the “summing” junction of a stereo signal, mechanically summing the stereo signals into a “mono” driver. One does not need to electronically sum the channels together. This dramatically eases applications where passive crossovers are used.

But the most important benefit for dual voice coils is flexibility for the T/S parameters. One can actually “dial in” a desired Q_{ts} of the driver, by resistively loading one voice coil and actively driving the other.

This configuration, which we call **Resistively Damped Operation (RDO)**, uses the second (undriven) voice coil as an electromagnetic brake. In essence, the resistance across the second coil will determine how strong the brake is. The smaller the resistance, the stronger the brake.

RDO affects the Q_{ts} of the driver by decreasing the Q_{ms} of the driver. The RDO brake acts to damp cone motion, as if the suspension was considerably stiffer. However, as it’s an electromagnetic brake, the F_s is NOT affected (as it would raise if the suspension components – the surround and spider – were stiffened).

This allows one to literally “dial in” a desired Q_{ts} by varying the Q_{ms} of the driver. In fact, a $250\ \Omega$ 5W potentiometer can be used to tune Shiva over a large range. For example, placing Shiva in an 80 liter box, and using the RDO configuration, one can dial in a system Q_{tc} ranging from 0.55 to 1.1. This allows tailoring the low-end response of the system to meet most musical/home theater reproduction needs.

3.3 Why a steel basket?

Many consider a cast basket as superior to a steel basket. In reality, a well-designed steel basket can be as effective as a cast basket. Let's review what a speaker basket should do:

- A basket is the foundation of the speaker. All parts are attached to the basket, in one way or another. The basket is responsible for holding all the moving parts in alignment with each other. Therefore a basket should be stiff (to handle the motion of the cone) as well as precision made (to keep everything in alignment).
- The basket also aids cooling of the system. Dynamic (moving cone) drivers are very inefficient. A full 99%+ of the power delivered to the driver is dissipated by the voice coil as heat. It's really up to the basket (along with the motor structure) to help dissipate this heat, to keep things from overheating.

So, in light of this information, why did we choose a stamped steel basket and not a cast aluminum basket? Let's address each issue one at a time.

A basket should be stiff. The basket used in Shiva is more than stiff enough. It's made of 15AWG/B&S gauge steel, which has a modulus of elasticity of greater than 84,000,000 kg per cm². Aluminum alloys tend towards a modulus of elasticity of 30,000,000 kg per cm². In terms of elasticity, steel is better than aluminum. To get the required strength out of an aluminum frame requires more aluminum, which unnecessarily adds cost to the driver.

A basket should be precise. Stamping is a process that allows great accuracy in the stamped part's dimensions. The stamping process used results in alignments of angles, location of centers of radii, etc. to better than 0.1%. Additionally, stamping has been a proven technology for precision applications (automotive/aerospace). Cast can offer greater tolerances, but both technologies are more than accurate enough for driver applications.

That leaves heat dissipation. Aluminum has better heat conduction than steel. However, the ability to dissipate heat is a function of surface area as well. The wide ribs of the stamped steel basket dissipate nearly as much heat as a typical "narrow" armed cast basket. In fact, the surface area of the Shiva basket is roughly 52% greater than a typical cast basket. And the rated (and fully tested) maximum power handling of 600W Shiva indicates that power dissipation is not an issue.

Overall, a cast aluminum basket doesn't have real-world advantages over a well-designed steel basket. In addition, the cast basket costs more.

3.4 Why a foam surround?

We chose a foam surround based on the requirement for large X_{max}. Simply put, available rubber (natural and synthetic) surrounds did not provide the long X_{max} (or X_{sus}) needed for Shiva. Going with a rubber surround would have removed several mm from both specifications, and would have run counter to the concept of Shiva being an extremely long-throw subwoofer.

Additionally, thin and loose surrounds, both foam and rubber, can experience "suck back" at high SPLs when the negative pressure (relative to ambient outside pressure) inside the box literally pulls the surround backwards, flipping it inside out and quickly destroying it. To avoid this effect, the surround must be made thick. However, synthetic and rubber surrounds of sufficient thickness to avoid this problem would have added dramatically to the stiffness of the suspension, resulting in a much higher F_s. The foam material used on the Shiva surround allows for sufficient thickness to avoid suckback, but without the negative effects of a much stiffer suspension.

Some people may be concerned about the reliability/longevity of the foam surround. The foam surround used in Shiva is fully UV resistant, and should exhibit a lifespan of considerably longer than 10 years.

3.5 How do multiple Shiva subs add up?

Many systems are designed using multiple drivers. However, calculation of the effective sensitivity and total impedance becomes complicated by the many connection options offered by multiple drivers. Using dual voice coil drivers only increases the confusion. The following table gives the nominal impedance and sensitivity of multiple driver setups.

Number Drivers	Voice Coil Connection	Driver Connection	Impedance, ohms	Efficiency @ 1 W, 1 m	Sensitivity @ 2.83Vrms, 1m
1	Parallel	N/A	4	87.2 dB SPL	90.2 dB SPL
1	Series	N/A	16	87.2 dB SPL	84.2 dB SPL
2	Parallel	Parallel	2	90.2 dB SPL	96.2 dB SPL
2	Parallel	Series	8	90.2 dB SPL	90.2 dB SPL
2	Series	Parallel	8	90.2 dB SPL	90.2 dB SPL
2	Series	Series	32	90.0 dB SPL	84.2 dB SPL
3	Parallel	Series	12	92.0 dB SPL	90.0 dB SPL
3	Series	Parallel	5.3	92.0 dB SPL	94.0 dB SPL
4	Parallel	Parallel	1	93.2 dB SPL	102.2 dB SPL
4	Parallel	Series	16	93.2 dB SPL	90.2 dB SPL
4	Series	Parallel	4	93.2 dB SPL	96.2 dB SPL
4	Series	Series	64	93.2 dB SPL	84.2 dB SPL

Table 2 - Multiple Shiva impedance and sensitivity chart

The effective efficiency and voltage sensitivity gains from running multiple drivers can be calculated as:

Efficiency gain @ 1W, 1m = $10 * \log_{10}(\text{Number Drivers})$

Sensitivity gain @ 2.83Vrms, 1m = $10 * \log_{10}(8\Omega / \text{nominal impedance})$

The net efficiency of the system is the base Shiva efficiency (87.2 dB SPL @ 1W, 1m) plus the efficiency gain for multiple Shivas.

The net sensitivity of the system is the base Shiva efficiency (87.2 dB SPL @ 1W, 1m) plus the efficiency plus the sensitivity gain for the impedance load.

EXAMPLE: assume that 7 Shivas will be used. Each will be wired with voice coils in series, and all units wired in parallel. The nominal impedance is $(16/7) 2.286\Omega$.

Efficiency gain = $10 * \log_{10}(7) = 8.45 \text{ dB SPL}$

Sensitivity Gain = $10 * \log_{10}(8\Omega / 2.286\Omega) = 5.44 \text{ dB SPL}$

Thus the net efficiency and sensitivity of the 7 Shiva system is:

System Efficiency = $87.2 \text{ dB SPL} + 8.45 \text{ dB SPL} = 95.65 \text{ dB SPL @ 1W, 1m.}$

System Sensitivity = $87.2 \text{ dB SPL} + 8.45 \text{ dB SPL} + 5.44 \text{ dB SPL} = 101.09 \text{ dB SPL.}$

Note that wiring for a net impedance higher than 8Ω will result in a reduction in system sensitivity, but will not affect the efficiency of the system.