

# *Sunfire*

## True Subwoofer

How it Works  
*By Bob Carver*

Summary on Page 11  
**White Paper**

To have lots of bass, you have to move lots of air. What does that mean? The measure of air movement is displacement --- cubic inches. If we want to shake the walls and rattle the rafters in a normal sized listening room, we need 135 cubic inches of air movement. It's a matter of raw power, and the air moved by a woofer is the surface area of its cone ( $\pi r^2$ ) multiplied by its to and fro movement. Bore times stroke. For example, a very high quality 15 inch woofer that can move to and fro half an inch can displace approximately 66 cubic inches of air. Now, that's a lot, but, as mentioned earlier, it still isn't quite enough to shake the walls and rattle the rafters.

For the new AC3 system we need even more than 135 cubic inches -- 265 cubic inches of air movement according to Dolby Laboratories. Now, 265 cubic inches of air displacement requires four 15 inch drivers moving back and forth half an inch. According to Dolby Laboratories.

Theoretically, the Sunfire True Subwoofer can displace 251 cubic inches of air. How does it do it? Small bore, very large stroke. The effective diameter of its piston is 8.0 inches. Its excursion is two and a half inches. So, ( $\pi r^2$ ) times 2.5 inches times two (there are two drivers in the box) yields 251 cubic inches of air displacement which is about the same as three or four (depending on their excursion) 15 inch drivers operating in a cabinet the size of a small refrigerator. In practice, it's somewhat less because the excursion limiter is set to prevent bottoming, and the maximum possible displacement occurs one half octave above the tuning frequency of 18 Hz.

A two and a half inch woofer movement required a whole new technology. The suspension, adhesives, surround, magnetic structure, even the voice coil are new and unique.

But having a large volume displacement is only half the battle because the efficiency of a woofer is proportional to the volume of the box it's mounted in. For example, if we had several woofers mounted in a 10 cubic foot box that worked fine with a 200 watt amplifier and if that box were reduced from 10 cubic feet to 1 cubic foot, the power requirement would go up by a factor of 10. A 2,000 watt amplifier would be required to produce the same results. The Sunfire True Subwoofer is an 11 inch cube, and a cube 11 inches square made of wood 3/4 inches thick has an internal volume of half a cubic foot. When the necessary drivers and amplifiers are added to the box, it's 0.4 cubic feet!

Hence, I built a 2,700 watt amp for the True Subwoofer.

I have a White Paper on the tracking down converter which explains how so much power is obtained in such a small volume and with little heat. Without this special amplifier, this subwoofer project would not be possible or practical.

Now we can see there are two parts to this system. 1) A brand new woofer design that can undergo two and a half inches of excursion. Five times the linear displacement of a conventional, large 15 inch driver. 2) The flip side of the coin is the small box, and that means lots and lots of power. (Remember, the efficiency of the system depends only on the volume of the box --- all other things being equal.) It doesn't depend on the size of the driver.

The 2,700 watt amp inside is the size of a large candy bar. (Albeit a \$2.25 candy bar.)

Here are some numbers that occur when such a wild system is put together. Internal box pressure is 150 pounds when the woofers move in. The woofers are bipole (both drivers move out simultaneously and both drivers move in simultaneously). They are mounted on opposite sides of a single 11 inch box so that the pressure wave is positive when they both move out and negative when they both move in. The giant magnet that drives this system can produce 150 pounds of force, this means if you put the woofer on the floor and you weigh 150 pounds or less and stand on it and drive it with a signal, you can be bounced up and down two and a half inches. At maximum output the air velocity in the pressure relief hole exceeds mach 1.2. And, guess what? It makes a small sonic boom. Special measures were required to eliminate this baby sonic boom. In spite of these large forces, from the outside, the woofer is a pussy cat except that it can shake the walls and rattle the rafters.

You may wonder why it doesn't get hot and smoke itself.

In home theater, special effects with low frequencies are very loud but they come and go quickly. Examples are a plane crash, a bomb exploding, a railway crash, an airplane taking off from a carrier, a boulder crashing into a large monolith. All these events produce tremendous low frequency energy but they never last very long. Even though the amplifier may be putting out enormous power, it never gets hot because it's never sustained. The average power is usually under 200 to 300 watts. The pro guys have been routinely making voice coils that can handle 600 watts continuously --- well in excess of what is rationally needed in a normal installation.

Just the same, it would seem that 2,700 watts is an unheard of power going into such a small box, so there must be another reason it doesn't smoke itself. There are several other reasons, and one important one is that for music, most bass is in the 40 Hz region. At 40 Hz this woofer has a reasonable efficiency, only slightly less than a normal bookshelf speaker. However, as we go down the frequency scale, efficiency becomes much worse because the efficiency of a loudspeaker is also related to the third power of its low frequency cut off. This means that if we extend the low frequency response by one octave (say from 40 Hz to 20 Hz) eight times more power is needed because  $\left(\frac{40}{20}\right)^3 = 8$ .

#### STALL MODE AND BACK ELECTROMOTIVE FORCE

Now we come to the main reason, and the conceptual explanation that provides this woofer with much, much more efficiency than a woofer this size would normally possess. A woofer is driven by an electric motor that consists of a magnet and a voice coil. Electric motors can be marvelously efficient, well over 80%, however, electric motors will also be terribly inefficient when operated close to their *stall*.

For a variety of technical reasons, all woofers on the face of this planet operate extremely close to the stall mode. Hence, the conversion efficiency of most high-fidelity speakers rarely exceeds several percent - not even close to 80%. This reality is enunciated by a law of the universe called Hoffman's Iron Law. Hoffman's Iron Law details the relationship between a loudspeaker's efficiency, its box size, and its low frequency cut off. It imposes the most frustrating and maddening constraints on loudspeaker designers, all but ensuring powerful woofers will come in giant boxes. With a slap in our face, it tells us there is no free lunch. We cannot have our cake and eat it too. We can't have big bass and small boxes.

For example, a loudspeaker designer can choose two of three variables arbitrarily and at will, but will be stuck with the third.

We can choose:

- 1) Low frequency limit
- 2) Efficiency

..... and we're stuck with: 3) Box size

Or we may choose: 1) Box size  
2) Efficiency

..... stuck with: 3) Low frequency limit

Or choose: 1) Low frequency limit  
2) Box size

..... and we're stuck with: 3) Efficiency

In short, Hoffman's Iron Law tells us it's not possible to choose all three at once.

With the new methods and technology developed for the Sunfire True Subwoofer, *We can choose all three at will!* And guess what? I chose small size, lots of low bass, and high efficiency. And in the end, Hoffman's Iron Law falls (actually it doesn't fall, but it must be interpreted in a way different from the classical interpretation).

A simple thought experiment clearly illustrates that it's theoretically possible to build a much more efficient woofer. The thought experiment is this: Imagine the voice coil being made of a super conductive wire that has zero resistance. Since we know that most of the input power is lost in the voice coil as joule heat, such a voice coil would not generate heat because heat, in this case, is current squared times resistance. If the resistance is zero the heat is zero. If the heat is zero that means instead of one, two or three percent of the input power becoming useful, the speaker suddenly becomes majestically efficient. A super conductive voice coil is clearly not practical, but the thought experiment itself tells us and teaches us it is possible, at least in theory, that fundamental, intrinsic laws of the universe do not prevent us from making a very small, very efficient woofer.

The secret to making this woofer efficient in spite of its small size and high output is to operate its electric motor, that is, its voice coil and magnetic system, far away from *stall*. Electric motors, when operated away from stall become very, very efficient. An electric motor operating far from stall generates a very large back electromotive force (emf). That is, most of the voltage that's delivered to the motor is subtracted away by a voltage generated inside the motor by virtue of its own motion; that voltage is called the back emf.

Getting back to woofers, all woofers (except the Sunfire) on the face of this planet, operate very close to stall. A scientist would say close to the stall mode. The stall mode is characterized by very little output power and lots of current running through the coils of the motor making the motor very hot. If the motor is turning fast the back emf is large, and the motor runs cool; the remaining voltage that pushes current through the windings is very small because it's counteracted by the back emf, and the motor becomes extremely efficient. As an example, diesel electric locomotives have a minimum operating speed below which the motors come too close to the stall mode and burn up. For passenger trains it's about 12 mph, for freight trains about 9 mph.

### A TRAIN AND A MOUNTAIN

Imagine a train going up a mountain, pulling hard. As it goes up the mountain fast, the train is putting out lots of power because the energy of going up the mountain is delivered in a short time. Since power is work per time, a scientist would say  $\text{Power} = mgh/t$  short, where  $m$  is the mass of the train,  $g$  is gravity,  $h$  is the height of the mountain, and  $t$  short is the short time it takes to get up the mountain. The power output is large, and the electric motors run cool. If the train goes very slow it will not be putting

out very much power because  $\text{Power} = mgh/t$  long, where  $t$  long is the long time it takes to go up the mountain. When  $t$  is small, power output is high, when  $t$  is large, power output is low. What's worse is the motors get very hot and overheat. Its motors are operating in stall mode.

Now back to the woofer. Because this woofer moves back and forth a lot, the voice coil is cutting many, many lines of magnetic flux in the magnet structure. It's the rate of flux change that generates back emf. The large back and forth stroke of this woofer is good for making lots of air move *but it's even better for generating a large back emf*. If the voice coil didn't move very far, it wouldn't generate very much back emf. Without a big back emf too much current would flow through the windings and the woofer would overheat. That's the case with all other woofers on the face of the earth. To have a large back emf, lots of voice coil motion is required.

Another requirement for lots of back emf is a very high magnetic flux. To have that requires a huge magnet. The magnet in this woofer is 225 ounces and that compares to around 20-28 ounces for a regular woofer. It's about an order of magnitude larger. Now the problem with all this is that because the woofer is moving so far, it makes a large back emf (due to the large stroke cutting many of lines of force). Consequently, if the woofer were driven by an ordinary amplifier, most of the driving force would go away and the woofer would have very little output. *Because the back emf is so large, the applied electromotive force to the woofer must be even greater than the back emf in order to overcome it.*

That requires an incredibly powerful amplifier. An amplifier that can swing over 100 volts rms.

Since the DC resistance of the voice coil is 3.3 ohms - that means it's a nominal 4 ohm woofer, 100 volts rms into 4 ohms is well over 2,000 watts. The woofer will not burn up because when it's moving, the back emf prevents the damaging stall mode current that would normally flow if it were a resistance load. Only a small fraction of that current flows in the voice coil, but since the magnet is so huge and because the driving force is equal to the magnetic field strength times the current, the force on the voice coil to drive the woofer and move the air is immense *even though not much current is flowing*. An alternate way to get drive force on the woofer cone is to increase the current, the normal way of doing it, but that makes the voice coil overheat because of the high current. Or we can make the magnet huge. Problem is if we make the magnet huge, the back emf causes us to run out of volts and therefore we need a very special amplifier to overcome the loss of volts. That requires a tracking down converter amplifier.

The tracking down converter amplifier is also unique. Without the tracking down converter amplifier, no matter what, this woofer wouldn't be practical. When all is said and done, the effective input power is not 2,700 watts, even though the amplifier has to be capable of delivering 2,700 watts into a 4 ohm load. When it's actually operating into the loudspeaker, the effective power is far, far less than that. And Hoffman's Iron Law suddenly tumbles. To put numbers to this, as any good scientist would, even though this woofer is one tenth the box volume of a normal woofer, when driven to full output at the same volume level and same low frequency as a giant woofer in a big cabinet, by all the laws of the universe and all the rules that woofer engineers and designers have been taught, the input power should be at least 10 times greater than the input power for the big woofer. But that's not the case. The input power is more, but only slightly more.

#### A THOUGHT EXPERIMENT

Suppose we wanted to build a woofer, and we had a 200 watt amp to do it with, an amp that could deliver 28 volts rms to our 4 ohm speaker.

Now imagine we mount our driver into a nice box. Imagine also that our driver has a "variable magnet", so we have a dial outside of the nice box that we can turn to change the strength of the magnet. The dial is calibrated continuously from zero magnetic strength to super magnetic strength. We drive the system

with some bass. Of course, with the dial set at zero, there is no output from the woofer. We begin advancing the dial and the bass comes up. As we advance the dial further, the bass gets louder and louder. However, as we advance the dial beyond a certain magnetic field strength, the woofer output begins to drop. The point of maximum output defines the optimum magnet size for our woofer. Consider Figure 1.

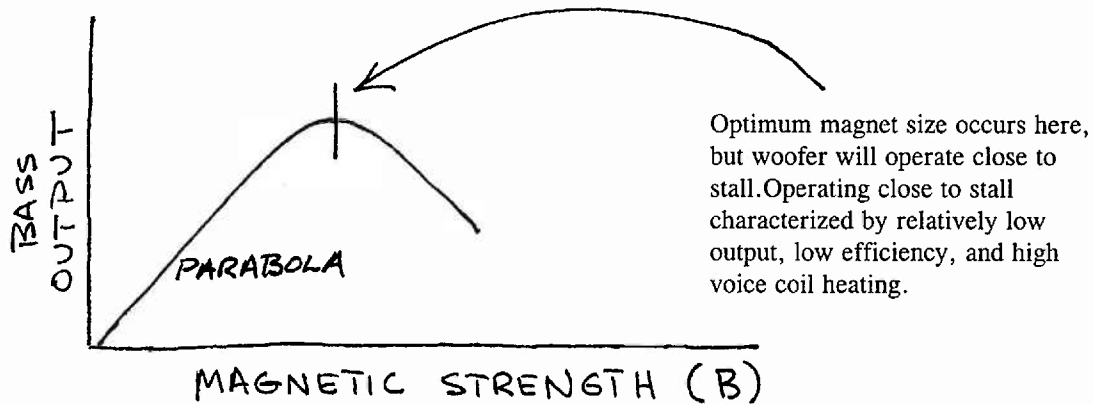


Figure 1

#### DISCUSSION OF THOUGHT EXPERIMENT

We know that as we advance our magnet from zero, the product of the current and magnetic field strength ( $B$ ) produces a force on the voice coil. As  $B$  increases, the force increases and the bass increases. However, no sooner than the woofer starts to move, it produces a back emf that begins to reduce the current through its voice coil. As the magnet becomes ever larger, the current becomes ever smaller, until by and by the ever increasing magnetic force cannot overcome the loss of current due to the increasing back emf. Consider Figure 1.

In this illustration, the back emf is 13 volts, leaving only  $(28-13) = 15$  volts to run the woofer.

If we wish to have more bass output we must have a larger amplifier, one that can deliver more volts in order to overcome the dreaded back emf. Now if we had in our possession an amplifier that had virtually unlimited output voltage, say one that could deliver 104 volts rms into 4 ohms with ease, then we could increase the magnet strength and let the dreaded back emf rise because we would know that we have almost unlimited drive to overcome it. See Figure 2.

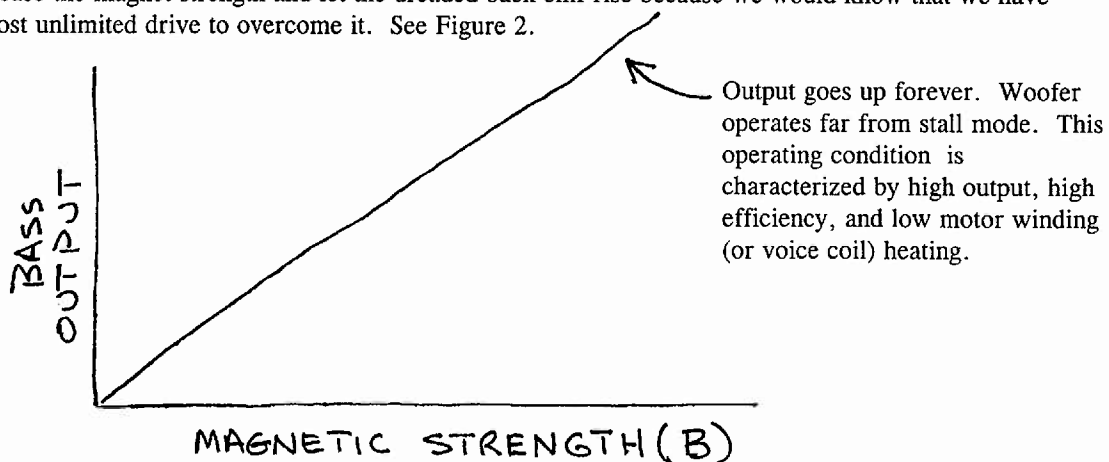


Figure 2

## THE PROOF IS IN THE PUDDING

The definitive demonstration.

I have several large and well designed subwoofers here in my laboratory. Klipsch, Bose, Velodyne, M & K, and several others. One of my favorites is a big one.

I hooked up the Big one (cabinet volume 4.3 cubic feet) and drove it to maximum output (its limiter activated) with a warble tone centered at 28 Hz. I measured the power input from the wall socket with a watt meter and measured the output Sound Pressure Level (SPL) with a simple SPL meter. Input power was 240 watts, output SPL was 112 dB. It was awesome!

I then removed the Big one and replaced it with my Sunfire True Subwoofer and drove it with the same signal until my SPL meter again read 112 dB. Input power was actually 40 watts less at 200 watts! Since my limiter had not yet activated, I turned it up until I activated the limiter with maximum output at 115 dB. Double the output of the Big one. Wow! Input power was then 360 watts.

## SUMMARY AND CONCLUSIONS

Big one woofer operating in stall mode.

True Subwoofer operating far from stall mode.

240 watts input, standard amplifier approximately 60% efficient at maximum output means  $(240) \times (.6) = 144$  watts into voice coil.

200 watts input, tracking down converter amplifier approximately 88% efficient means  $(200) \times (.88) = 176$  watts into voice coil.

Big one has 4.3 ft<sup>3</sup> box volume.

Sunfire has 0.38 ft<sup>3</sup> box volume.

However, input power for Sunfire should be (by Thiel-Small and Hoffman's Iron Law):

$$\left( \frac{4.3}{0.38} \right) \times 144 = 1,629 \text{ watts}$$

But it's not! It's only 176 watts. An order of magnitude less! Magic, uh? Indeed, at full output, the True Subwoofer requires 360 watts (115 dB) but it should need 2 (twice the output)  $\times 1,629 = 3,258$  watts, but it doesn't!!

So that's the secret. The conceptual secret of how this woofer can be so small, put out so much bass and yet not burn itself up and also not draw tons of power from the wall. As a matter of fact, in spite of all the bass it can put out, it uses only a six amp slow-blo fuse.

Putting it all together, this woofer is flat to 18 Hz, can move 251 cubic inches of air (again, the same as four 15 inch woofers operating linearly in a box the size of a small refrigerator), the distortion is extremely low, it has a built in power amplifier, a built in crossover system, input volume controls, crossover control, a phase control to allow it to be blended with any other speaker system and it has a two position switch that allows the woofer to be optimized for stereo (flat to 18 Hz) or to have a contour that rolls off very low frequencies if they bother you.

The following are commonly asked questions:



- Q) With these huge motions and large inertial forces, what prevents the woofer from hopping around the room when driven to full output?
- A) The two drivers are quasi balanced and reduce the vibration to a rational amount. In fact, the vibration is just enough to help shake the floor and provide a tactile sensation to your toes, feet, or body if you're sitting on the floor, but not so much vibration that the woofer bounces around the room.
- Q) Is the dreaded back emf good or bad?
- A) It's a double edged sword. On one hand, it's bad because it makes bass go away. On the other hand, it's good because the diminished bass is being produced at a higher efficiency, waiting only for a giant amplifier to bring it back.
- Q) If the woofer uses only several hundred watts, why must the amplifier have several thousand watts?
- A) A woofer has an impedance that an engineer calls *complex*. It's made up of two parts. A *real* (resistive) part, and an *imaginary* (reactive) part. Consider an example: Suppose the amplifier is delivering 104 volts and 10 amperes of real and imaginary current to the loudspeaker. From the amplifier's point of view, it thinks power =  $V_i$  = 10 amperes times 104 volts = 1,040 watts. The speaker thinks Power =  $i^2 R$  = 10 squared times 3.3 ohms = 330 watts.

The power company is thinking it has been taken advantage of and is upset because the watt meter installed at your house cannot detect imaginary current, but it costs the power company money and water over the dam to generate it. Additionally, a giant magnet means giant reactive currents which the amplifier *must* accommodate. These currents impose large stresses on the amplifier, as much stress as if it were operating at several thousand watts into a regular speaker.

Strictly speaking, it's more complex (pardon the pun) than this illustration, but you get the conceptual picture, n'est ce pas?

#### A COMPUTER DESIGNED SUBWOOFER

All computer operated SPEAKER DESIGNER software programs use Thiel-Small parameters. A.N. Thiel\* told the world, in a footnote to his original paper years ago that his equations were only approximations and would be valid *only if the efficiencies were very low*. If a modern speaker designer sits down at her computer and asks it to build a woofer flat to 18 Hz in a 0.38 ft<sup>3</sup> box that can do 110 dB SPL, the computer will gently inform her she will need an amp with more than 5,000 watts.

Nothing could be further from the truth!

At this point the speaker engineer just drops his head, lets ten fingers fall aimlessly onto the keyboard, pushes his chair away from the computer, turns around, goes downstairs and makes himself a peanut butter and jelly sandwich.

#### HOW THE DRIVERS MOVE

Both drivers are driven by a common electric motor and magnetic structure. One driver is driven by a voice coil, the other by a 1.7 lb weight. Both drivers move inward together and both move outward

together. The voice coil driven driver is moved by a force  $= Bli$ . The mass driven driver is moved by the force  $(= ma)$  of a 1.7 lb weight. The two forces are exactly equal and opposite.

The mass driven driver is often called "passive" because it lacks a voice coil. It is anything but passive, and contributes equally to the output in its chosen operating band.

\*A.N. Thiel was an Australian university researcher. He wrote a paper approximately 30 years ago that put rigorous mathematics into the design of subwoofers. With that remarkable paper, and arresting insight, he taught the world how to design subwoofers (albeit in jumbo boxes).

### ONE LAST NUANCE

Electric motors that are required to operate without benefit of a gearbox or transmission, *if required to turn slowly*, will almost certainly be operating in stall. This occurs when it is not practical to include a gearbox or transmission at the output of the electric motor. Examples are electric fans, diesel electric locomotives, and of course, subwoofers.

### FOR LIEUTENANT DATA AND SCIENCE TECHIES ONLY

An electric motor is operating *in stall* when its stall ratio is less than one, i.e., when

$$\left( \frac{emf_b}{V_f - emf_b} \right) < 1$$

Where  $emf_b$  is the back emf, and  $V_f$  is the applied forward voltage.

This mode of operation is characterized by poor efficiency, high joule heating, and relatively low power output.

### A CONVENTIONAL WOOFER

Consider a very high quality but otherwise standard eight inch driver operating at maximum excursion. A typical drive unit would possess approximately the following parameters. Magnet size 28 ounces,  $B_l = 6$ , maximum excursion = 0.5 inches peak to peak (.0063 meters peak).

Now we know that the back emf is the time rate of flux change. Consider the drawing below. A rectangular loop of wire is pulled out of a magnetic field with a velocity  $v$ .

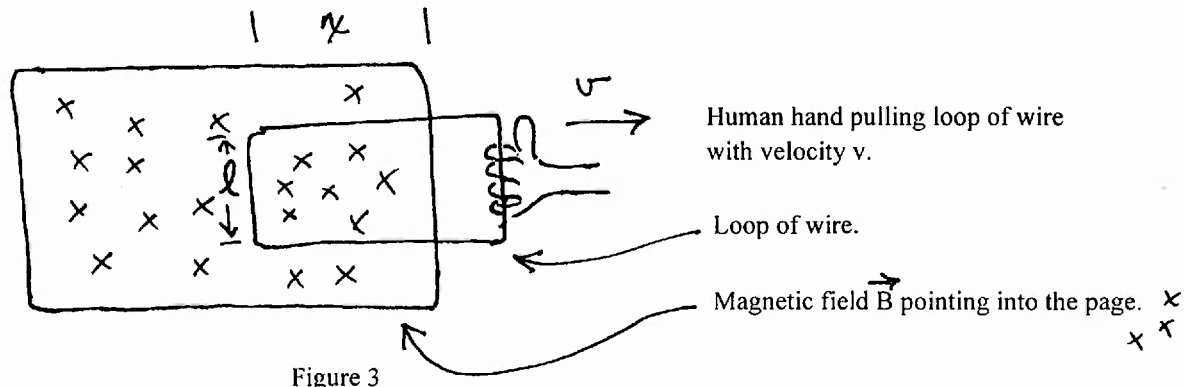


Figure 3



Refer to Figure 3.

The flux enclosed by the loop is  $\Phi = Blx$

$$\frac{d\Phi}{dt} = Bl \frac{dx}{dt} \quad \text{But } \frac{dx}{dt} = \text{velocity} = v.$$

Therefore,  $\text{emf} = Blv$ .

The voice coil is undergoing motion given by:

$$x = A \sin \omega t$$

And its voice coil velocity,

$$v = \frac{dx}{dt} = A \omega \cos \omega t$$

For our standard 8 inch driver at maximum output:

$$A = 0.5 \text{ inches peak to peak} = .0063 \text{ meters peak}$$

Back emf =  $Blv$

Using 27 Hz and the 200 watt amp of the earlier example:

$$\begin{aligned} &= (Bl) A \omega \cos \omega t \\ &= (6)(.0063)(2\pi)(27)(1) \\ &= 6.46 \text{ volts peak} = 4.56 \text{ volts rms} . \end{aligned}$$

Stall ratio:

$$\left( \frac{\text{emf}_b}{V_f - \text{emf}_b} \right) = \frac{4.56}{28 - 4.56} = 0.19 \ll 1$$

Since this value is substantially less than one, the woofer is operating well in stall, and is characterized by low conversion efficiency and low output.

Now consider the Sunfire True Subwoofer.

Same 27 Hz, but with a 2,700 watt amp.

$$\begin{aligned} \text{Back emf} &= Blv = 26 A \omega \cos \omega t \\ &= (26)(.0317)(2\pi)(27)(1) \\ &= 139.8 \text{ volts peak} \\ &= 98.8 \text{ volts rms} \end{aligned}$$

$Bl = 26$ ,  $A = 2.5 \text{ inches p/p} = 0.0317 \text{ meters peak}$ .  $V_f = 102 \text{ volts rms}$ .

Stall ratio:

$$\left( \frac{\text{emf}_b}{V_f - \text{emf}_b} \right) = \frac{98.8}{102 - 98.8} = 31 \gg 1$$

Hence this woofer is operating far from stall, and is characterized by high efficiency and relatively small joule heating.

Don't forget, bass  $\propto F = il \times \vec{B} = Bli$

Strictly speaking, the above examples are somewhat simplified because the maximum back emf actually occurs at maximum voice coil velocity, not at peak amplitude. This causes a phase shift with  $V_f$ , making the effective back emf not so dreaded.

# PROOF THAT BACK EMF REDUCES BASS, AND THAT A GIANT AMPLIFIER RESULTS IN HIGH EFFICIENCY

The force exerted on the voice coil is

$$F = il \times \vec{B} = Bli \text{ ----- (1)}$$

The current in the voice coil is

$$i = \frac{V}{R} = \left( \frac{V_f - \text{emf}_b}{r_e} \right) \text{ ----- (2)}$$

where  $r_e$  is the voice coil resistance.

Combining (1) and (2), we obtain

$$\begin{aligned} F &= Bl \left( \frac{V_f - \text{emf}_b}{r_e} \right) \\ &= \frac{Bl V_f}{r_e} - \frac{B^2 l^2 v}{r_e} \\ &= cB - dB^2, \text{ a parabola -- (3)} \end{aligned}$$

Strictly speaking,  $d$  is a function of  $v$ , hence we have a modified parabola. Finally

$$F = \underline{\underline{cB - f(v)B^2}} \text{ a modified parabola.}$$

SEE FIGURE 4

Inspecting equation (3), we note that it has the form of a parabola as shown below. Note also we can make the force as large as we please by increasing the constant  $C$  faster than we increase  $B^2$ . Since  $c = \frac{V_f e}{r^2}$ , all we must do is increase  $V_f$  as  $B$  is increased. The current drops, the force increases, and we obtain the dashed line shown below. Since the current drops,  $I^2 R$  heating drops and we have more force and less heat, i.e., more efficiency.

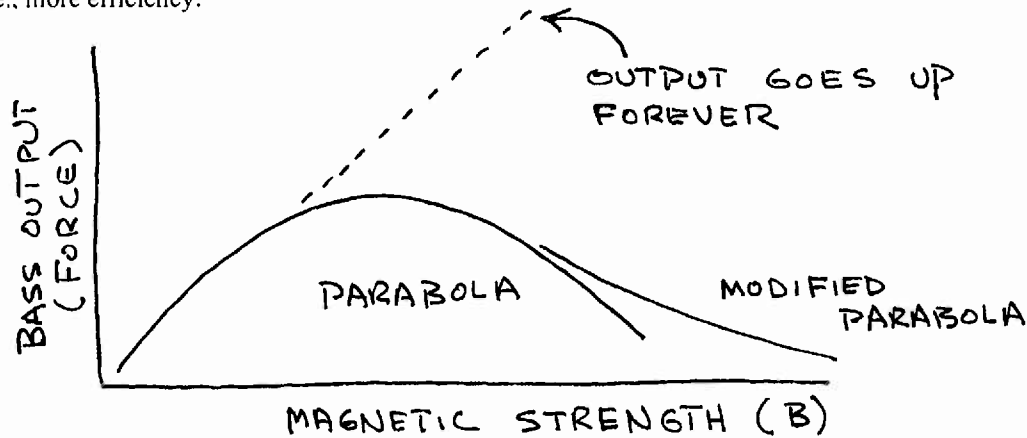


FIG 4

### SUMMARY

This small subwoofer puts out as much bass as an extremely large woofer for three reasons:

1) **Large Excursion**

Its to and fro movement (excursion) is approximately five times greater than a conventional woofer. Since it can move back and forth 2.5 inches, it can move lots of air.

2) **Giant Amplifier**

Since the woofer is in an extremely small box, whenever it moves back and forth, very high air pressure is generated within the box. To overcome the box pressure, a giant amp is needed. The built-in amp can deliver 2,700 watts rms into a 3.3 ohm load.

3) **High Back Electromotive Force**

The magnet weight is approximately ten times greater than in a conventional driver. This increases the back emf, allowing the driver to operate away from the stall mode, and consequently at an efficiency more than ten times greater than a woofer this size would ordinarily possess.

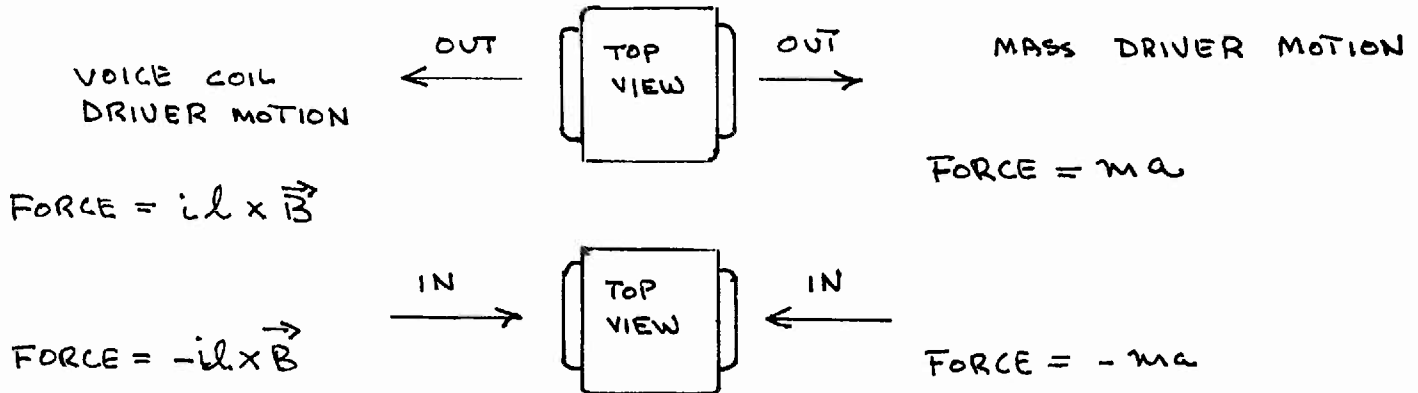
*Bob Carver*

Bob Carver  
October, 1996

## POST SCRIPT

### HOW THE DRIVERS WORK TOGETHER

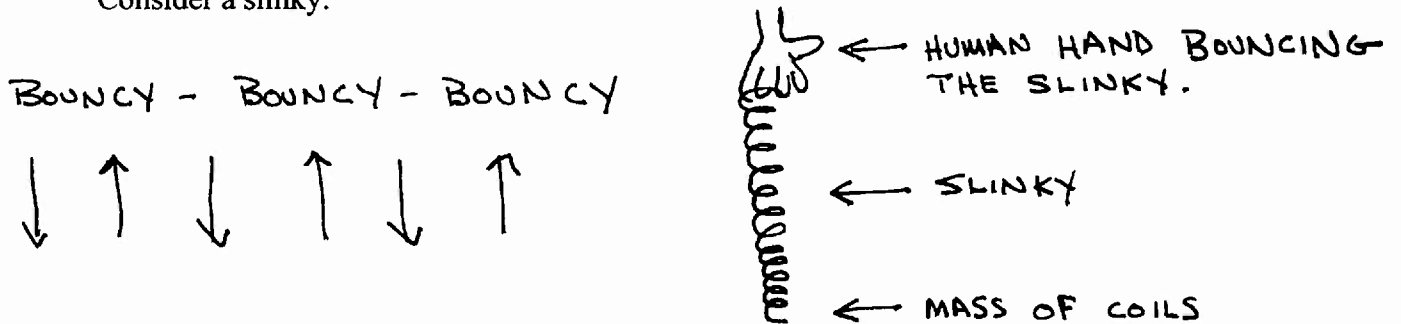
The mass driven driver works as follows. Consider the drawings below.



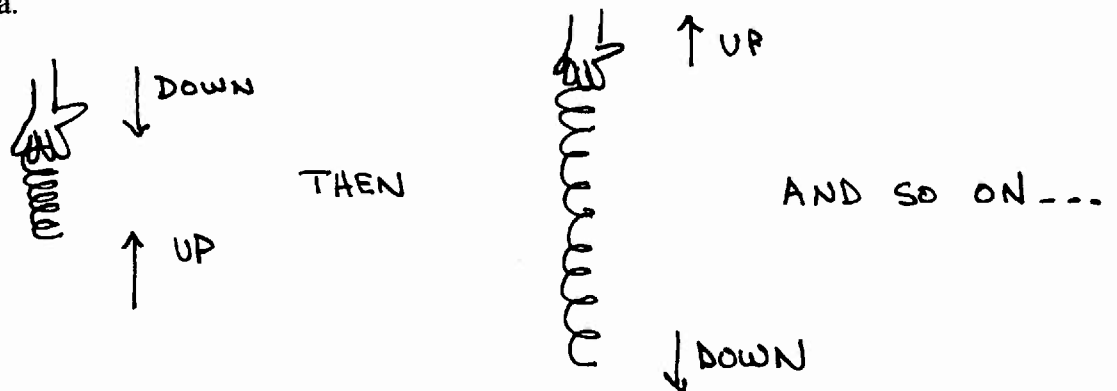
The force that moves the voice coil driver is the product of current  $i$ , voice coil wire length  $l$ , and magnetic field strength  $B$ .

The force that moves the mass driven driver is the reaction force of a large mass bonded to the driver core. Its magnitude (By Issac Newton) is equal to force times acceleration.

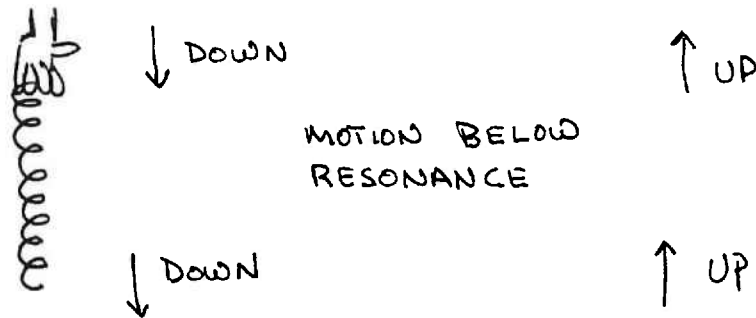
There is a spring inside. It is the air in the cabinet. This is a classic mass/spring system. Consider a slinky.



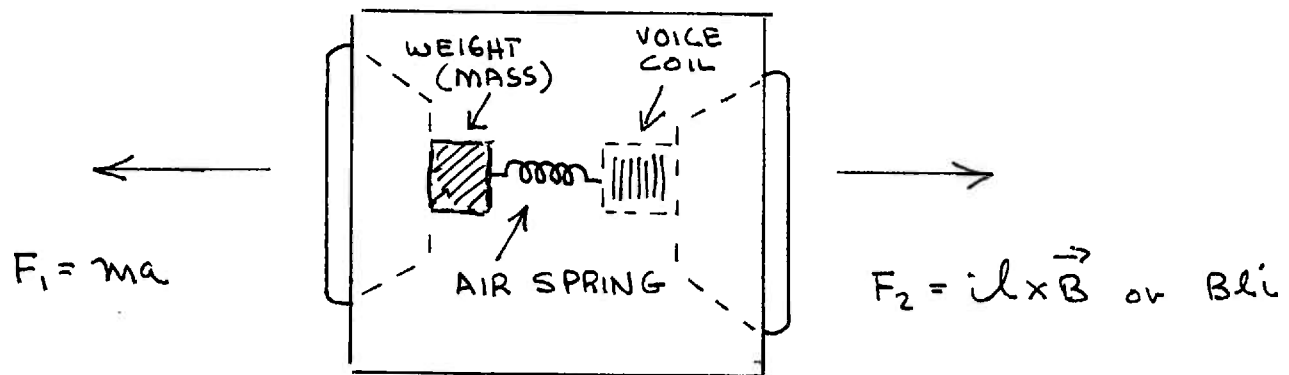
The motion is such that as the hand goes down, the other end of the slinky moves up. And visa-versa.



If the bouncing is *above* the resonance frequency of the mass/spring system, the motion is as shown above. If the bouncing is *below* the resonance frequency of the system, the motion follows our intuitive idea of the motion, i.e., both hand and spring move up and down together.



Now, back to the woofer.



By Issac Newton, for every force there exists an equal and opposite force.

$$\underline{\underline{F_1 = F_2}}$$

At maximum output these forces are over 75 lbs.

END

