Loudspeaker Parameters

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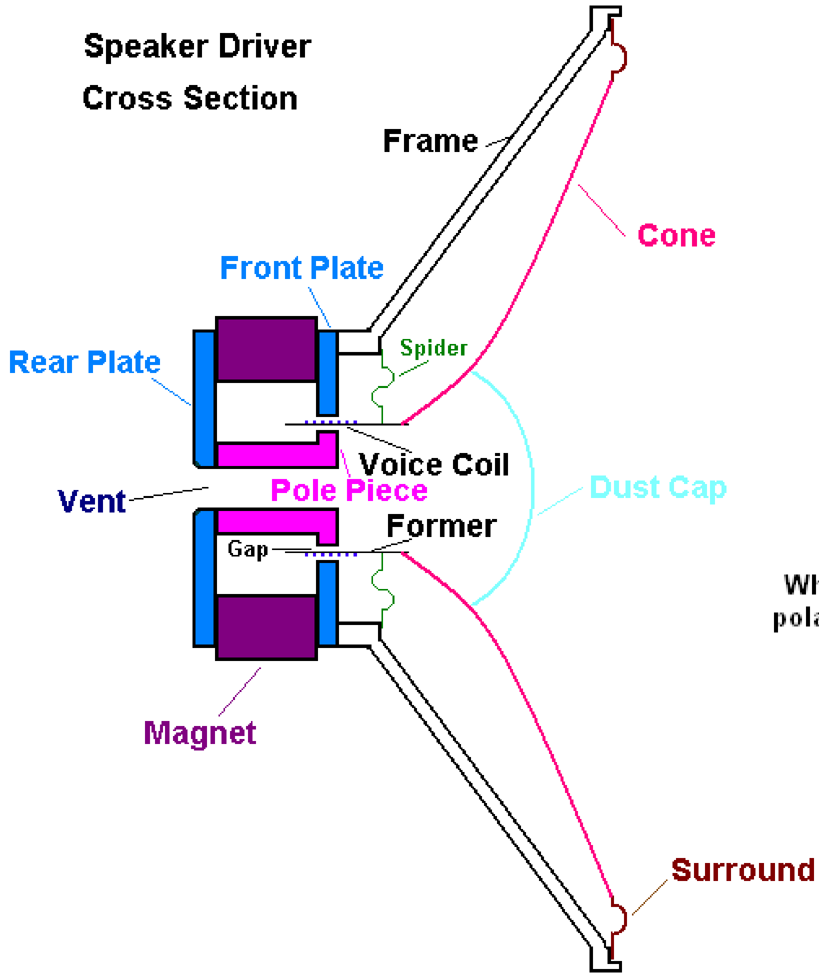
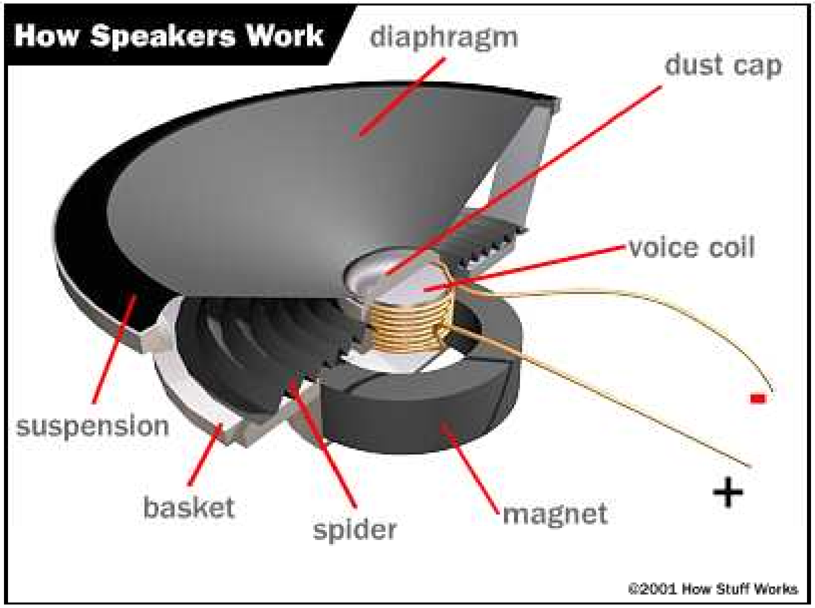
Outline

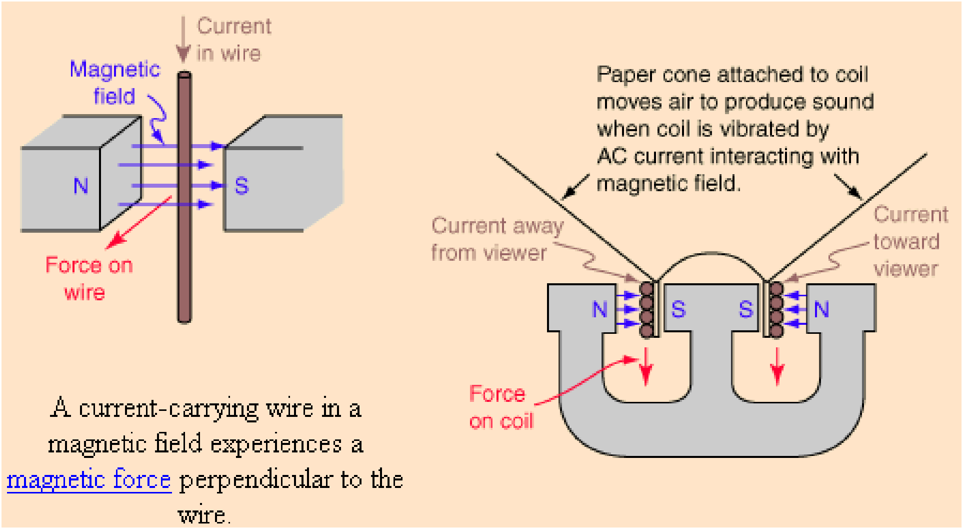
- **Review of How Loudspeakers Work**
- **Small Signal Loudspeaker Parameters**
- **Effect of Loudspeaker Cable**
- **Sample Loudspeaker**
- **Electrical Power Needed**
- **Sealed Box Design Example**

How Loudspeakers Work

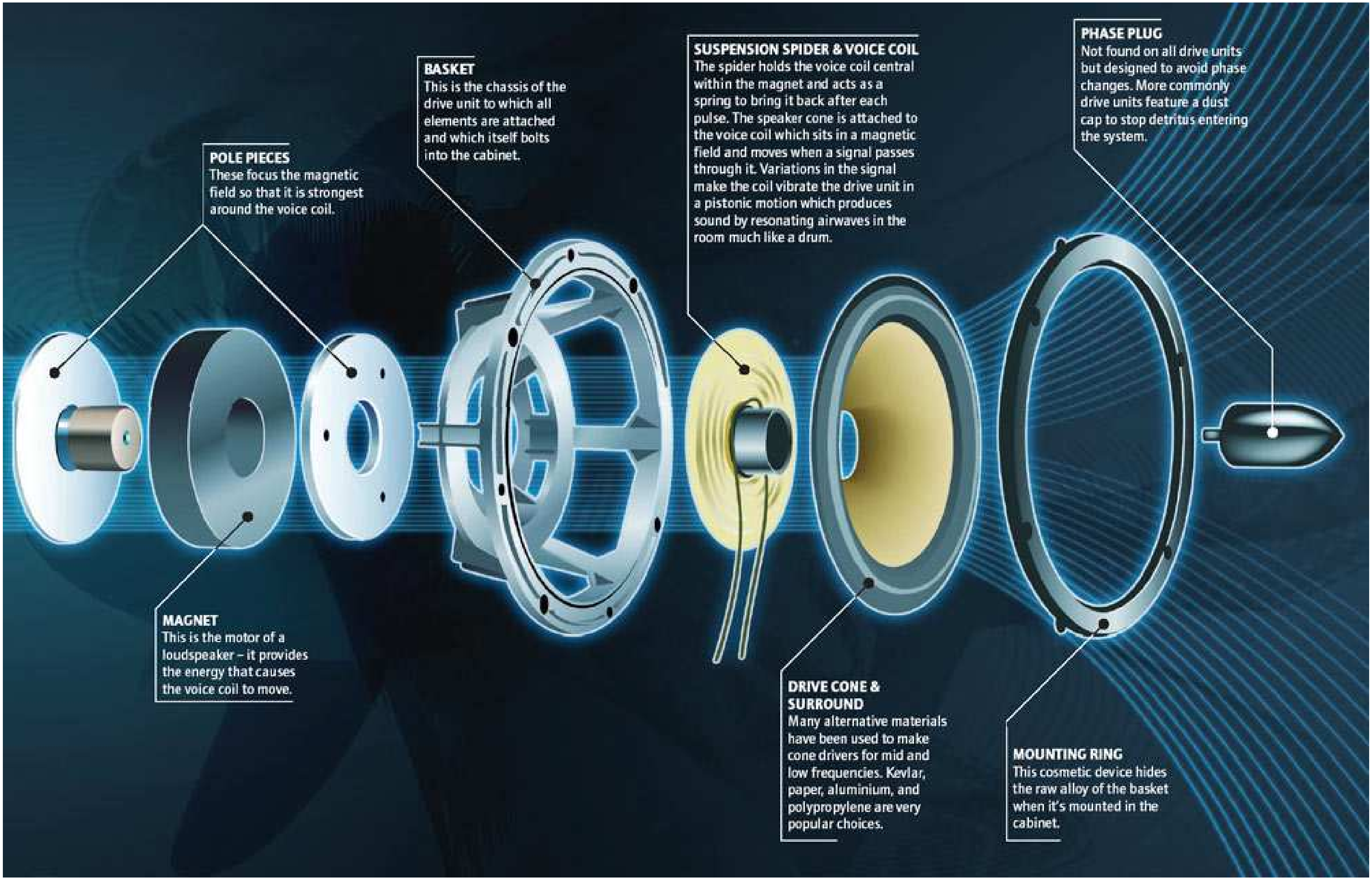




When the electrical current flowing through the voice coil changes direction, the coil's polar orientation reverses. This changes the magnetic forces between the voice coil and the permanent magnet, moving the coil and attached diaphragm back and forth.



How Loudspeakers Are Made



Fundamental Small Signal Mechanical Parameters

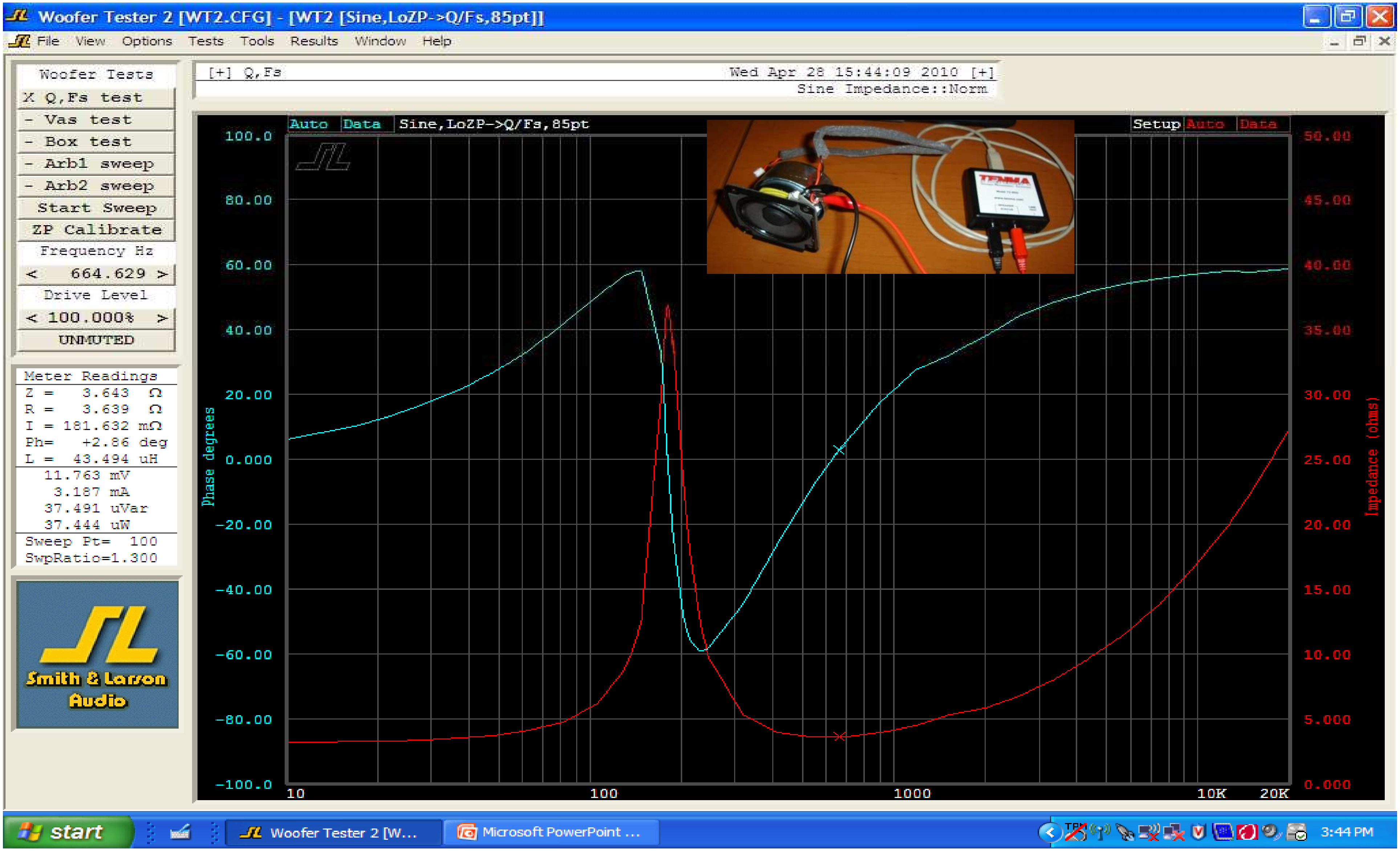
- **S_d – projected area of driver diaphragm (m^2)**
- **M_{ms} – mass of diaphragm (kg)**
- **C_{ms} – compliance of driver's suspension (m/N)**
- **R_{ms} – mechanical resistance of driver's suspension (N•s/m)**
- **L_e – voice coil inductance (mH)**
- **R_e – DC resistance of voice coil (Ω)**
- **B*l* – product of magnetic field strength in voice coil gap and length of wire in magnetic field (T•m)**

Small Signal Parameters

These values can be determined by measuring the input impedance of the driver, near the resonance frequency, at small input levels for which the mechanical behavior of the driver is effectively linear.

- **F_s – (free air) resonance frequency of driver (Hz)**
  - **frequency at which the combination of the energy stored in the moving mass and suspension compliance is maximum, which results in maximum cone velocity**
  - **usually it is less efficient to produce output frequencies below F_s**
  - **input signals significantly below F_s can result in large excursions**
  - **typical factory tolerance for F_s spec is ±15%**

Measurement of Loudspeaker Free-Air Resonance



Small Signal Parameters

These values can be determined by measuring the input impedance of the driver, near the resonance frequency, at small input levels for which the mechanical behavior of the driver is effectively linear.

- **Q_{ts} – total Q of driver at F_s**
  - **unitless measurement, characterizing the combined electrical and mechanical damping of the driver**
  - **proportional to the energy stored, divided by the energy dissipated**
  - **most drivers have Q_{ts} values between 0.2 and 0.5**

Small Signal Parameters

These values can be determined by measuring the input impedance of the driver, near the resonance frequency, at small input levels for which the mechanical behavior of the driver is effectively linear.

- **Q_{ms} – mechanical Q of driver at F_s**
  - **unitless measurement, characterizing the mechanical damping of the driver, i.e., losses in the suspension (surround and spider)**
  - **varies roughly between 0.5 and 10 (typical value is 3)**
  - **high Q_{ms} indicates lower mechanical losses**
  - **main effect of Q_{ms} is on impedance: high Q_{ms} drivers display a higher impedance peak**

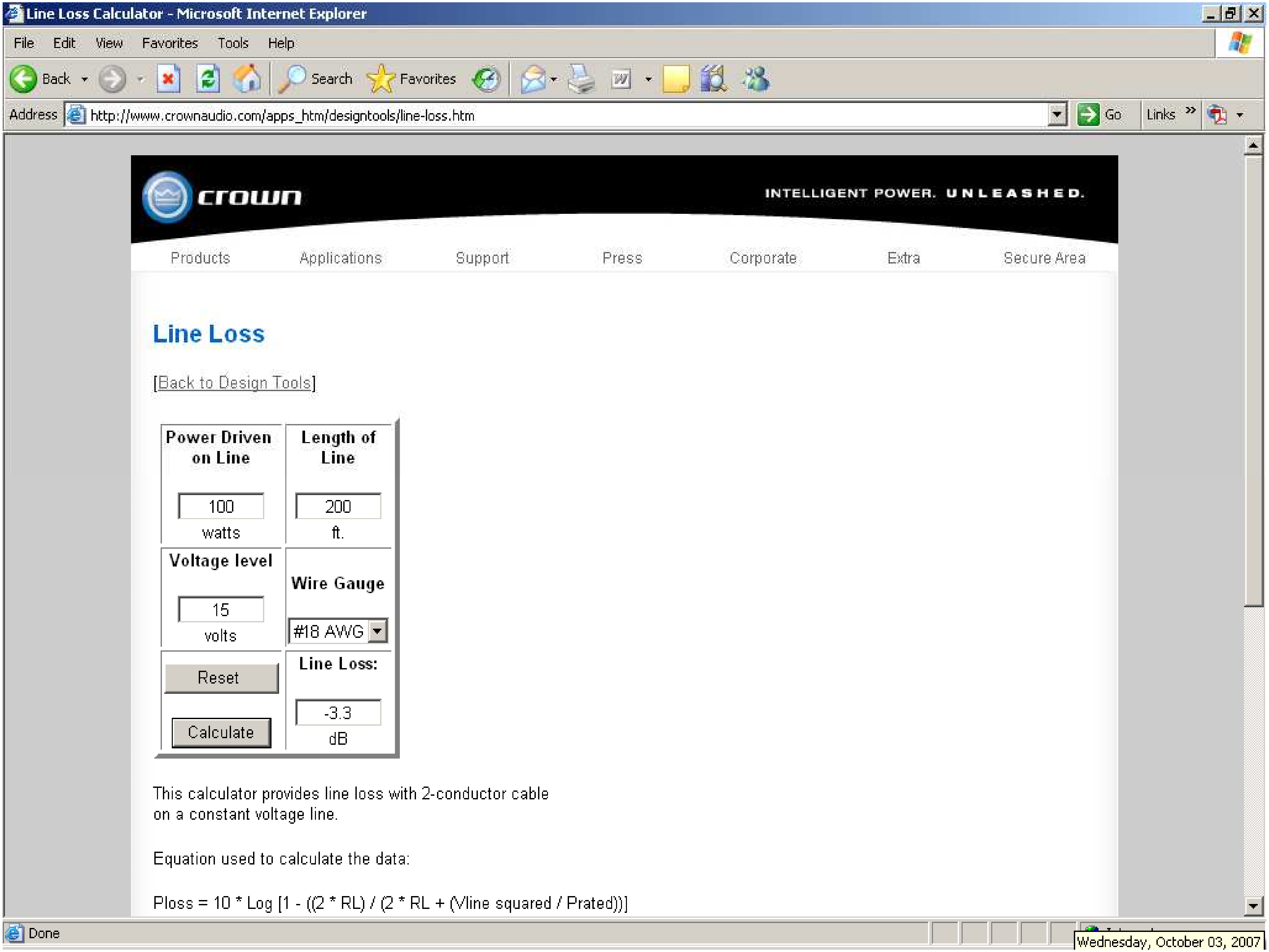
Small Signal Parameters

These values can be determined by measuring the input impedance of the driver, near the resonance frequency, at small input levels for which the mechanical behavior of the driver is effectively linear.

- **Q_{es} – electrical Q of driver at F_s**
  - **a unitless measurement, describing the electrical damping of the speaker**
  - **as the coil of wire moves through the magnetic field, it generates a current which opposes the motion of the coil (“back EMF”)**
  - **the back EMF decreases the total current through the coil near F_s, reducing cone movement and increasing impedance**
  - **Q_{es} is the dominant factor in voice coil damping for most drivers (depends on amplifier output impedance)**

Aside: How Does Loudspeaker Cable And Power Amplifier Output Impedance Affect Performance?

- **Damping is a measure of a power amplifier's ability to control the back EMF motion of the loudspeaker cone after the signal disappears**
- **The damping factor of a system is the ratio of the loudspeaker's nominal impedance to the total impedance driving it**
- **Example: Amplifier with damping factor of 300 (bigger is better) driving an 8Ω load means that the output impedance is 0.027Ω (lower is better)**
- **Impedance of speaker cable used can significantly reduce the damping factor (larger gauge wire has lower impedance)**


Line Loss Calculator - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites
Address http://www.crownaudio.com/apps_htm/designtools/line-loss.htm
Go Links
crown
INTELLIGENT POWER. UNLEASHED.
Products Applications Support Press Corporate Extra Secure Area
Line Loss
[Back to Design Tools]
Power Driven on Line
100
watts
Length of Line
200
ft.
Voltage level
15
volts
Wire Gauge
#18 AWG
Reset
Calculate
Line Loss:
-3.3
dB
This calculator provides line loss with 2-conductor cable on a constant voltage line.
Equation used to calculate the data:
Ploss = 10 * Log [1 - ((2 * RL) / (2 * RL + (Vline squared / Prated))]
Done
Wednesday, October 03, 2007

Small Signal Parameters

These values can be determined by measuring the input impedance of the driver, near the resonance frequency, at small input levels for which the mechanical behavior of the driver is effectively linear.

- **V_{as} – equivalent compliance volume (volume of air which, when acted upon by a piston of area S_d, has the same compliance as the driver's suspension)**
  - **measure of the "stiffness" of the suspension with the driver mounted in free air**
  - **represents the volume of air that has the same stiffness as the driver's suspension when acted upon by a piston of the same area (S_d) as the cone**
  - **larger values mean lower stiffness (and generally require larger enclosures)**
  - **V_{as} varies with the square of the speaker's diameter**
  - **typical factory tolerance for V_{as} is ±20-30%**

Sample Loudspeaker

4" Aluminum Cone Woofer

MCM Audio Select Part #: 55-1856 | MCM Order #: 55-1856

All Categories Audio & Video

No reviews yet!
Write a review

Versatile driver offers high power capacity and wide frequency response making it ideal in applications including full range and midbass in compact monitors. Large vented magnet, heavy duty voice coil and thick aluminum cone provide tremendous durability in high SPL applications.

Sensitivity = 86 dB
Fs = 65 Hz
Re = 6.6Ω
Le = 0.48 mH
Qts = 0.365
Qes = 0.436
Qms = 2.25
Vas = 3.15 liters

Product Description

- Aluminum cone
- Synthetic dust cap
- Rubber surround
- Stamped steel basket
- 1" copper voice coil
- 17.7oz. magnet

Specifications:

- Power Capacity: 50W/100W RMS/peak
- Sensitivity: 86dB (W/M)
- Impedance: 8Ω
- Re: 6.6Ω
- Le: 0.48mH
- Frequency response: 65Hz ~ 17KHz
- Fs: 65Hz
- Qts: 0.365
- Qes: 0.436
- Qms: 2.25
- Vas: 3.15 (liters)
- Xmax: 2.25mm
- Overall frame diameter: 4.13" (pincushion)
- Required cutout: 3.66"
- Mounting depth: 2.5"

Aside: How Loud Does This Thing Get? (And, How Much Power Do I Need?)

- Relating electrical power needed to produce desired SPL at a given listening distance:
  - sensitivity rating of loudspeaker (typically spec as 1 m on-axis with input of 1 electrical watt)
  - acoustic level change/attenuation between loudspeaker and farthest listening position
- Example: want 90 dB program level at listening distance of 4 m outdoors (i.e., no reinforcement of sound due to room reflections)
  - loudspeaker sensitivity measured as 86 dB
  - acoustic level change = 20 log (4) $\cong$ 12 dB
  - SPL required at source is 90 + 12 = 102 dB
  - need 16 dB above 1 watt, or $10^{(16/10)}$ = 40 W
  - **check to make sure driver can handle it!**

Amplifier Power Required Calculator - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://www.crownaudio.com/apps_htm/designtools/elect-pwr-req.htm

Amplifier Power Required

http://www.crownaudio.com

[Back to Design Tools]

Listener Distance from source	Desired Level at Listener distance
32 M	90 dBSPL
Loudspeaker Sensitivity Rating (1W/1M)	Amplifier Headroom
110 dB	10 dB
Calculate / Reset	Required Amplifier Power: 102 watts

Equations used to calculate the data:

dBW = Lreq - Lsens + 20 * Log (D2/Dref) + HR

W = 10 to the power of (dBW / 10)

Where:
Lreq = required SPL at listener
Lsens = loudspeaker sensitivity (1W/1M)
D2 = loudspeaker-to-listener distance
Dref = reference distance
HR = desired amplifier headroom
dBW = ratio of power referenced to 1 watt
W = power required

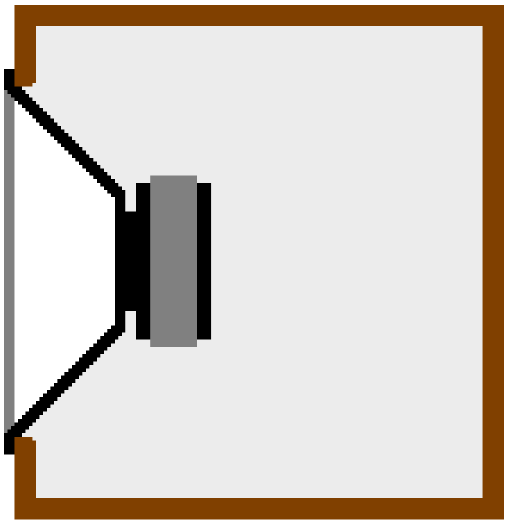
This calculator provides the required electrical power (power output from the amplifier) to produce a desired Sound Pressure Level (SPL) at a given distance, along with an amount of headroom to keep the amplifier(s) out of clip.

Example: You are designing a system where the farthest listening position from the loudspeaker is 100 meters, and the desired Sound Pressure Level is 85 dB SPL The loudspeaker chosen for the job has a sensitivity rating of 95 dB. With the minimum recommended amplifier headroom of 3 dB, then you need to choose an amplifier that can supply at least 1,995 watts to the loudspeaker.

Enclosure-Related Parameters

- **EBP = F_s / Q_{es}**
  - **used loosely to decide what type of enclosure will be best for a given speaker ("rule of thumb")**
  - **sealed box EBP $\approx$ 50**
  - **vented enclosure EBP $\approx$ 100**
- **F_c = sealed enclosure resonance**
- **V_c = internal volume of a sealed enclosure**
- **V_b = internal volume of a vented enclosure**
- **F_b = bass reflex enclosure resonance**
- **L_v = length of port**
- **Q_{tc} – desired value determines size and type of enclosure**
  - **value of 0.707 is what most designers aim for (yields flattest response)**
  - **enclosures designed to enhance bass may range from 0.8 to 1.1 (bigger value, "boomier" sound)**
  - **enclosures that are too big ($Q_{tc} < 0.707$) can sound "tinny"**

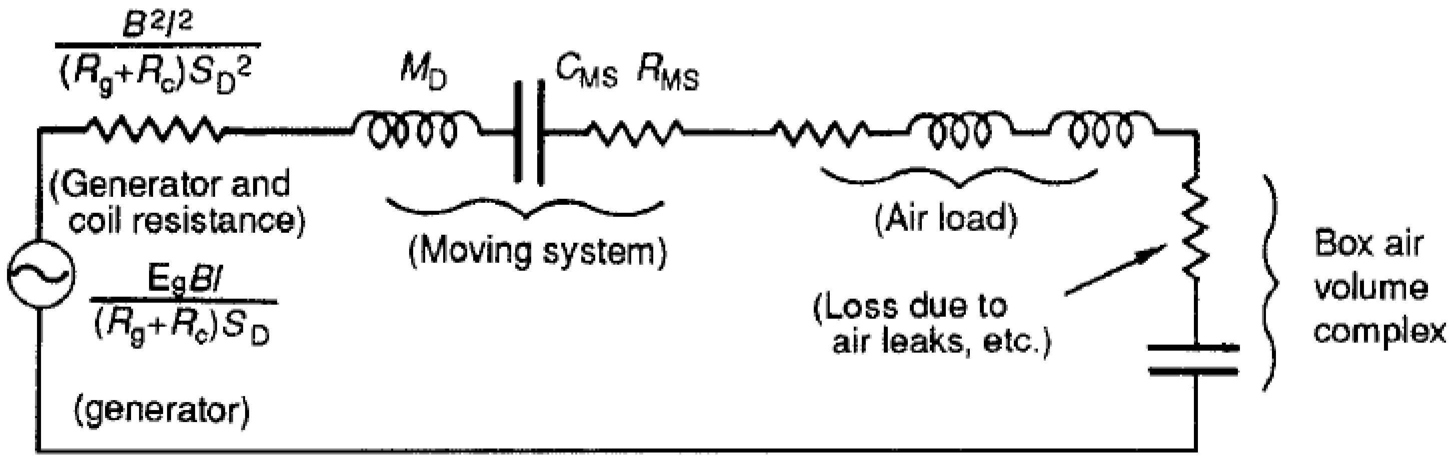
Sealed Box

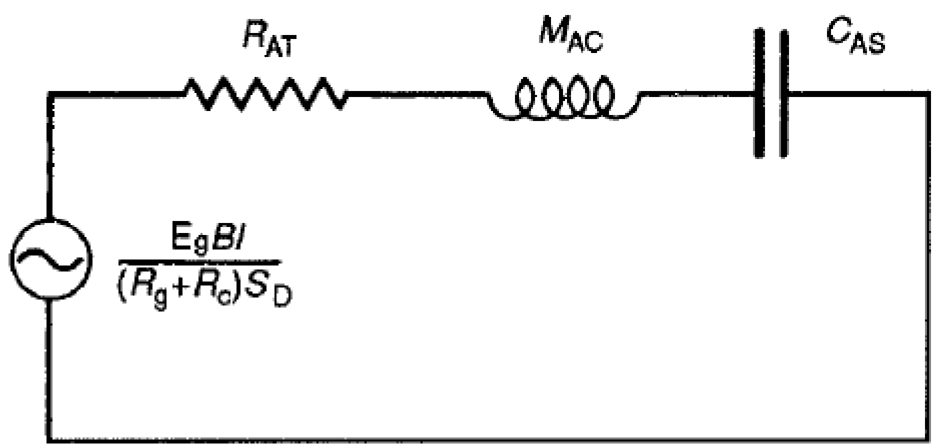


Sealed Box

- Theoretically an infinite baffle with an additional stiffness component added (to the existing suspension compliance) due to the springiness of the air volume trapped in the enclosure
- A smaller box will have a greater stiffness contribution than a larger one – in sealed box systems the air restoring force is normally made dominant (compared with that of the driver suspension)

Electromechanical Equivalent for Driver in a Sealed Box



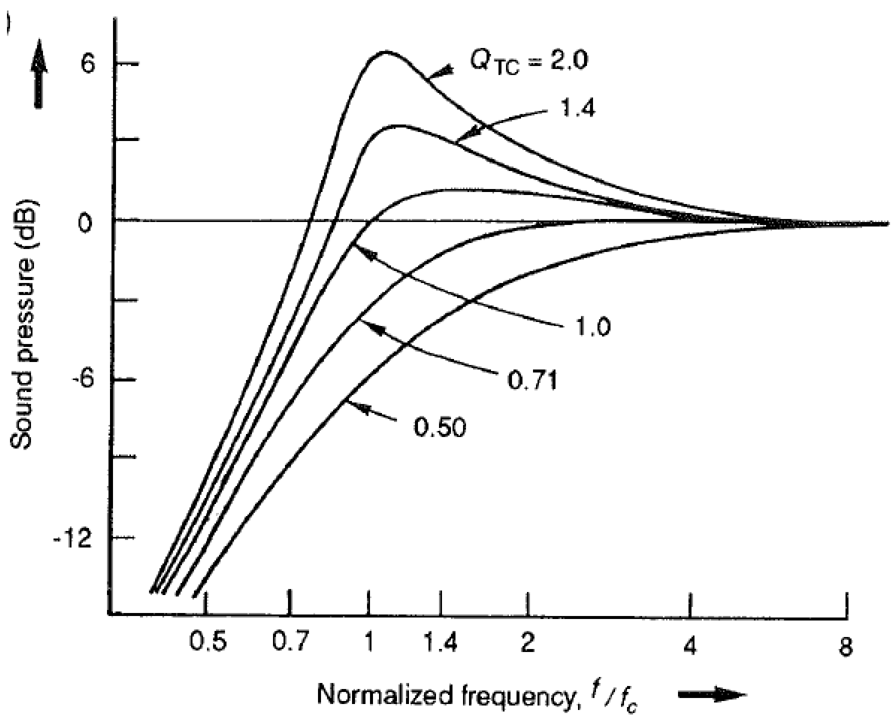


Simplified form – system response is that of a damped single-resonant circuit

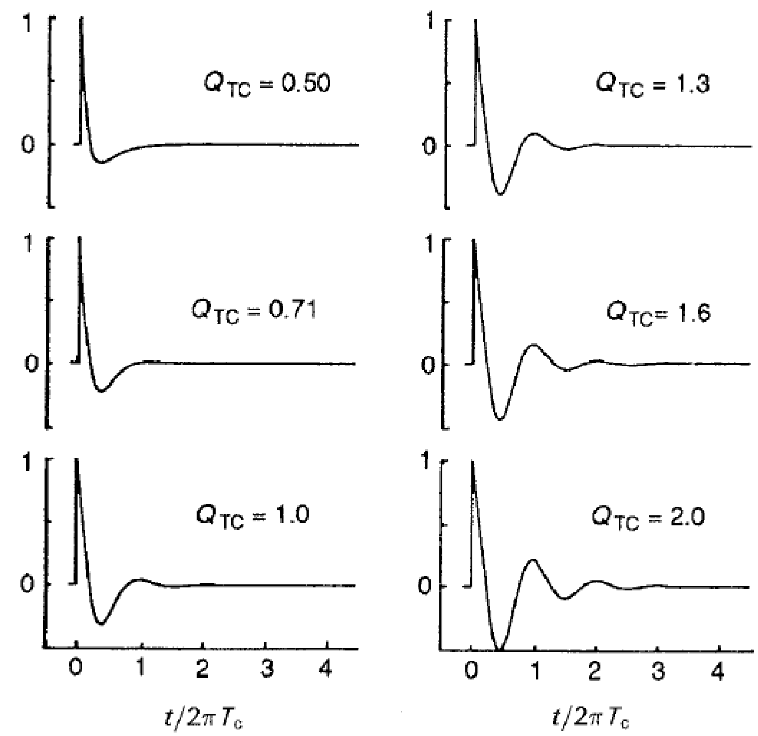
Response Shape

- Critically damped (Q_{TC} = 0.5): response is -6 dB at resonance (no ringing/overshoot in transient response)
- Butterworth alignment (Q_{TC} = 0.7): response is -3 dB at resonance (response is "maximally flat" and has good transient behavior)
- Q_{TC} =1: provides greater bandwidth at expense of transient response accuracy
- Chebychev alignment (Q_{TC} = 1.1): 2 dB peak in response at resonance – results in optimum efficiency alignment for a sealed box system, and is permissible for a small system of limited bandwidth (e.g., F_C of 65 Hz and above)

Behavior of a Closed-Box Loudspeaker System for Several Values of Total System Q_{TC}



Amplitude vs. Normalized Frequency Response



Normalized Step Response

Enclosure Volume and Efficiency

- The maximum efficiency even a large sealed-box enclosure can achieve is small (1-2%)
- Increasing the box cutoff frequency increases the theoretical efficiency
- The closed-box system efficiency in the passband region (system reference efficiency) is the reference efficiency of the driver operating with the particular value of air-load mass provided by the system enclosure
- Reference efficiency (η_0) calculation:

$$\eta_0 = 4\pi^2/c^3 \times (F_S{}^3\, V_{AS})/Q_{ES} = 4\pi^2/c^3 \times (F_C{}^3\, V_{AT})/Q_{EC}$$

where V_{AT} is a volume of air having the same total acoustic compliance as the driver suspension and enclosure acting together

Relationship of Maximum Reference Efficiency to Cutoff Frequency and Enclosure Volume

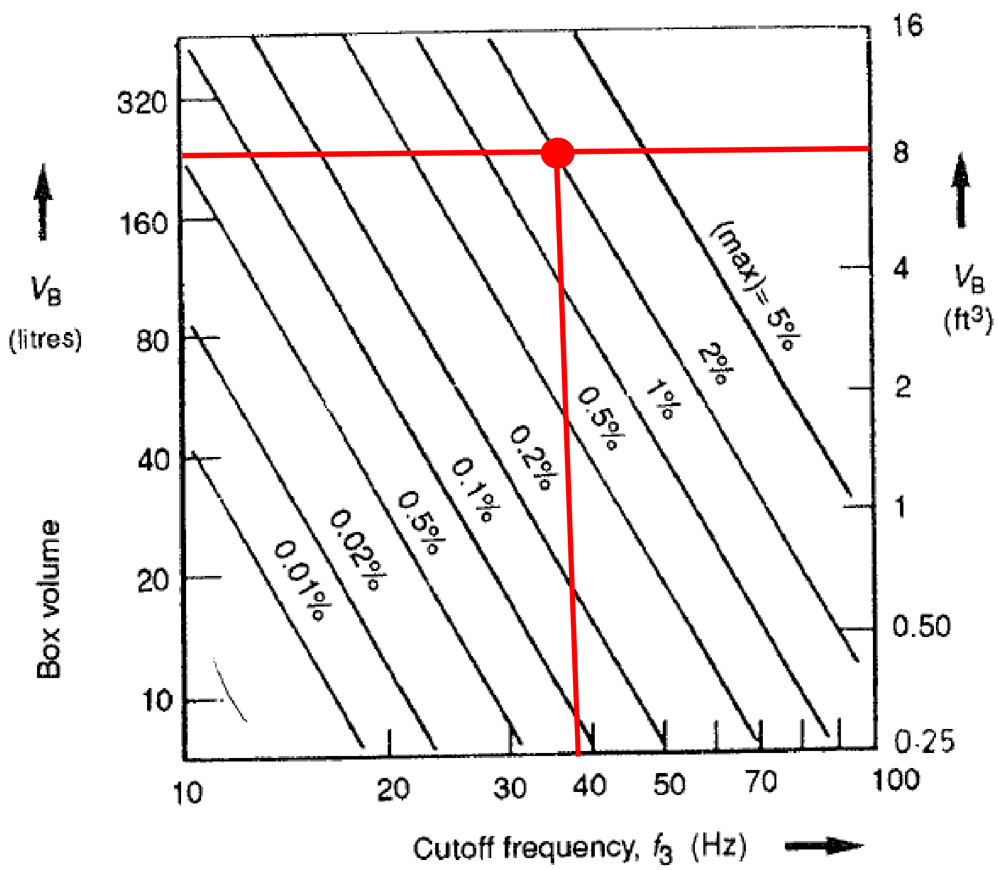


Chart for Chebychev Alignment

Example: An 8 cu. ft. (e.g. 2'x2'x2') sealed box with a reference efficiency (η_0) of 2% would have a cutoff frequency (Fc) of slightly less than 40 Hz

Box Filling or Damping

- Stuffing may offer an apparent air volume increase of up to 15%
- Additionally, stuffing may add a mass component due to physical movement of the filling at lower frequencies
- Combined effects lower the system resonance and must be accounted for in the design (the effective cone mass increase could be as much as 20%)
- Very dense fillings will increase frictional air losses in the enclosed air volume and augment the damping
- If system is designed correctly, such damping is not required, but may help control a system where the Q_{TC} is too high (e.g., due to inadequate magnet strength)
- Movement of the filling is undesirable!

Sealed Box Design

- Compliance Ratio: $\alpha = V_{AS} / V_B$
- System-driver relationships:

  $Q_{TC}/Q_{TS} \approx Q_{EC}/Q_{ES} = F_C/F_S = (\alpha + 1)^{0.5}$

  $F_C / Q_{TC} \approx F_S / Q_{TS}$ where Q_{TS} is the total Q of the driver at F_S for zero source resistance, i.e.

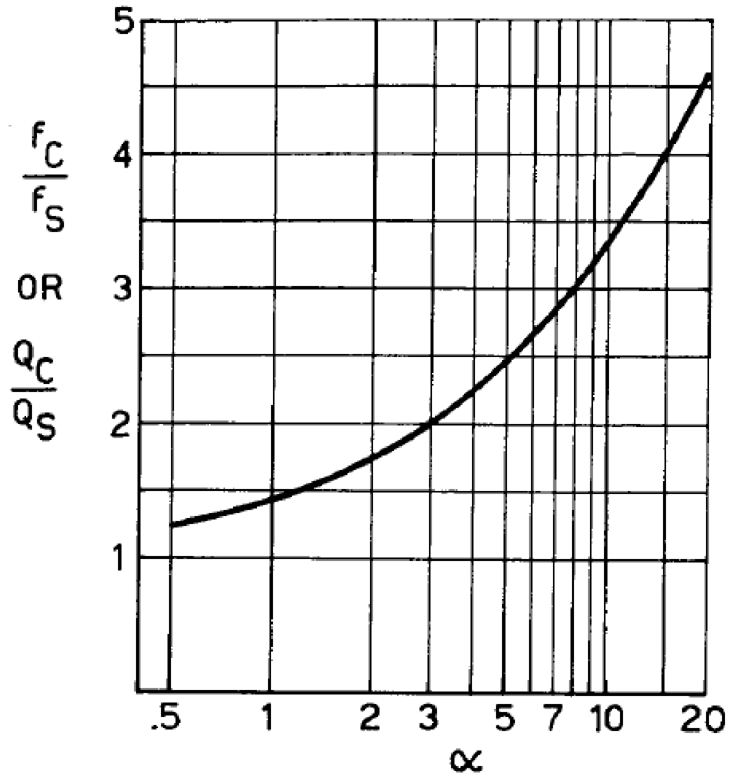
  $$Q_{TS} = Q_{ES}Q_{MS} /(Q_{ES} + Q_{MS})$$

- These equations show that for any enclosure-driver combination the <u>speaker</u> resonance frequency must always be lower than that of the <u>system</u> resonance frequency (i.e., value of α) and Q will be in the same ratio as those of the driver, but individually raised by a factor of $(\alpha+1)^{0.5}$
- Provides guidance for both "fixed driver" designs and designs where only a final system specification is given

Ratio of Closed-Box System Resonance Frequency (F_C) and Total Q (Q_{TC}) to Driver Resonance Frequency (F_S) and Q_T, as a Function of the System Compliance Ratio (α)

f_C = box cutoff frequency

f_S = loudspeaker free-air resonance frequency



Compliance Ratio: $\alpha = V_{AS} / V_B$

Sealed Box Design Example

- F_S = 31 Hz
- Q_{ES} = 0.77

EBP = 40 $\rightarrow$ use sealed enclosure

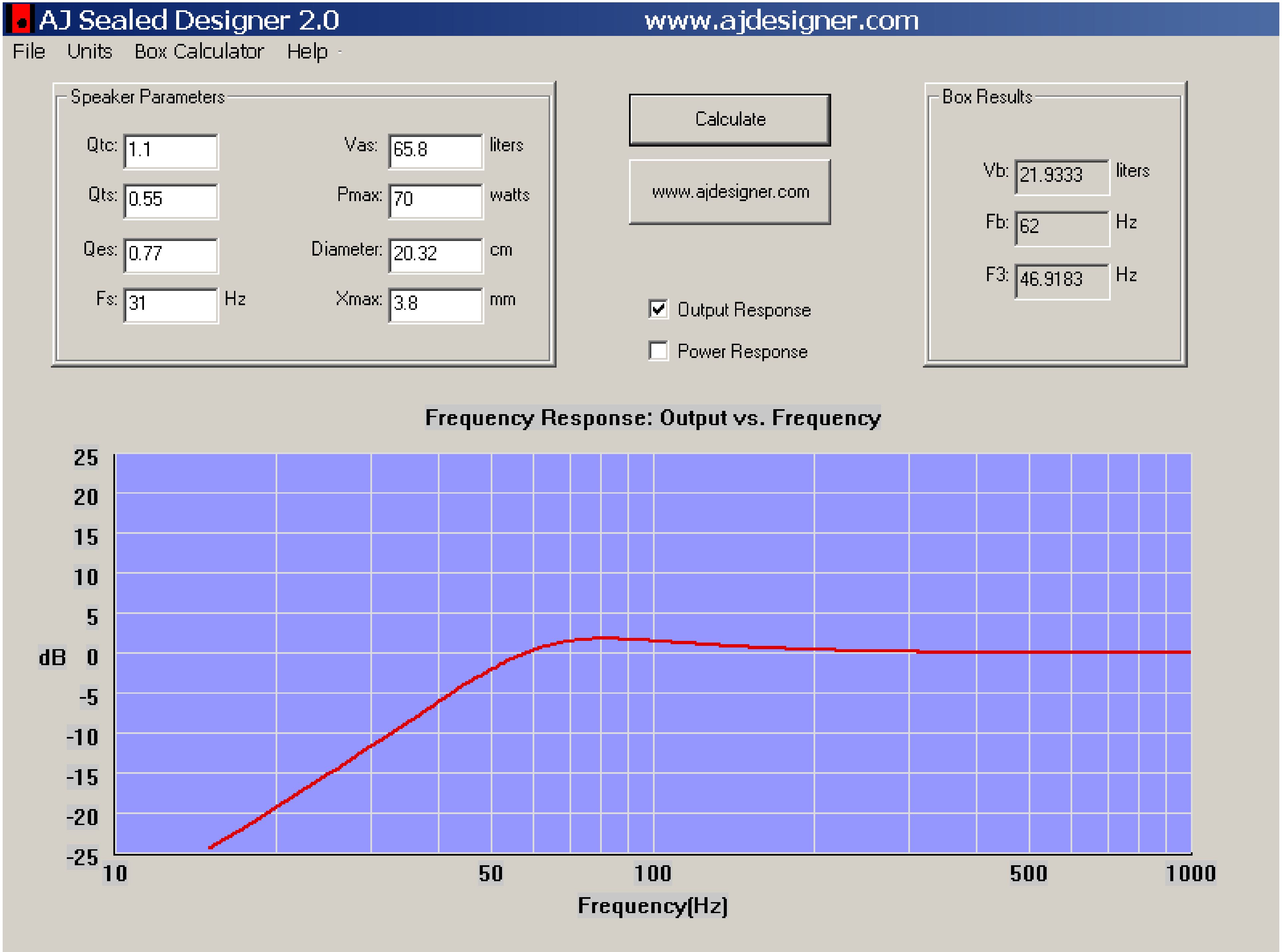
- Q_{MS} = 1.89
- V_{AS} = 65.8 liters
- $\eta_0 = 4\pi^2/c^3 \times (F_S{}^3\, V_{AS})/Q_{ES}$

  $= (9.64 \times 10^{-7}) \times (31^3 \times 65.8)/0.77 = 2.45\%$
- effective diaphragm radius = 10.2 cm (0.102 m), giving $S_D = 3.27 \times 10^{-2}\ m^2$
- peak linear displacement (Xmax) given as 3.8 mm (3.8×10^{-3} m)
- peak displacement volume = $V_D = S_D$ Xmax = $1.24 \times 10^{-4}\ m^3$ ($124\ cm^3$)
- power rating given as 70W RMS

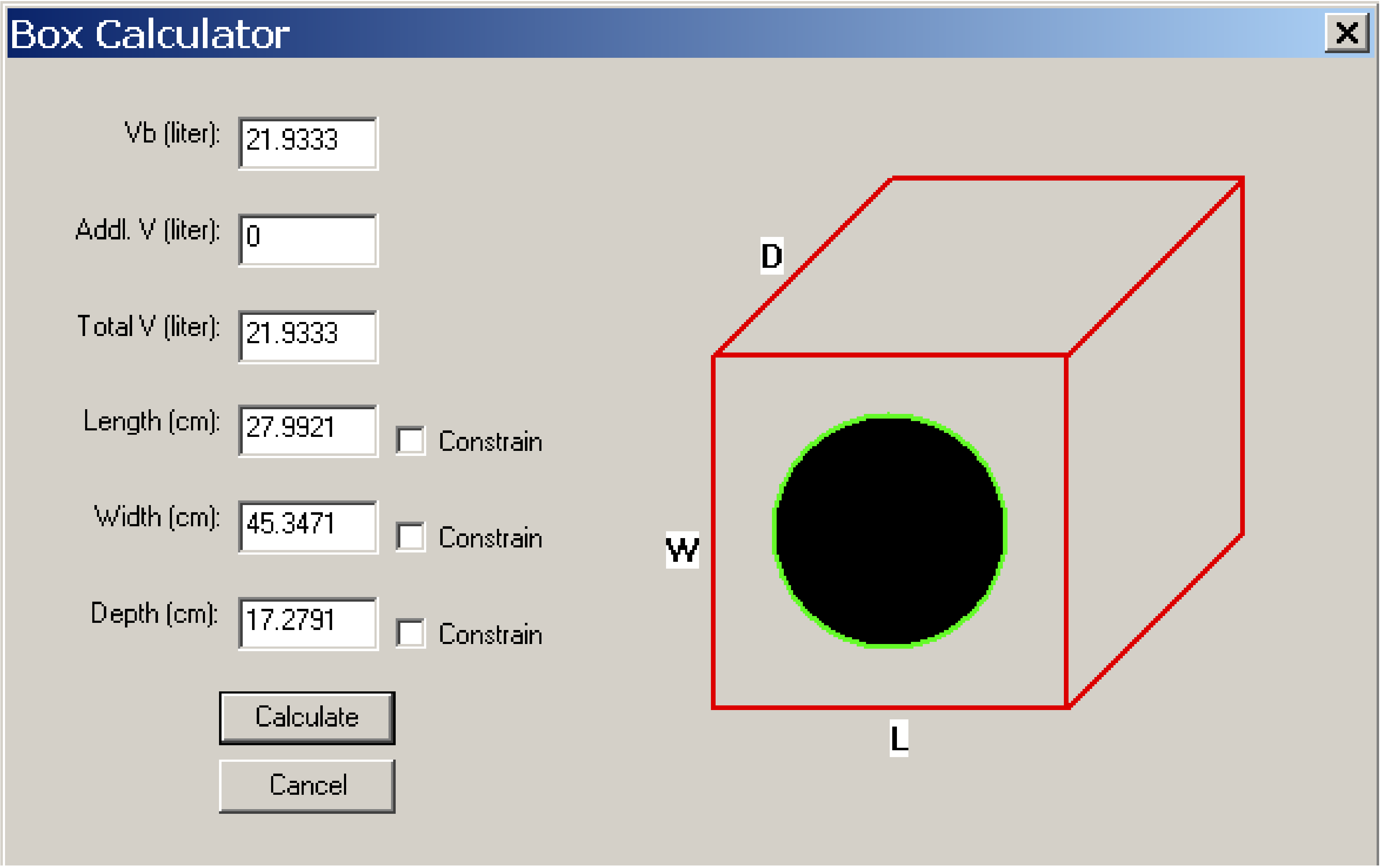
Sealed Box Design Example

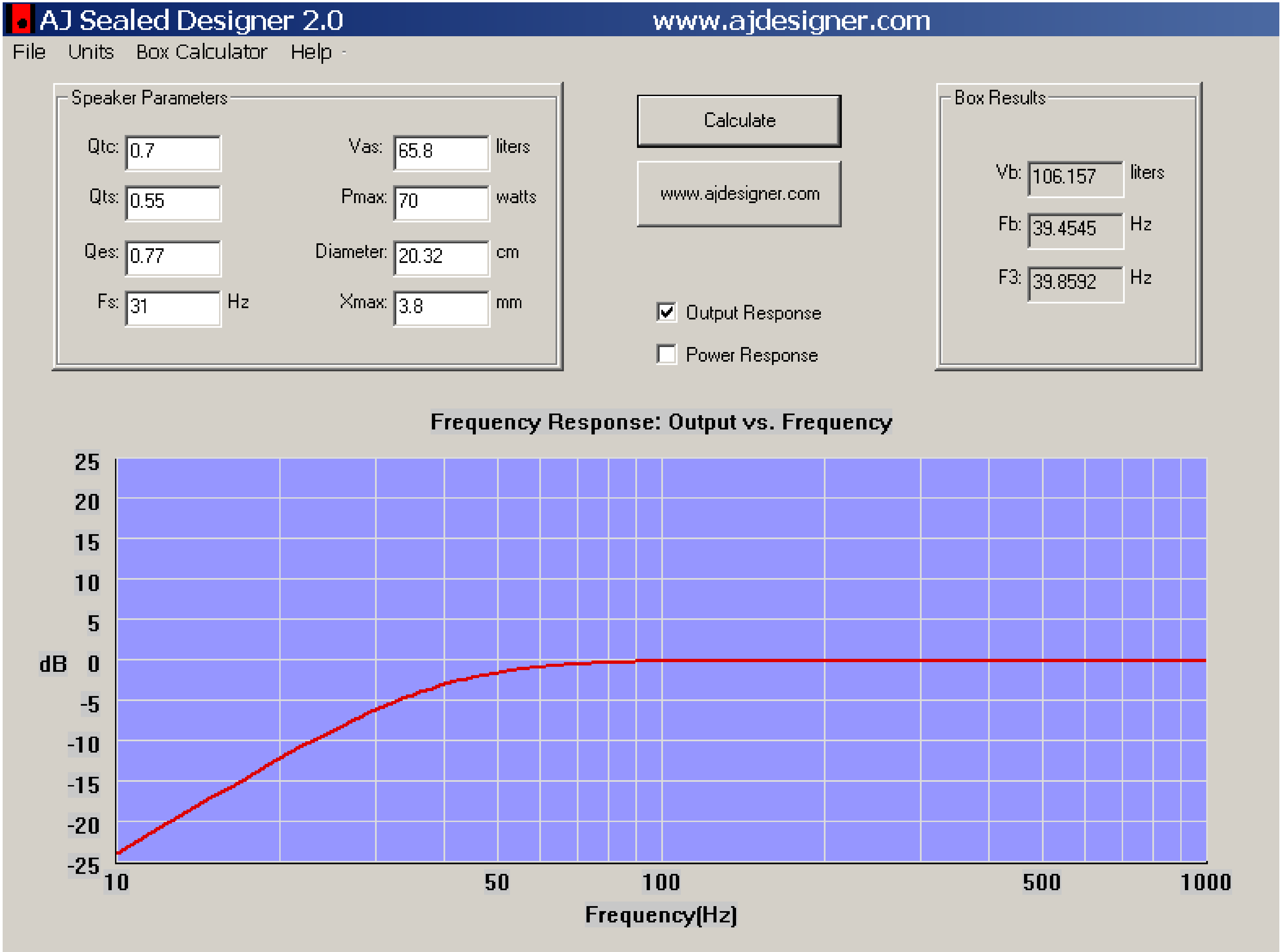
- constraints
  - driver resonance frequency (F_S) must always be lower than that of the system (F_C)
  - α must be at least 3
  - Q_{TS} must be lower than highest acceptable Q_{TC}
  - V_{AS} must be at least several times larger than the enclosure size (volume)
  - select most desirable combination of F_C and Q_{TC} that satisfies $F_C / Q_{TC} \approx F_S / Q_{TS}$ and then calculate $\alpha = V_{AS} / V_B$
- calculations
  - $Q_{TS} = (0.77)(1.89)/(0.77+1.89) = 0.547$
  - based on $\alpha \geq 3$ requirement, $F_C/F_S \geq 2 \rightarrow F_C \geq 62$
  - $F_S / Q_{TS} = 56.7 \approx F_C / Q_{TC} \rightarrow$ for $F_C = 62$ get $Q_{TC} \approx 1.1$ ("Chebychev Alignment" $\rightarrow$ maximum efficiency)
  - internal volume of box needed based on α

    $\alpha = V_{AS} / V_B$ (want $\alpha \geq 3$) $\rightarrow V_B \leq 22$ liters ($0.022\ m^3$)
  - yields approximate size of: 0.28 m x 0.28 m x 0.28 m



AJ Sealed Designer 2.0
www.ajdesigner.com
File
Units
Box Calculator
Help
Speaker Parameters
Qtc: 1.1
Qts: 0.55
Qes: 0.77
Fs: 31 Hz
Vas: 65.8 liters
Pmax: 70 watts
Diameter: 20.32 cm
Xmax: 3.8 mm
Calculate
www.ajdesigner.com
Output Response
Power Response
Box Results
Vb: 21.9333 liters
Fb: 62 Hz
F3: 46.9183 Hz
Frequency Response: Output vs. Frequency
25
20
15
10
5
dB 0
-5
-10
-15
-20
-25
10
50
100
500
1000
Frequency(Hz)


Box Calculator
Vb (liter): 21.9333
Addl. V (liter): 0
Total V (liter): 21.9333
Length (cm): 27.9921
Constrain
Width (cm): 45.3471
Constrain
Depth (cm): 17.2791
Constrain
Calculate
Cancel
D
W
L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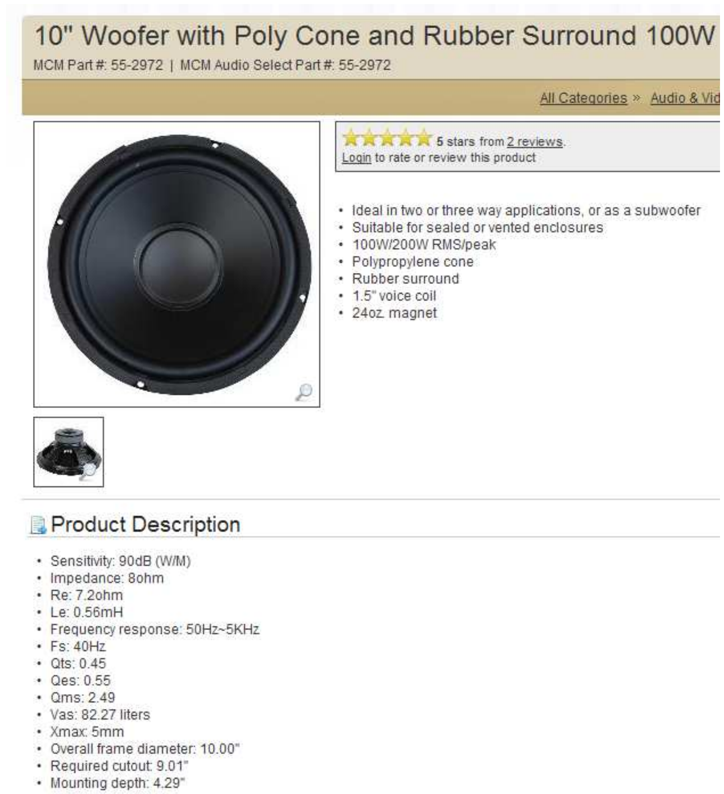
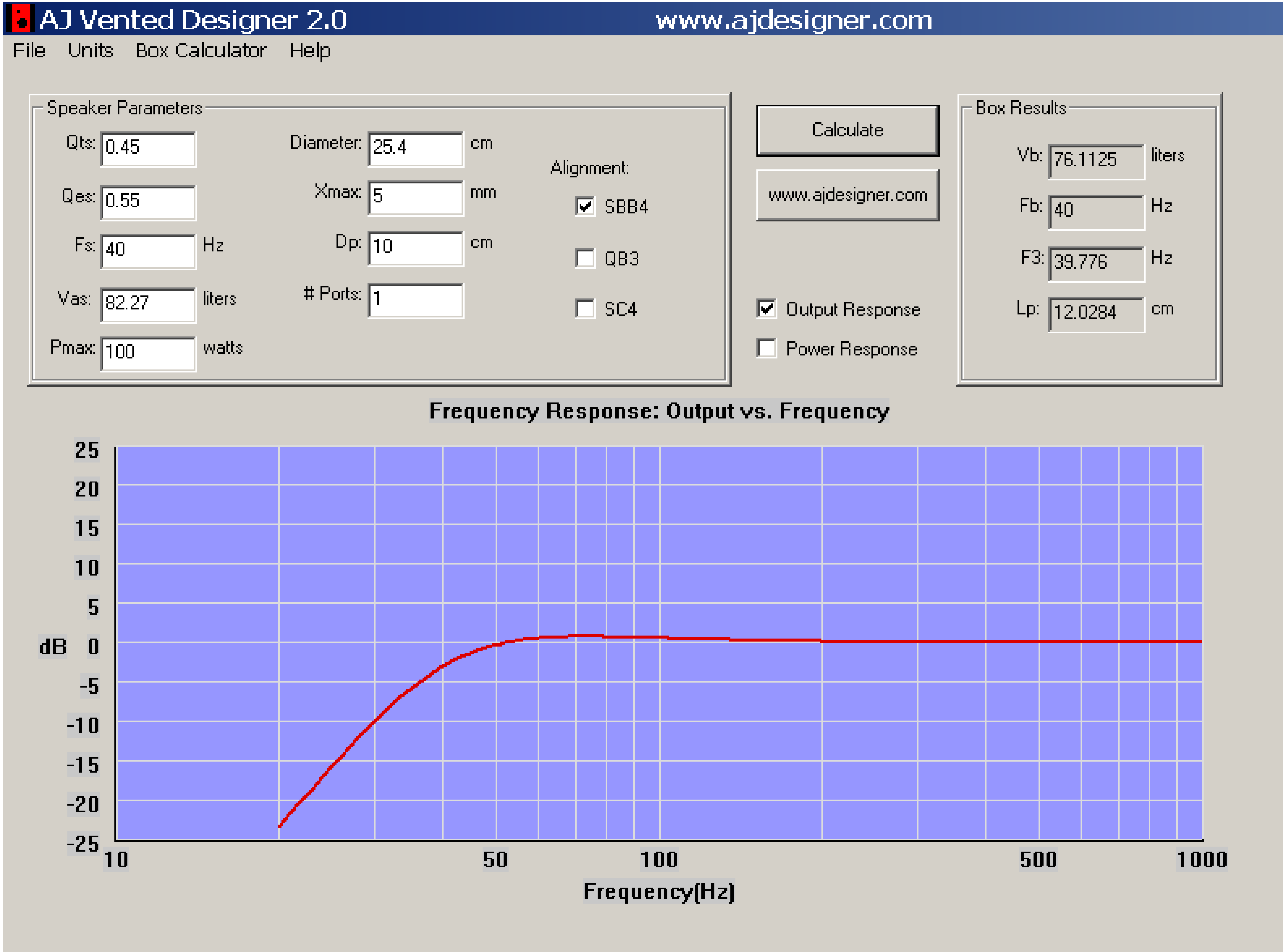
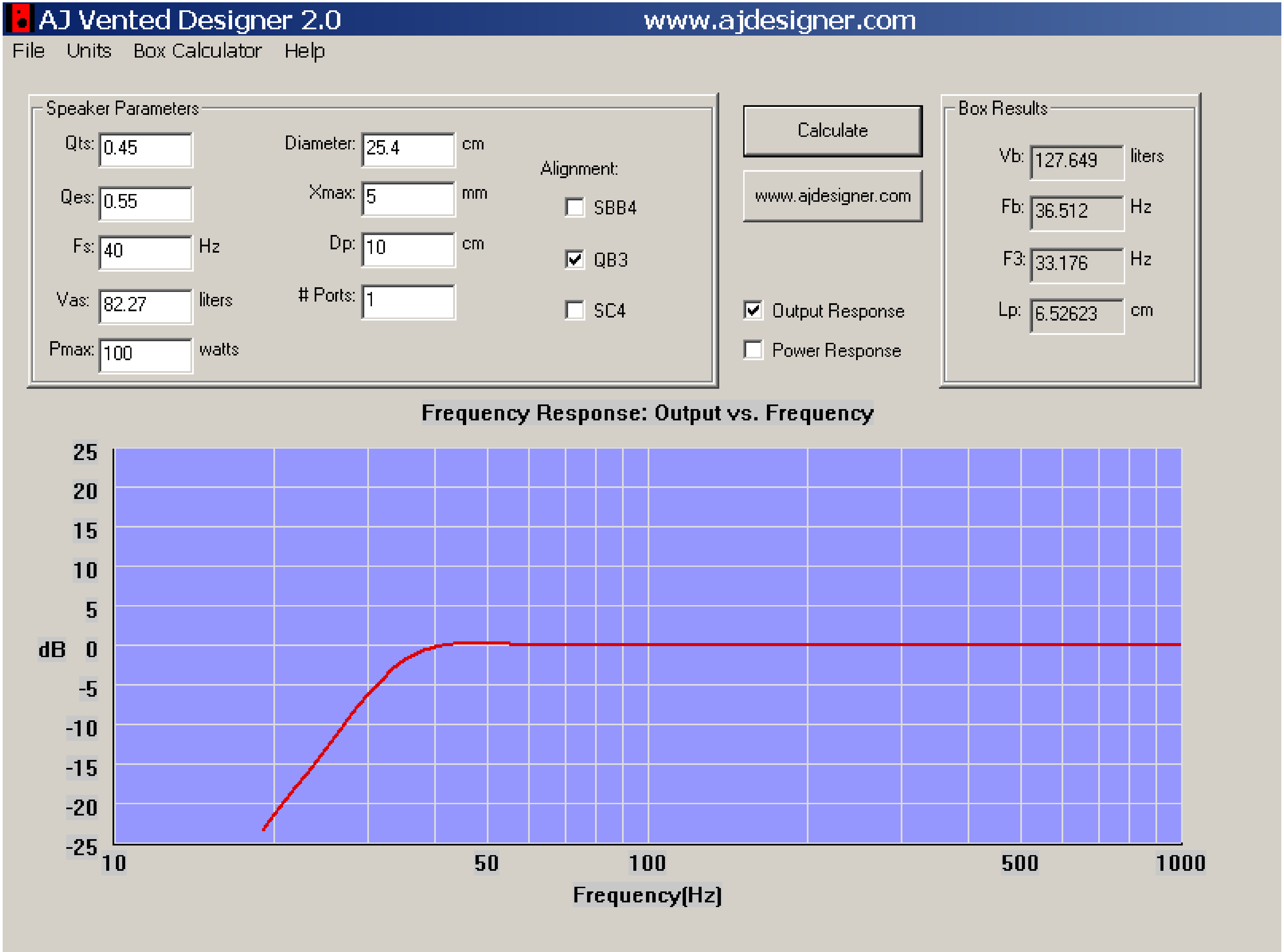
File
Units
Box Calculator
Help
Speaker Parameters
Qtc: 0.7
Qts: 0.55
Qes: 0.77
Fs: 31 Hz
Vas: 65.8 liters
Pmax: 70 watts
Diameter: 20.32 cm
Xmax: 3.8 mm
Calculate
www.ajdesigner.com
Output Response
Power Response
Box Results
Vb: 106.157 liters
Fb: 39.4545 Hz
F3: 39.8592 Hz
Frequency Response: Output vs. Frequency
25
20
15
10
5
dB 0
-5
-10
-15
-20
-25
10
50
100
500
1000
Frequency(Hz)

Vented Box Design Example

- alignments (choice depends on Q_{ts})
  - QB3 – quasi 3rd order Butterworth
  - SBB4 – 4th order Butterworth (“maximally flat”)
  - C4 – 4th order Chebychev
- need to determine port size/length




AJ Vented Designer 2.0
www.ajdesigner.com
File
Units
Box Calculator
Help
Speaker Parameters
Qts: 0.45
Qes: 0.55
Fs: 40 Hz
Vas: 82.27 liters
Pmax: 100 watts
Diameter: 25.4 cm
Xmax: 5 mm
Dp: 10 cm
Ports: 1
Alignment:
SBB4
QB3
SC4
Calculate
www.ajdesigner.com
Output Response
Power Response
Box Results
Vb: 76.1125 liters
Fb: 40 Hz
F3: 39.776 Hz
Lp: 12.0284 cm
Frequency Response: Output vs. Frequency
25
20
15
10
5
dB 0
-5
-10
-15
-20
-25
10
50
100
500
1000
Frequency(Hz)


AJ Vented Designer 2.0
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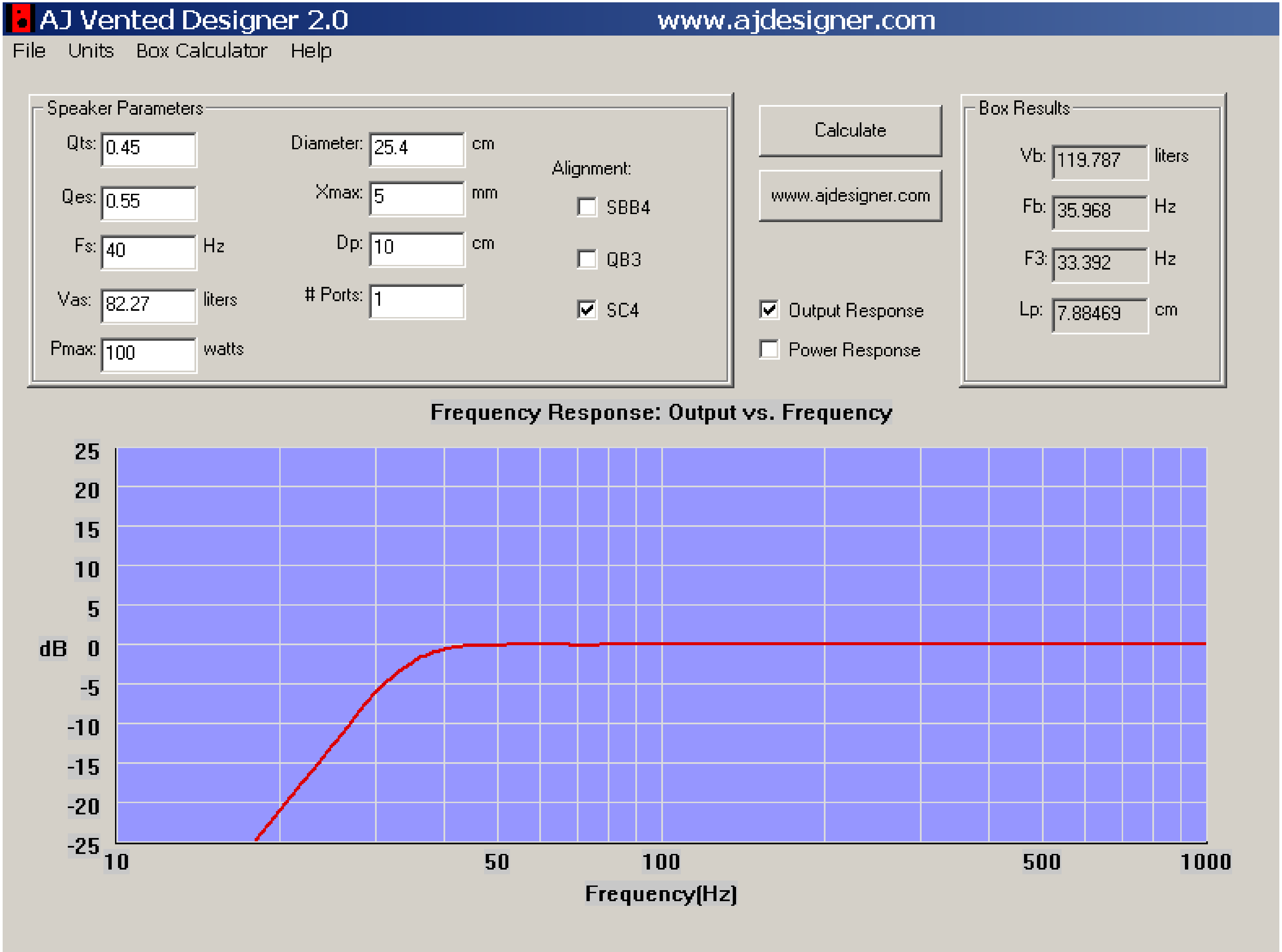
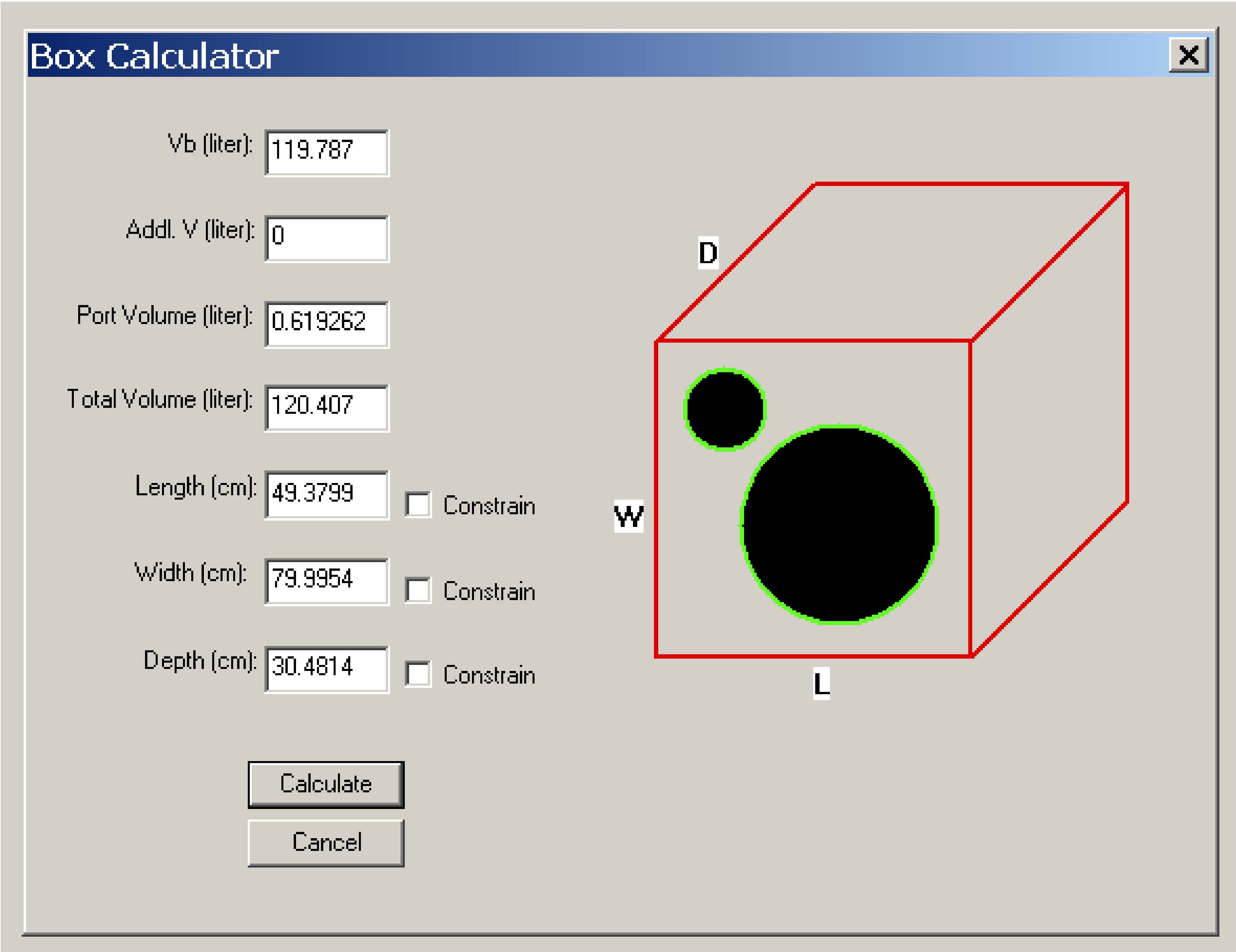
File
Units
Box Calculator
Help
Speaker Parameters
Qts: 0.45
Qes: 0.55
Fs: 40 Hz
Vas: 82.27 liters
Pmax: 100 watts
Diameter: 25.4 cm
Xmax: 5 mm
Dp: 10 cm
Ports: 1
Alignment:
SBB4
QB3
SC4
Calculate
www.ajdesigner.com
Output Response
Power Response
Box Results
Vb: 127.649 liters
Fb: 36.512 Hz
F3: 33.176 Hz
Lp: 6.52623 cm
Frequency Response: Output vs. Frequency
dB
25
20
15
10
5
0
-5
-10
-15
-20
-25
10
50
100
500
1000
Frequency(Hz)


AJ Vented Designer 2.0
www.ajdesigner.com
File
Units
Box Calculator
Help
Speaker Parameters
Qts: 0.45
Qes: 0.55
Fs: 40 Hz
Vas: 82.27 liters
Pmax: 100 watts
Diameter: 25.4 cm
Xmax: 5 mm
Dp: 10 cm
Ports: 1
Alignment:
SBB4
QB3
SC4
Calculate
www.ajdesigner.com
Output Response
Power Response
Box Results
Vb: 119.787 liters
Fb: 35.968 Hz
F3: 33.392 Hz
Lp: 7.88469 cm
Frequency Response: Output vs. Frequency
25
20
15
10
5
dB 0
-5
-10
-15
-20
-25
10
50
100
500
1000
Frequency(Hz)


Box Calculator
Vb (liter): 119.787
Addl. V (liter): 0
Port Volume (liter): 0.619262
Total Volume (liter): 120.407
Length (cm): 49.3799
Constrain
Width (cm): 79.9954
Constrain
Depth (cm): 30.4814
Constrain
Calculate
Cancel
D
W
L