Power Dissipation in Linear Audio Power Amplifiers

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Introduction

Driving speakers to produce a certain amount of 'audible noise' has the potential for creating conflict between the design engineer and the marketing and sales departments. The marketing and sales teams usually require that the music be louder and better sounding. The power supply designer replies back that he only has a certain power budget allowable. The audio designer working on the audio portion has to determine a way to befriend the marketing requests and live within the power budget.

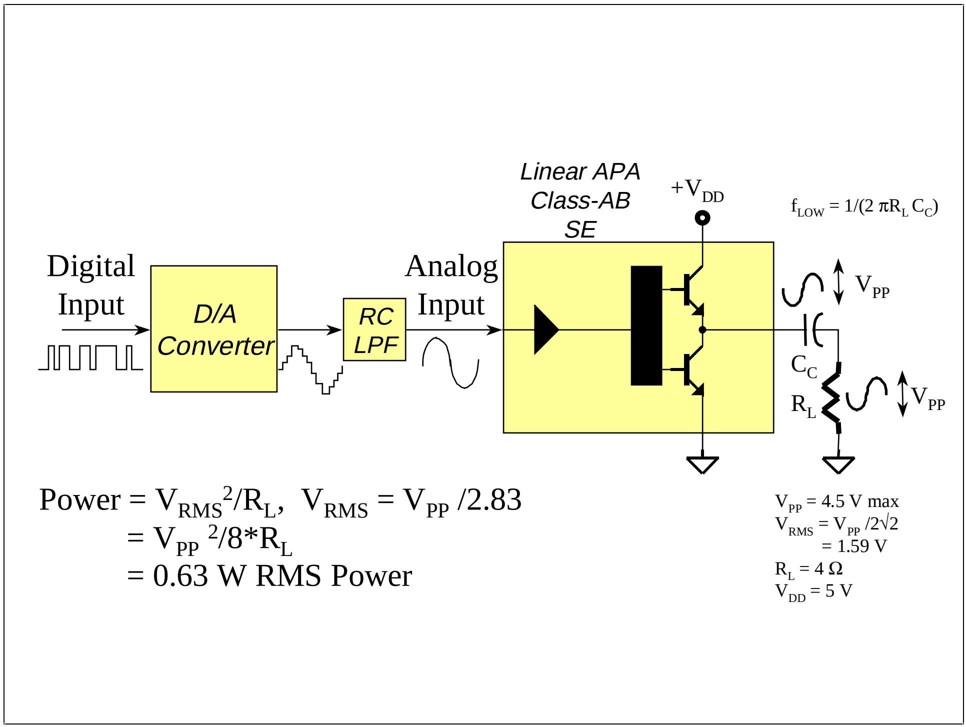
Speaker drive is usually done with linear audio power amplifiers, mainly because these amplifiers are optimized to drive loads representative of speakers, typically 4-32Ω, in a frequency band of most music, 20Hz – 20kHz. In multimedia or computer systems, the power requirements can range from a few milli-watts to a few watts, depending on the specific application. The power from the supply is delivered to the speaker through the audio amplifier. This power is thus delivered to the load in the form of sound, and is also dissipated in the IC itself in the form of heat, or in other words, lost power. Again, depending on the application, the dissipated power in the audio power amplifier may or may not require heatsinking. The issue of space may also be a factor for a heatsink, as there may be the need for very small packaging to dissipate some heat loss. This paper will enable designers to develop an understanding of how much power will be dissipated in the IC, and possible means to deal with it.

Audio Amplifier Configurations

Single Ended Configuration (SE)

There are several things that need to be understood in order to analyze the power driven into the load and dissipated within the IC. For example, audio power amplifiers can be configured in a couple of ways. The single ended (SE) configuration, as shown in Figure 1, shows the APA (Audio Power Amplifier) driving the load.

Figure 1. Class-AB Audio Power Amplifier Single Ended Load (SE) Configuration



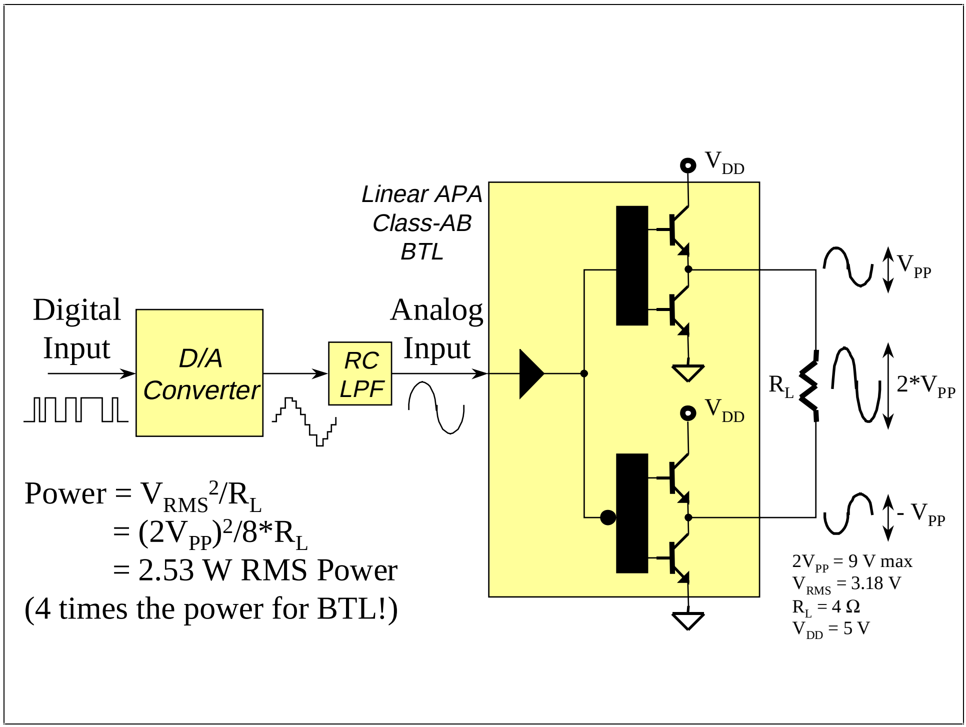
This configuration drives the load from a single supply, and is called "single ended" because the APA is driving the load from one end, and the other end is connected to ground. A DC blocking capacitor is required here because the APA will be biased midway from the supply, and the capacitor will prevent the DC power from being wasted in the system. This capacitor is also likely to prevent the speaker from being damaged. The blocking capacitor also limits the low frequency response, creating a highpass filter with the load. In terms of average power provided to the load, the equation looks like this: $P_{RMS} = V_{RMS}^2 / R_L$ where $V_{RMS} = V_{pp} / 2\sqrt{2}$ (equations valid only for a sinewave)

So for a 5V supply, you might achieve 4.5Vpp into a 4Ω load. Plugging these numbers into the equations, we can get around 0.63W of RMS power into a 4 ohm load. If you change the speaker to an 8Ω type, then you would get half the power, whereas if you change the load to 2Ω, you would expect 1.26 Watts into the load. However, not all amplifiers can handle 4 or 8 ohm loads. Also, changing the load affects the power dissipated into the IC. This is also stated as the efficiency of the amplifier. That aspect will be discussed later in the paper.

Bridge Tied Load Configuration (BTL)

Another way of providing more power to the load rather than lowering the impedance of the speaker is a technique called ‘bridging.” The bridge tied load (BTL) configuration is depicted in Figure 2.

Figure 2. Class-AB Audio Power Amplifier Bridge Tied Load (BTL) Configuration



While one amplifier is slewing high, the other is slewing low, effectively doubling the peak-to-peak voltage on the load. So by inserting these numbers into the power equation, you can get four times more power from a given supply than from the single ended configuration. And since both amplifiers are referenced to mid-supply, the DC bias cancels out and the need for the DC blocking capacitors goes away. A problem with the bridged amplifier configuration is that there are twice as many amplifiers inside driving twice as hard, providing four times more heat dissipated inside the IC than for the SE type. Note: In order to deliver the same power into the load from the SE configuration, the power supply must be raised. Thus, the IC power dissipation ends up being approximately equal for the same output power.

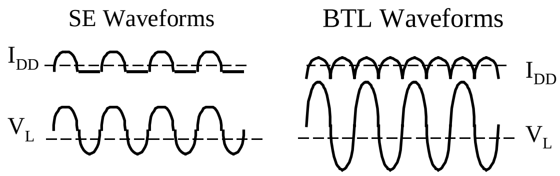
Efficiency

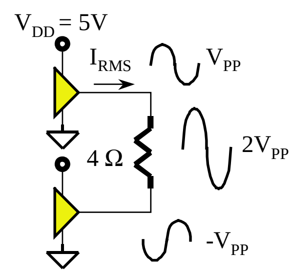
Efficiency has been mentioned briefly. Let’s now discuss it in more detail since this is what is determining the power dissipation in the amplifier itself. Efficiency is basically defined as the amount of power delivered to the load from the supply, or in other words: $Eff = P_L / P_{SUPPLY}$. We would like to get as much of the power from the supply to the load; to maximize the utility of the power that is budgeted from the supply.

Linear amplifiers are notoriously inefficient. The primary cause of these inefficiencies is voltage drop across the output stage transistors. There are two components of the internal voltage drop. One is the headroom or DC voltage drop that varies inversely to output power. The second component is due to the sinewave nature of the output. The total voltage drop can be calculated by subtracting the RMS value of the output voltage from V_{DD}. The internal voltage drop multiplied by the RMS value of the supply current, I_{DDrms}, determines the internal power dissipation of the amplifier.

To accurately calculate the RMS values of power in the load and in the amplifier, the current and voltage waveform shapes must first be understood. These shapes are shown in Figure 3.

Figure 3. Class-AB Amplifier Efficiency





Linear BTL Amplifier (Class AB)

$$\text{Eff.} = P_L / P_{SUP}$$

(....after many many steps....)

$$\text{Eff.}_{BTL} = \pi V_P / 2V_{DD} = \pi (P_L R_L / 2)^{1/2} / 2V_{DD}$$
$$= 22\ \%\ @\ P_L = .25\ W,\ P_{dis} = 0.89\ W$$
$$= 31\ \%\ @\ P_L = .5\ W,\ P_{dis} = 1.11\ W$$
$$= 44\ \%\ @\ P_L = 1\ W,\ P_{dis} = 1.27\ W$$
$$= 63\ \%\ @\ P_L = 2\ W,\ P_{dis} = 1.17\ W$$
$$= 70\ \%\ @\ P_L = 2.5\ W,\ P_{dis} = 1.07\ W$$

Although the voltages and currents for SE and BTL are sinusoidal in the load, currents from the supply are very different between SE and BTL. In an SE application, the current waveform is a half-wave rectified shape, whereas in BTL it is a full-wave rectified waveform. Why is this? In SE, during the negative half cycle the current comes from the DC blocking capacitor, not the supply voltage. In BTL, the supply provides current to the upper amplifier on the positive cycle *and* the lower amplifier on the negative cycle. This means RMS conversion factors are different. Keep in mind that for most of the waveform both the push and pull transistors are not on at the same time, which support the fact that each amplifier in the BTL device only draws current from the supply for half the waveform. Let's walk through the equations for the efficiency of the BTL configuration:

$$Efficiency = \frac{P_L}{P_{SUP}}$$

where: $$P_L = \frac{V_{Lrms}^2}{R_L} = \frac{V_P^2}{2R_L}$$

$$V_{Lrms} = \frac{V_P}{\sqrt{2}}$$

$$P_{SUP} = V_{DD} I_{DDrms} = \frac{V_{DD} 2V_P}{\pi R_L}$$

$$I_{DDrms} = \frac{2V_P}{\pi R_L}$$

$$Efficiency_{BTL} = \frac{\pi V_P}{2V_{DD}} = \frac{\pi \left(\frac{P_L R_L}{2} \right)^{1/2}}{2V_{DD}}$$

Table 1 outlines some example calculations looking at efficiencies for a BTL configuration.

Table 1. Efficiencies for a BLT Configuration Using a 5V Supply Driving a 4Ω Load

Efficiency	Power into Load	Power Dissipated into IC
22%	0.25W	0.89W
31%	0.5W	1.11W
44%	1.0W	1.27W
63%	2.0W	1.17W
70%	2.5W	1.07W

What we see from the example calculations is that the efficiency is quite low for lower power levels resulting in a nearly flat internal power dissipation over the normal operating range. What is a little surprising at first is the fact that the internal dissipation at full output power is less than at the half power range. Also remember that the above example is mono; double everything for stereo. So, for a stereo 2.5W audio system with a 4Ω load and 5V supply, the maximum draw on the power supply will almost be 7.25W.

Another point to remember about linear amplifiers whether they be SE or BTL configured is how to manipulate the terms in the efficiency equation to your advantage whenever possible. Note that in the efficiency equation, V_{DD} is in the denominator. This means as V_{DD} goes down, efficiency goes up. Consider this example, if you replaced the 5V supply with a 12V supply in the above calculations, then efficiency at 2.5W would fall to 29% and internal power dissipation would rise to 6.12W. The moral of this story is to use the right supply voltage and speaker impedance for your application!

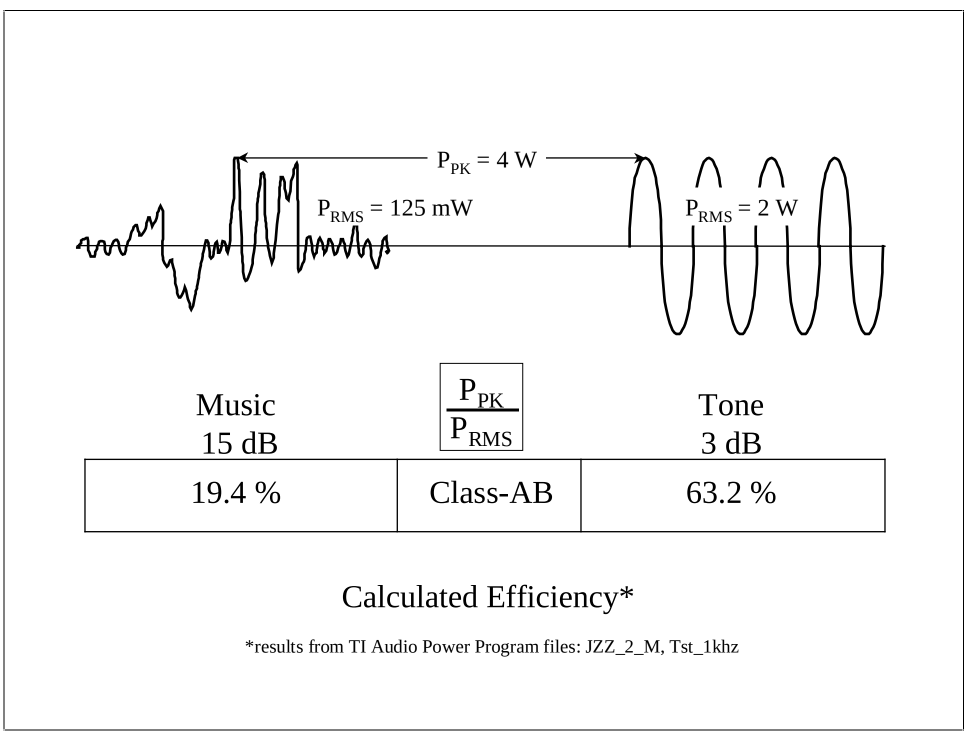
In the entire previous discussion, the signal source used was sinusoidal in nature. We must remember that voice or music does not look sinusoidal at all. Thus, the equations that have been shown so far would not help much at all in determining real world dissipation numbers.

<u>Crest Factor</u>

We will now discuss actual music or voice source. This is how the real world works, and one of the factors that influences power dissipation is Crest Factor. Crest Factor is defined as a ratio of peak power out to RMS power out:

$$CrestFactor = 10\log\frac{P_{Peak}}{P_{RMS}}$$

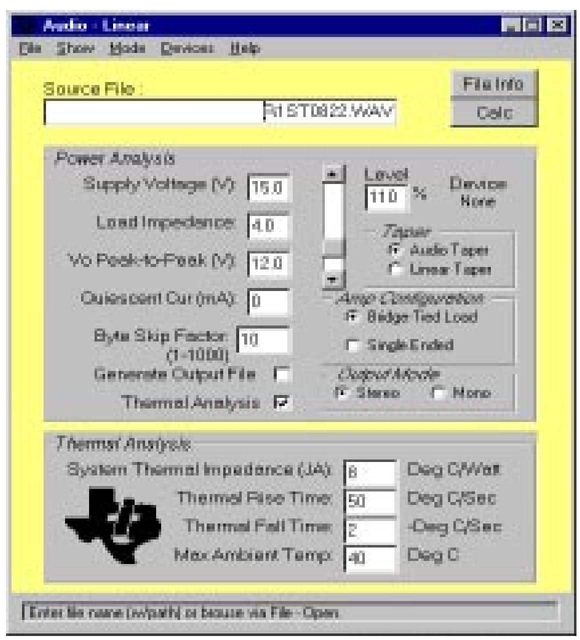
Figure 4. Crest Factor: Music vs Sinewave



Pure sinewaves exhibit a 3dB crest factor, whereas music may exhibit crest factors ranging from 12-21dB. This is better illustrated in Figure 4. Moreover, APA datasheets are most generally specified with sinewave sources, which show worst case when it comes to power dissipation. Thus, a person needs to take into account the crest factor when looking at average dissipation in the IC. Peak power may be the same for both the sinewave and the music source, but crest factor will more closely determine what power will be dissipated. Remember once again that the equations for finding the RMS voltage in the load does not apply to music sources, only to sinewaves.

Crest factor can be a tedious number to calculate. One way is to actually measure it by first measuring the peak power and then measuring the average power. However, there are simpler ways to determine crest factor. Texas Instruments has developed an Audio Power Analysis Program to help determine crest factor, along with many other parameters of interest when dealing with APAs. The Audio Power Analysis Program allows a system designer to use .wav files as a source. The designer can then model specifics such as supply voltage, load impedance, Vo Peak-to-Peak, amplifier configuration, and quiescent current. This definition screen is seen as Figure 5

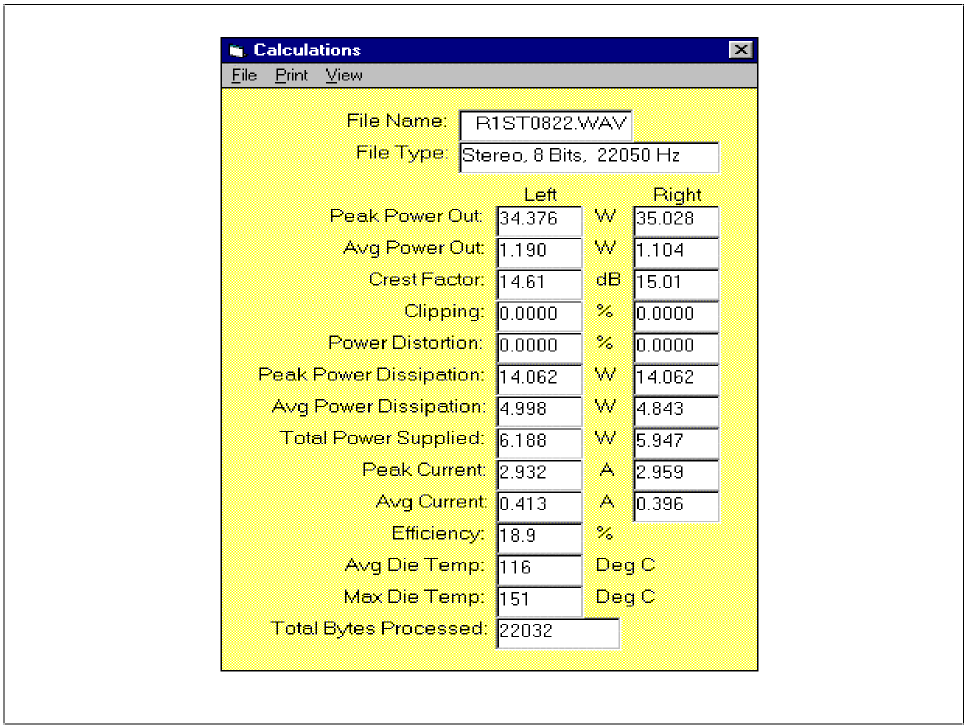
Figure 5. Audio Power Analysis Program System Definition Screen



www.ti.com/sc/docs/msp/pran/app_supp.htm

The user can then generate an output file allowing him to playback the source if he has the proper audio cards, and to also perform a thermal analysis. These results could then be viewed on the screen as shown in Figure 6, displaying all the information that would be of interest.

Figure 6. Audio Power Analysis Program System Results Screen



For example, let's run a test case using the same configuration, but use a 1 kHz tone and jazz source .wav files for comparison. By running these .wav files in the audio analysis program, you can see the differences in the table below. The following amplifier system model set up was the same for both files:

Supply Voltage:	5V
Peak-to-peak output voltage	4V
Load impedance	4Ω
Quiescent current	0mA
Volume level	100%
Amp configuration	BTL
Processing mode	Mono
Byte skip factor	1

The output parameters are shown in Table 2.

Table 2. Output Parameters Based On the Calculations From The Audio Analysis Software.

Parameter	JZZ_2_M.WAV	TST_1KHZ.WAV
Peak Power Out (W)	3.574	3.938
Avg Power Out (W)	0.067	1.969
Crest Factor (dB)	17.24	3.01
Peak Pwr Dissipation (W)	1.563	1.562
Avg Pwr Dissipation (W)	0.400	1.189
Total Pwr Supplied (W)	0.467	3.158
Peak Current (A)	0.945	0.992
Avg Current (A)	0.093	0.632
Efficiency (%)	14.4	62.4

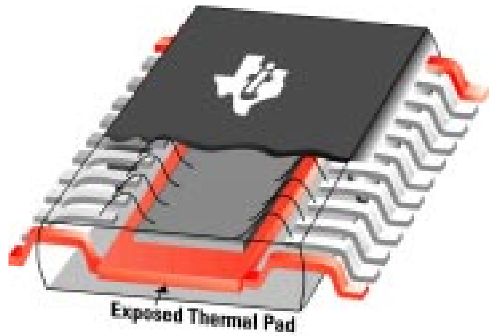
A person can easily see how crest factor relates to average power dissipation within the IC. Once you have determined what your peak and average power dissipation will be, you need to determine whether a heatsink is needed. Or if it is even possible if in a very small space. Most surface mount IC's can dissipate the amount of heat generated by most op amps (but not power amplifiers). In the case of driving speakers and combined with the inefficiencies of linear amplifiers, some form or method of dissipating power is usually required.

Getting the Heat Out – The PowerPad™ package

To overcome very small spaces, and at the same time needing to dissipate a good amount of power, TI has developed what we call the PowerPad™ package. This is a package which enables the designer to solder directly to the leadframe on which the die actually attaches to, thus being able to get the heat out very efficiently. A good representation of this package can be seen in Figure 7.

Figure 7. PowerPad™ Thermally Enhanced TSSOP (PWP)

- PowerPAD features
  - Simple to install
  - 4X standard TSSOP power handling capability
  - Dissipates over 2W
  - $R_{\theta JC}$ = 3.5°C/W



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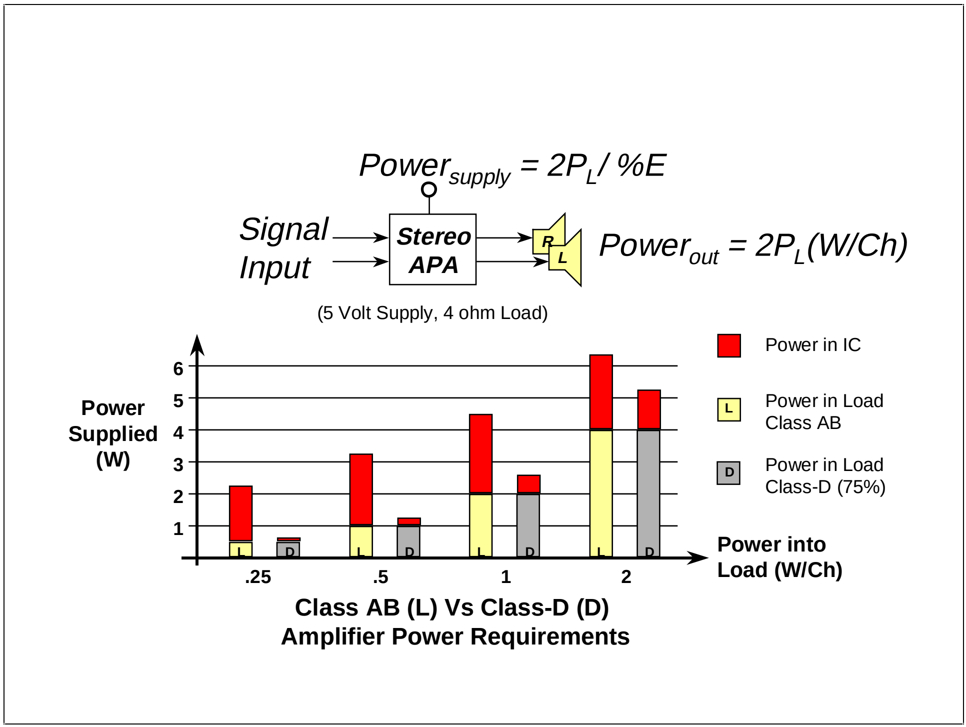
This particular package is a 24-pin TSSOP, but TI has made the PowerPad concept in other pin and package options. The smallest being an 8-pin MSOP PowerPad for those applications that require the smallest in packaging for audio power amplifiers.

There are future possibilities to help reduce the power dissipation in linear audio power amplifiers, or in other words, increase the efficiency. One answer to this is Class D amplifiers. Class D can significantly increase the efficiency, but the design will not be as simple and straightforward as a linear amplifier. Figure 8 reveals just how much Class D can reduce the dissipation in the IC itself, and further increase the life of batteries in those battery sensitive applications. For more information on this, keep your ears tuned to Texas Instruments.

Figure 8. Power Dissipation Comparison (constant envelope tones)



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Presented by
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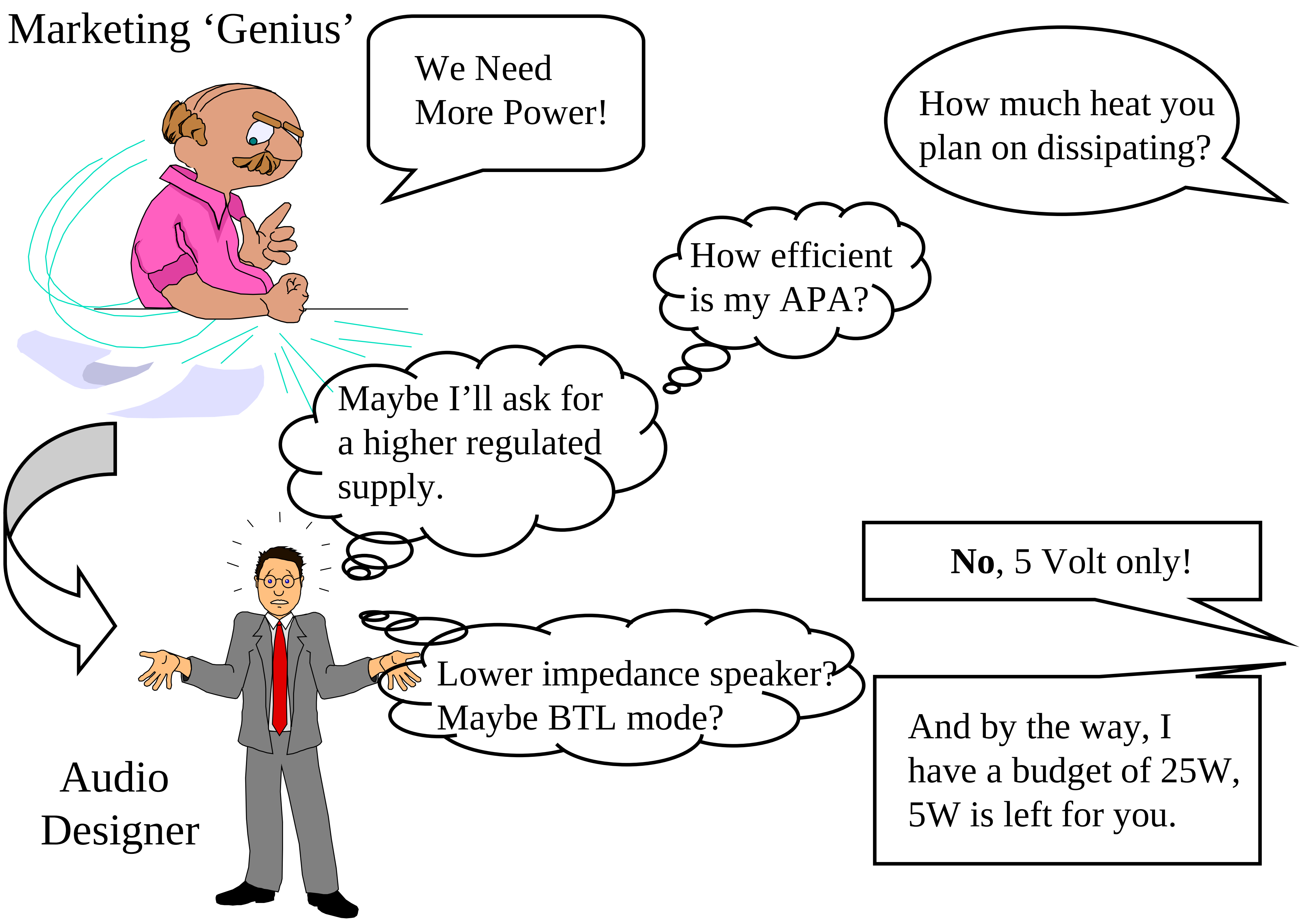
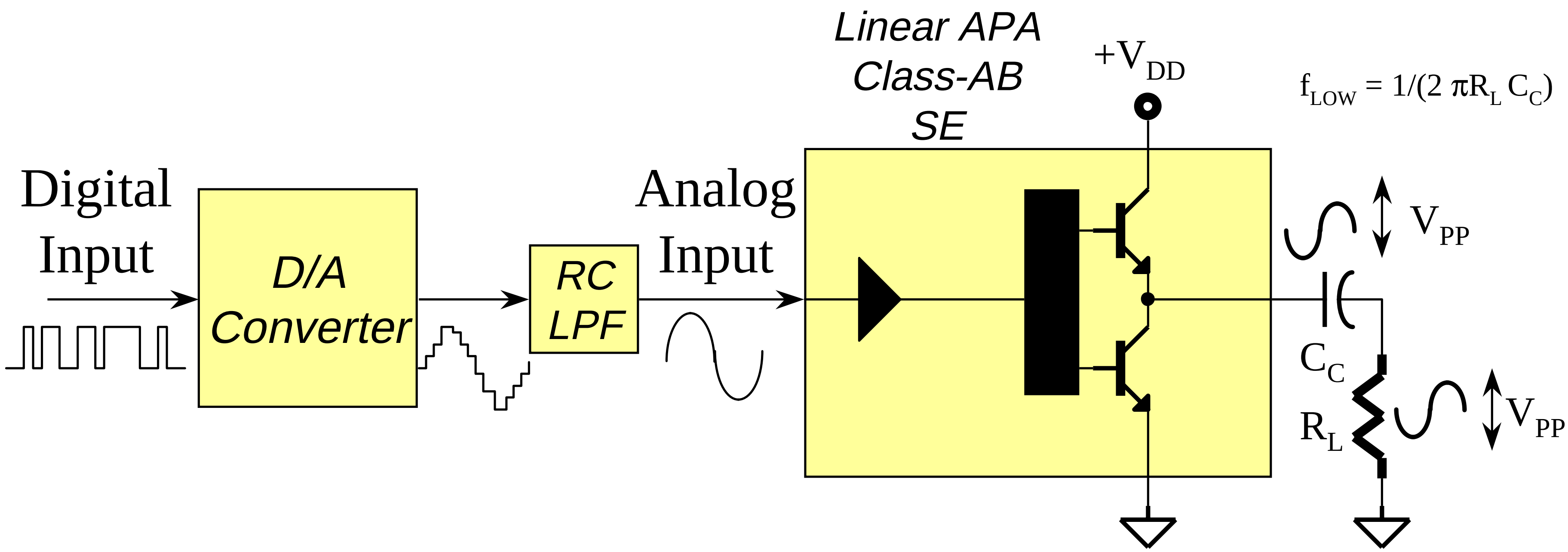
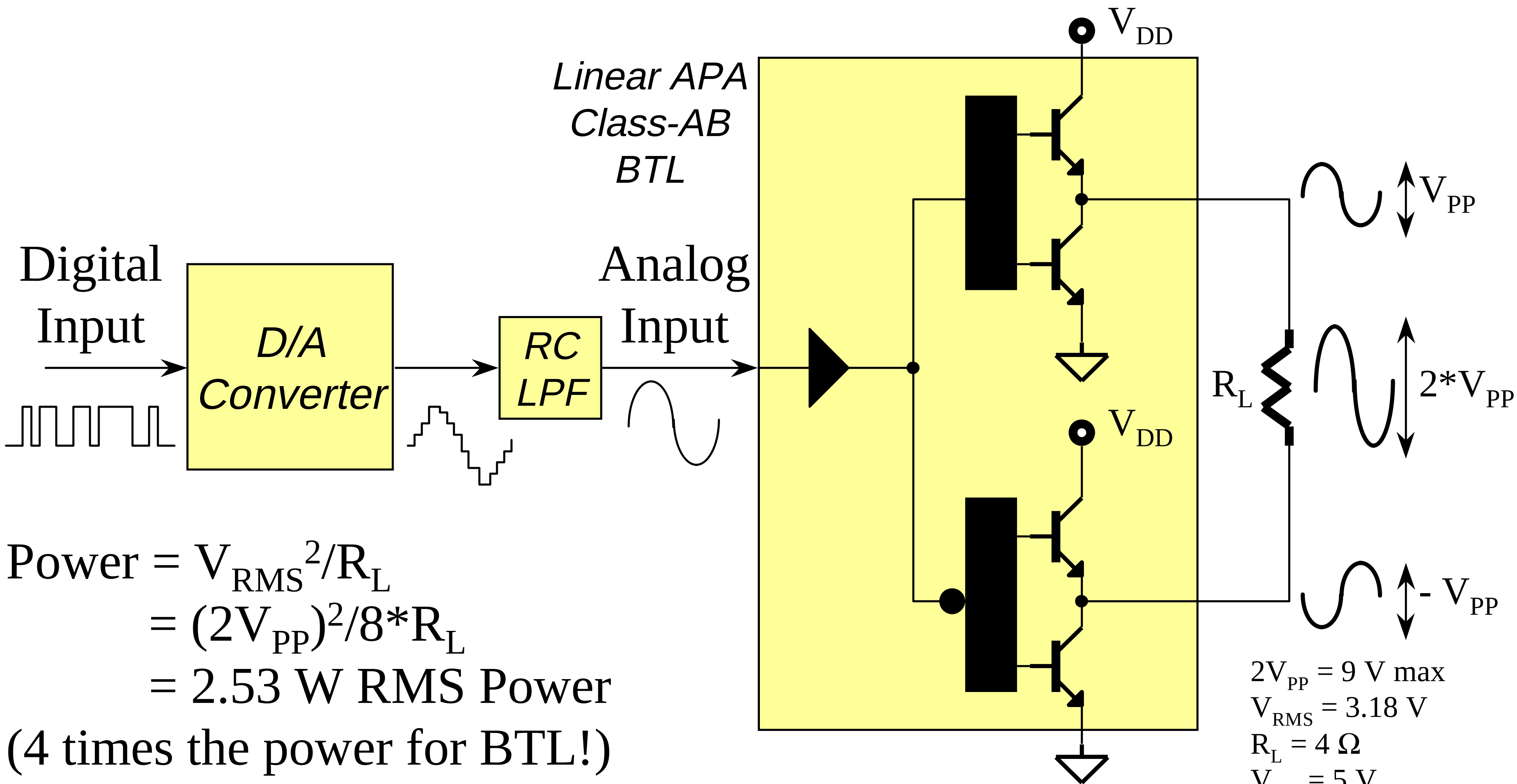


Marketing ‘Genius’
We Need More Power!
How much heat you plan on dissipating?
How efficient is my APA?
Maybe I’ll ask for a higher regulated supply.
No, 5 Volt only!
Lower impedance speaker? Maybe BTL mode?
And by the way, I have a budget of 25W, 5W is left for you.
Audio Designer



$$\text{Power} = V_{RMS}^2/R_L,\quad V_{RMS} = V_{PP}/2.83$$
$$= V_{PP}^{\ 2}/8{*}R_L$$
$$= 0.63 \text{ W RMS Power}$$

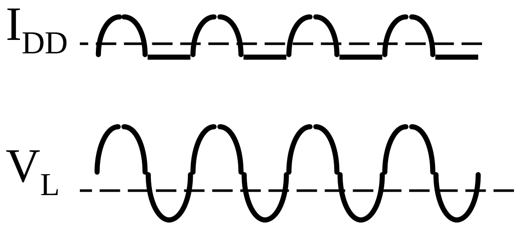
V_{PP} = 4.5 V max
$V_{RMS} = V_{PP}/2\sqrt{2}$
= 1.59 V
$R_L = 4\ \Omega$
V_{DD} = 5 V



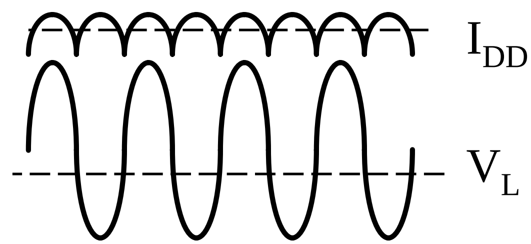
$$\text{Power} = V_{RMS}{}^2/R_L$$
$$= (2V_{PP})^2/8*R_L$$
$$= 2.53 \text{ W RMS Power}$$

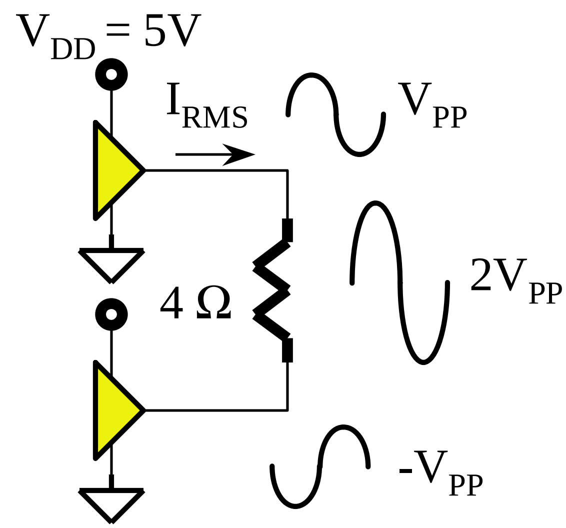
(4 times the power for BTL!)

SE Waveforms



BTL Waveforms





Linear BTL Amplifier
(Class AB)

$$\text{Eff.} = P_L / P_{SUP}$$

(....after many many steps....)

$$\text{Eff.}_{BTL} = \pi V_P / 2V_{DD} = \pi (P_L R_L /2)^{1/2} / 2V_{DD}$$

$= 22\ \%\ @\ P_L = .25\ W,\ P_{dis} = 0.89\ W$

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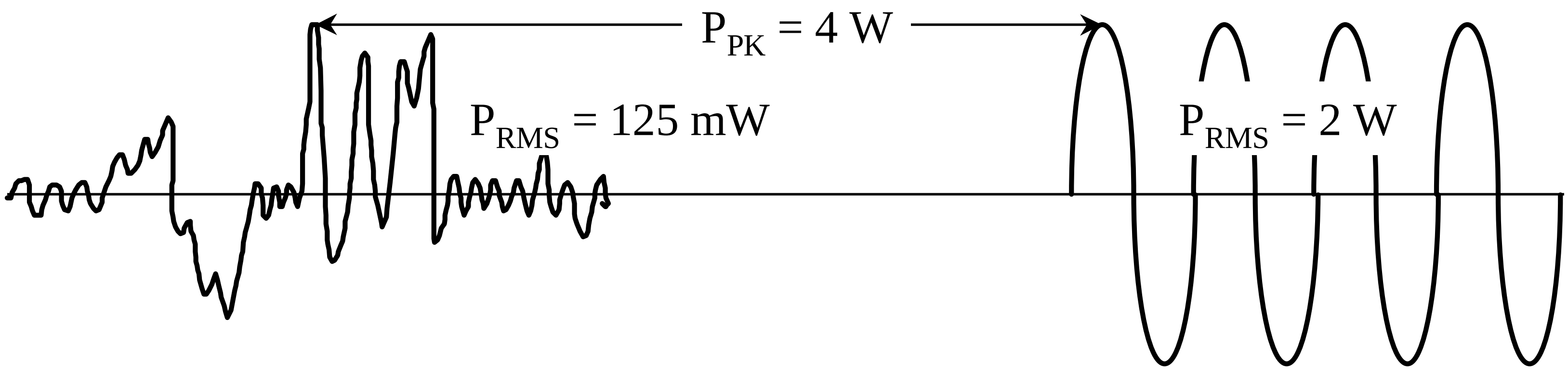
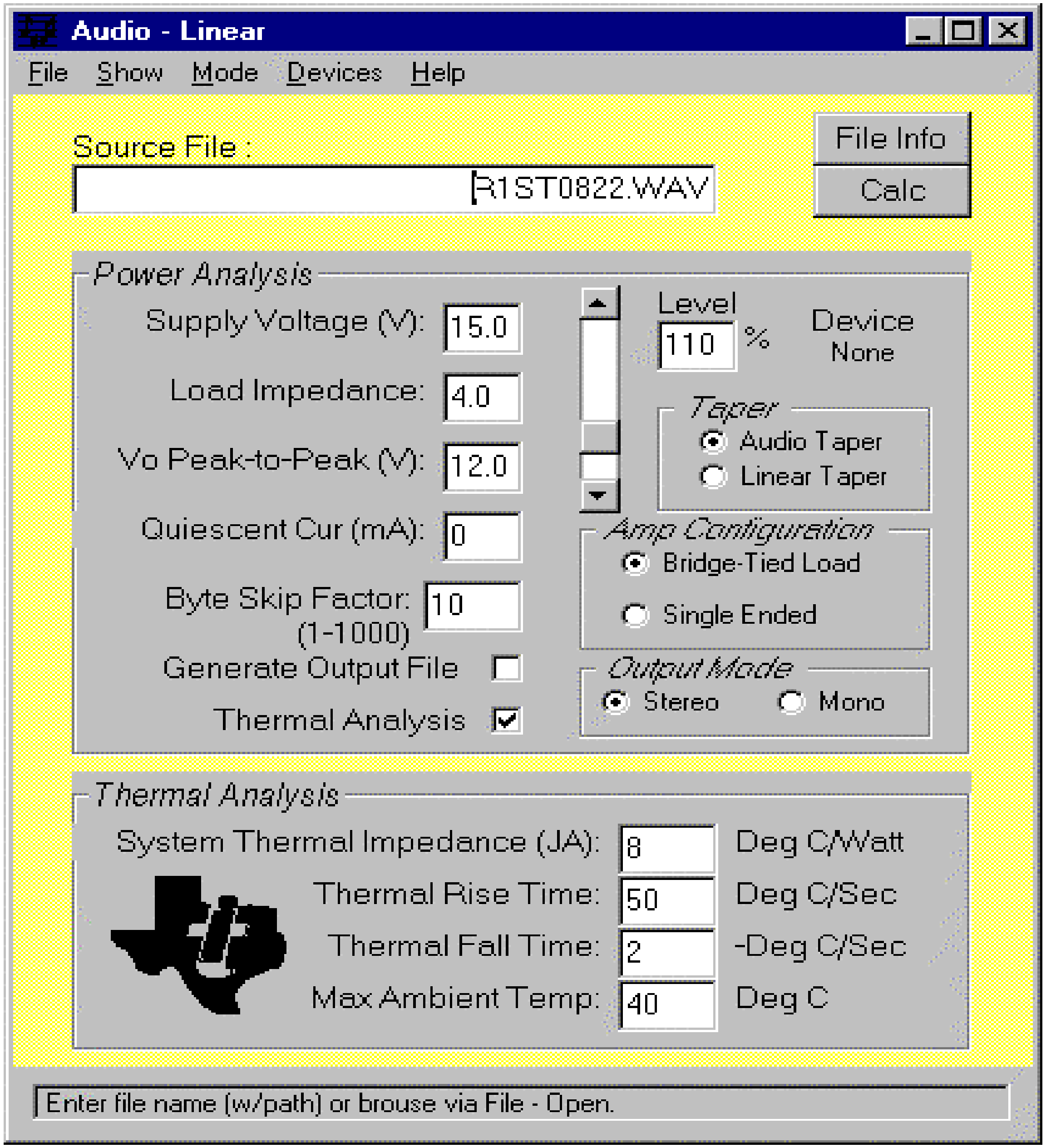


Music 15 dB	$\dfrac{P_{PK}}{P_{RMS}}$	Tone 3 dB
19.4 %	Class-AB	63.2 %

Calculated Efficiency*

*results from TI Audio Power Program files: JZZ_2_M, Tst_1khz



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Calculations

File Print View

File Name: R1ST0822.WAV

File Type: Stereo, 8 Bits, 22050 Hz

	Left		Right
Peak Power Out:	34.376	W	35.028
Avg Power Out:	1.190	W	1.104
Crest Factor:	14.61	dB	15.01
Clipping:	0.0000	%	0.0000
Power Distortion:	0.0000	%	0.0000
Peak Power Dissipation:	14.062	W	14.062
Avg Power Dissipation:	4.998	W	4.843
Total Power Supplied:	6.188	W	5.947
Peak Current:	2.932	A	2.959
Avg Current:	0.413	A	0.396
Efficiency:	18.9	%	
Avg Die Temp:	116	Deg C	
Max Die Temp:	151	Deg C	
Total Bytes Processed:	22032		

◆ PowerPAD features

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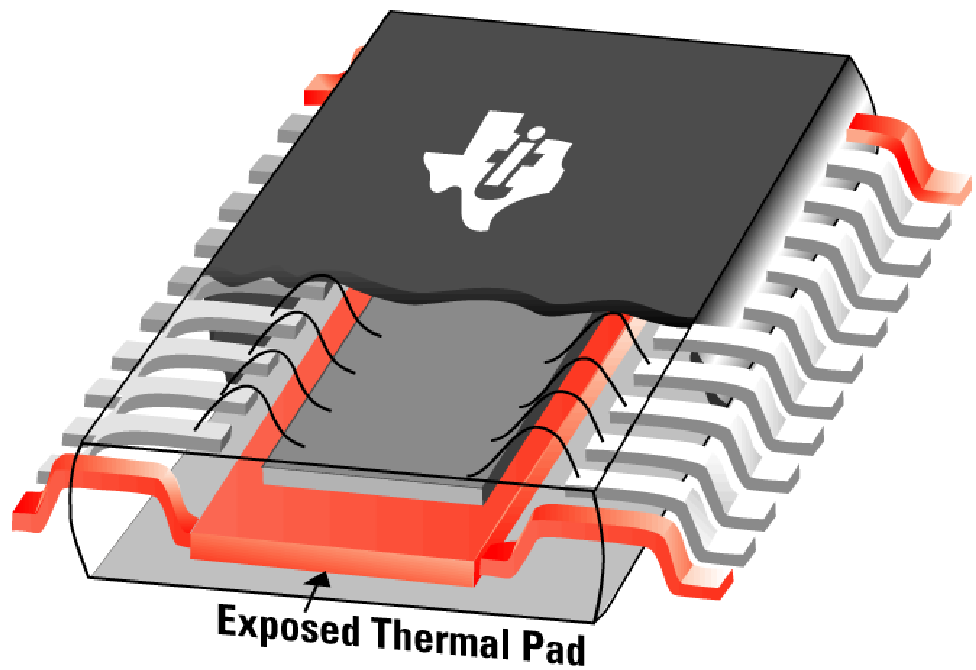
- 4X standard TSSOP power handling capability
- Dissipates over 2W
- $R_{\theta JC}$ = 3.5°C/W



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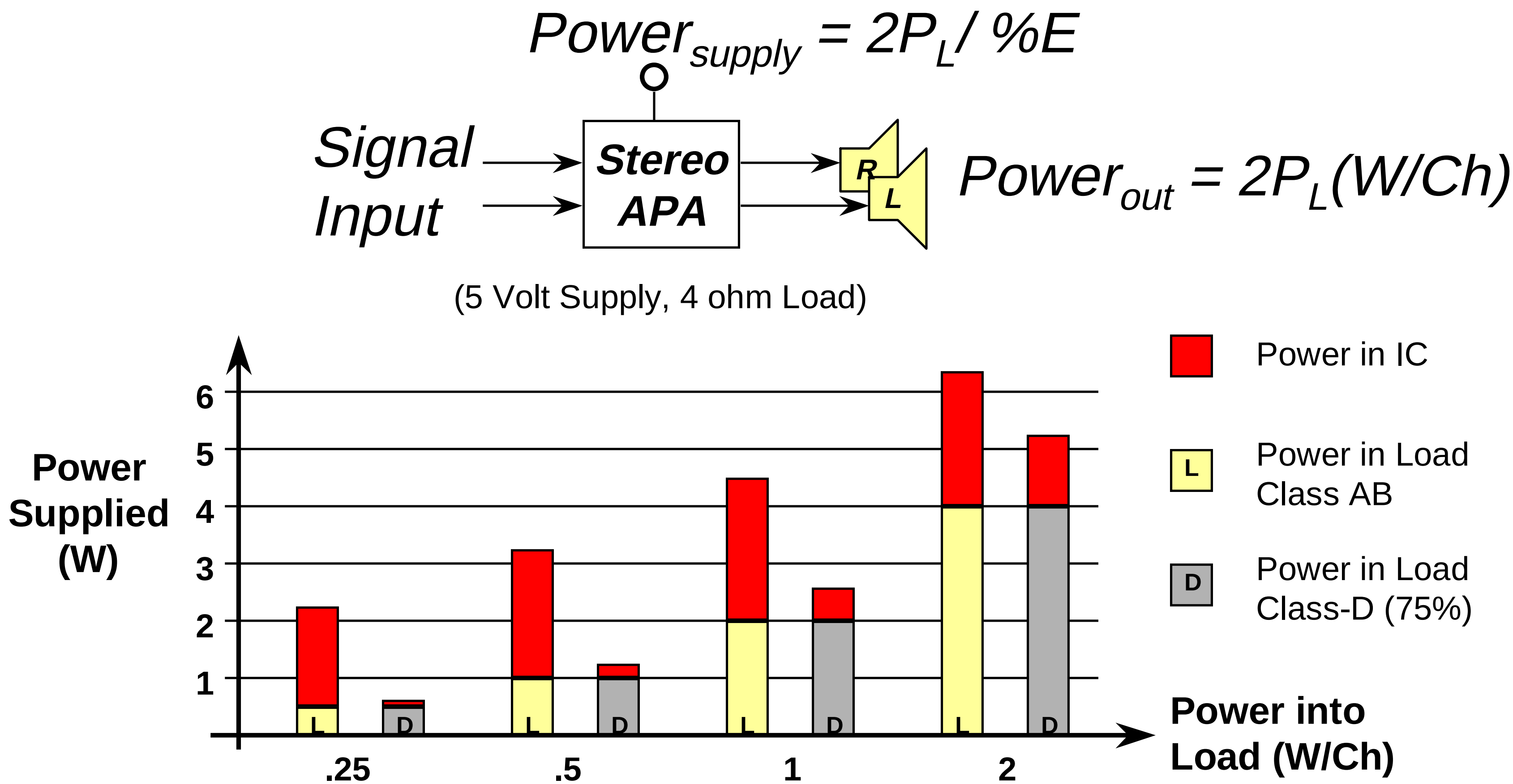

Class AB (L) Vs Class-D (D)
Amplifier Power Requirements