Using the Class D Design Guide
Rev 1.3

Overview:

The Design Guide was created to allow for quick calculations of performance with various values of external components, supply voltages, loads as well as efficiency and thermal performance in a common format (Excel 97 or Excel 5.0/95 for Mac or PC). The idea behind using the Design Guide is to allow the system designer to quickly and easily adjust various parameters of the LM4651/52 chipset to meet a particular set of design requirements before going to the bench. The Design Guide them provides the values for the external control components, the correct thermal design, and the correct output filter design so that the system designer may verify performance on the bench quickly. The goal is to provide a solution that is very close to the final desired specifications with minimal cost, effort and time. Warnings and errors in using the LM4651/52 chip set will be highlighted so adjustments can be made for correct use. The Design Guide is not without limitations which must be understood to avoid errors or wasted time and money. It is recommended that the system designer reads through these directions completely with the Design Guide opened as a reference before adjusting parameters to meet a particular set of design specifications. For those with little experience with class D the LM4651/52 chipset, reading completely through the LM4651/52 data sheet will be very helpful.

Assumptions, Limitations, and Accuracy:

The main assumption of the Design Guide is that the LM4651/52 chipset is used as shown in the LM4651/52 data sheet. The general schematic can be found on page 4. This assumes split supply operation with ground as the midpoint between the two voltages and considered 0 Volts. External control components (like R_{osc}) must be connected as shown and the output filter should be configured as shown. The thermal calculations assume the use of thermal grease between the package back and heat sink and that the LM4652 package is mounted directly to the heat sink. There are no limitations on the audio frequency range of use due to the LM4651/52 but rather the selection of external components and desired performance. Output power is shown at 1% THD which refers to the output power level at the start of clipping. Nominal THD or THD at lower power is not calculated nor guaranteed to be lower than 1% in all possible designs. See the LM4651/52 data sheet for performance graphs for more detail. The Design Guide will supply warnings and errors when trying to use the LM4651/52 chipset incorrectly.

The limitations are due to complexity. The output filter calculations are for a 2 pole filter only. A more sophisticated and advanced 4 pole output filter calculation is not provided. A pre-amp/active input filter which is recommended for all designs is also not included but information on such can be found in the data sheet on page 12. The Design Guide only supports the standard configuration in the calculations. Other configurations such as single supply or dual FET (dual LM4652s with a single LM4651) configurations do not have supporting calculations. Although performance can be extrapolated from the Design Guide for these configurations the accuracy will be reduced and the possibility of errors in implementation are increased.

The accuracy of the Design Guide is very good when used within the constraints of the assumptions and limitations listed above. As with any IC fabrication, variations in the fab process will introduce a certain amount of performance variation from IC to IC. The Design Guide calculates what the typical performance may be for any given IC. It is best to verify performance on the bench for accuracy.

Features:

The following performance or component values are calculated in the Design Guide:
Peak voltage and current seen by the load.
Output Power at clipping (1% THD).
Complete System and Class D amplifier (LM4651/52 chipset only) efficiency.
Power dissipation in the LM4651, LM4652 and the output filter inductors.
Heat sink size for each package type of the LM4652 for full power thermals or ½ power thermals.
Filter response, Q factor of the output filter and ripple current in the output inductors.
Feedback filters and error amplifier bandwidth limiting (C_F).
Gain in V/V and dB
Lower frequency 3dB point when using a input coupling capacitor (C_{in})
Upper 3dB frequency when using a simple RC filter at the input (R_{lp}, C_{lp})
DC offset voltage seen at the load.
External control components: R_{OSC}, R_{SCKT}, R_{Offset}, $C_{Start\text{-}Up}$ and dead time due to R_{DLY}.
Supply regulation and Efficiency and Power Dissipation vs. Output Power graph.
Warnings and Errors.

Calculations for Gain, Output Filter, Feedback Filter, and Misc. Externals have two boxes for either entering the external component's value or the desired effect with the other being calculated. For example, a system designer may have limited values for the output inductors and capacitors that make up the output filter. The box that allows for the individual value of the inductor and capacitor (middle upper right) would be easiest to use. If the desire is to get a feel for the values when a particular 3dB frequency is chosen the second box would be used by simply entering the 3dB frequency and reading the required values of L, C_{BYP} and C_1 . These boxes are found either side by side or on top of each other on the sheet. Values entered in one box do not affect the calculations contained in the other box for the same parameters.

How To Use:

There are three (3) sheets to the Design Guide workbook. The tab at the bottom left shows the three sheets named *Quick Calculations, Efficiency Graph* and *Warnings & Errors*. You can access each sheet by clicking on it's tab. The *Quick Calculations* sheet will be explained first. Each major section of calculations has a purple header above the calculation boxes describing what calculations are performed. Blue highlighted cells are input cells and yellow highlighted cells are calculations. As values are entered in the blue cells the calculations will update with the new value just entered. The speed of Excel is rather slow with so many calculations and condition checks. The Design Guide calculates values using an iteration process. Due to this iteration process it is advisable to wait until the calculations stabilize before entering another value in a blue cell. With protection turned on (default) it is not possible to enter data into any cells other than the blue highlighted input cells. All the boxed cells will fit on a monitor if the resolution of the monitor is set to 1024x768 or higher with Excel maximized. Thousands of colors (16 bit) is needed to see the color of each cell clearly. The revision and date of last update are displayed in the upper left corner.

Explanation of Each Calculation Box:

The Design Guide starts with all the values entered for the standard solution used on the LM4651/52 demo boards and shown in the data sheet. To maintain these settings always chose "NO" when closing the Design Guide or Excel. The first set of boxes on the upper left row are for the **Output Power Calculations** and set up the most basic inputs and outputs. Many cells will change color if an incorrect value is entered and the "Warnings" or "Error" box(es) will change color (found on the upper right and highlighted in green when there are no errors or warnings) to show that there are errors, warnings or both that need to be checked. Errors highlight to red and warnings highlight to orange. Often the cell that needs to change will also be highlighted in the appropriate color. Clicking on the *Warnings & Errors* tab will show what the exact warning and/or error is with suggested corrective action. Warnings do not have to be fixed but are to alert the system designer that the results may not be as expected. Errors must be fixed and are normally due to trying to use the LM4651/52 outside of operational ranges causing destruction of the chipset.

Vcc and Vee should be equal in value. A sign is not needed. The load impedance can be any value but values that require output current to exceed 14.5A will result in an incorrect power calculation and possible destruction of the LM4652 on the bench. The R_{dc} of the Filter is the DC resistance of the inductor used in the output filter. Switching frequency can be chosen anywhere in the range of 50kHz – 200kHz per the LM4651 specification. The value of R_{DLY} should be left at 5.1kΩ and reduced to as low as 0Ω as the audio frequency of operation is increased from subwoofer ranges up to 20kHz. The resulting output in peak voltage, peak current and peak output power at the start of clipping (1% THD) will be shown in the box to the right. The value of R_{OSC} and the Dead Time due to R_{DLY} will also be show.

Below the **Output Power Calculations** boxes are the **System Efficiency and....Thermal Design** boxes. Here the system efficiency and the Class D efficiency are shown. The difference between the two efficiency numbers is that the Class D efficiency is the efficiency of the LM4651/52 Class D amplifier chipset only. The total power dissipation is calculated. The major power losses are shown occurring in the inductors, the LM4652 and the LM4651. The box to the right will calculate the needed heat sink (Θ_{SA} in °C/W) for a given ambient temperature. The correct heat sink for both the non-electrically isolated (T) and electrically isolated packages (TF) are show. The calculation assumes that thermal grease will be used and the LM4652 package will be mounted directly to the heat sink. Because Class D has peak power dissipation at peak output power a heat sink size is also shown for ½ peak power. When playing music the amplifier spends very little time at peak output power resulting in a much lower average output power. This feature allows for a smaller heat sink in real world applications than Class A or AB amplifiers. A reasonable safe value would be ½ peak output power. It is up to the system designer to determine the correct heat sink relative to size, cost, and the application.

The last section on the left is **Misc. External Calculations**. The start up capacitor value based on the desired start up time is calculated. The R_{SCKT} value is shown which limits the output current as required by the output power and ripple current. The DC offset based on **Gain A** box and the needed value of R_{Offset} to minimized the DC offset is calculated. If the demo board is used or a RC input filter, the values for this filter are entered in this box. The box to the right has the second option for calculating start up time by entering the value of the capacitor instead of time. The DC offset based on **Gain B** box and the needed value of R_{Offset} are shown. The upper input 3dB frequency is calculated for both Gain boxes using the values of R_{lp} and C_{lp}.

The boxes on the top right are **Output Filter Calculations** and **Feedback Filter Calculations** just below the disclaimer and the **Warning** and **Error** boxes. All cells in the **Feedback Filter Calculations** are in yellow and are calculated according the values in the **Output Filter Calculations** box to the left. Either the value for L, C_{BYP} and C_1 or the 3dB frequency point can be entered to determine the output filter details. The Q is also shown and should be near 0.707 for a maximally flat response.

The **Gain Calculations** boxes are labeled **A** or **B**. The **A** box calculates gain from the values entered in the blue cells (R_1, R_2, R_F). The **B** box calculates the resistor values based on the input gain value. Both boxes also use the value entered in R_{lp} for calculations. Near the bottom of each box the value of C_{in} is entered and the resulting lower 3dB frequency is shown. C_{in} is the input capacitor commonly used to block DC at the input of an audio amplifier.

Many calculations use multiple cells from other boxes for data . All cells should have the desired value entered to be sure all calculations are correct.

Advanced Features:

Clicking on the *Efficiency Graph* tab brings up a couple of advanced features. No user inputs are entered on this sheet. Shown is the supply regulation percent based on the supply voltage entered on the *Quick Calculations* sheet and the approximate VA rating needed if using a unregulated supply with a transformer. A graph of system efficiency and power dissipation in the LM4652 verses output power is shown. This efficiency plot is in red and uses the left Y axis. The power dissipation plot is in blue and uses the right Y axis. Both plots are approximations only. The graphs are provided to give information at operating areas other than the clipping point.

Clicking on the *Warnings & Errors* tab will show any warnings or errors. The warning or error will be explained in more detail and corrective action will be suggested. Clicking on this tab is not necessary unless one or both of the Warning or Error boxes found on the upper right alert the system designer there is a problem and the color of the box changes from green to orange (Warnings) or red (Errors). This sheet is very helpful when correcting one warning or error results in another warning or error (as can often be the case). Warnings alert the system designer to possible performance issues that may be overlooked. Warnings do not need to be corrected but should be noted by the designer. Errors alerts the system designer when trying to use the LM4651/52 outside of the operating range that will often result in the destruction of the LM4651/52 silicon. Errors must be fixed or the LM4651/52 will fail. With so many calculations and possible variations this tab is a very valuable tool for designing a complete design that will function as desired.

Helpful Tips:

Increasing output power

Output power can be increase by minimizing the losses in the output path and the amount of wasted time switching. The DC resistance of the coil (R_{dc}) can be significant depending on the amount of output current. Obviously, reducing the resistance will lower the power loss in the inductors allowing for more power to be delivered to the load. The switching frequency can be reduced to give higher output power levels. Less time is spent switching increasing the voltage swing across the load and subsequently the power to the load. Dead Time can be reduced for a small increase in output power but with reduced efficiency results.

Flat response with real world speaker

The output filter's frequency response will be maximally flat when the Q is set to 0.707 and the load impedance is constant over frequency. Since real world speaker drivers have an impedance dependant on frequency the Q of the output filter will change with frequency. To obtain a flat response with the output filter the maximum impedance of speaker to be used must be known and the output filter designed for this maximum value. Another approach is to know the speaker impedance around the desired roll off point and design the output filter using this impedance. In any case, bench work will most likely be need to fine tune the filter response for near flat performance. The response will be relatively flat (+0.50dB) with a Q of less than 1.0

Filter points

There are several filter points to consider: Input filter, feedback filter, error amplifier filter and output filter. The feedback and error amplifier filter points should be set higher than the output filter point and the Design Guide does this automatically. The output filter point should be set higher than the input filter with the input filter set for the audio range of the application. Setting the input filter lower than the output filter allows for flatter frequency response since the output filter effects are outside of the audio range of interest. An example would be a subwoofer application:

Input filter point: 250Hz
Output filter point: 7kHz
Feedback filter point:12kHz
Error Amplifier filter point: 35kHz

When the different filters are designed in this manner, having a maximally flat response from the output LC filter is not as critical to performance. As the audio bandwidth of the application increases the output filter design becomes more difficult and important. A process of trial and error may be the best method for determining the output filter that best meets the design specifications.