Design Kit

Class D Audio Amplifier Using IRS2092
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</table>
# 1. Specifications

## General Test Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>± 15V</td>
</tr>
<tr>
<td>Load Impedance</td>
<td>8-4 Ω</td>
</tr>
<tr>
<td>Self-Oscillating Frequency</td>
<td>400kHz</td>
</tr>
<tr>
<td>Gain Setting</td>
<td>24dB</td>
</tr>
</tbody>
</table>

## Electrical Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Power</td>
<td>25W (1kHz, 4Ω)</td>
</tr>
<tr>
<td>Efficiency</td>
<td>93% (25W, 4Ω)</td>
</tr>
</tbody>
</table>

## Audio Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distortion</td>
<td>Less than 0.015%THD (1kHz, 4Ω, 10W)</td>
</tr>
<tr>
<td>Frequency Response</td>
<td>± 1dB (20 ~ 20000 Hz, 4Ω, 2V Output)</td>
</tr>
</tbody>
</table>
**Specifications: Efficiency Evaluation Circuit**

**Test Condition:**
- **Po = 25[W]**
- **RL = 4Ω**
- **f in = 1kHz**

**Parameters:**
- **Po = 25W**
- **Gv = 15.85**
- **RL = 4Ω**
- **f in = 1kHz**

**Analysis**
- **Time Domain (Transient)**
  - Run to time: 3ms
  - Start saving data after: 1ms
  - Maximum step size: 100n
  - **✔ Skip the initial transient bias point calculation (SKIPBP)**

**Options**
- **RELTOL: 0.01**
- **VNTOL: 1.0u**
- **ABSTOL: 1.0n**
- **CHGTOL: 0.01p**
- **GMIN: 1.0E-12**
- **ITL1: 500**
- **ITL2: 200**
- **ITL4: 10**

**Condition:**
- **Po = 25[W]**, **4Ω Load**

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Specifications : Efficiency Simulation Result

![Graph showing efficiency simulation results](image-url)
Condition : 
\[ f_{in} = 1\text{kHz} , \ Po = 10\text{[W]}, \ 4\Omega \text{ Load} \]

Analysis
Time Domain (Transient)
- Run to time: 3ms
- Start saving data after: 0s
- Maximum step size: 100n
- \( \checkmark \) Skip the initial transient bias point calculation (SKIPBP)

Output File Options...
- \( \checkmark \) Perform Fourier Analysis
- Center Frequency: 1kHz
- Output Variables: V(OUT)

.Options
- RELTOL: 0.01
- VNTOL: 1.0u
- ABSTOL: 1.0u
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 200
- ITL4: 10
### Specifications: THD Simulation Result

#### V\textsubscript{OUT} 0.0144%THD

<table>
<thead>
<tr>
<th>No</th>
<th>Harmonic Frequency (Hz)</th>
<th>Fourier Component</th>
<th>Normalized Component</th>
<th>Phase (Degree)</th>
<th>Normalized Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00E+03</td>
<td>8.81E+00</td>
<td>1.00E+00</td>
<td>1.79E+02</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>2</td>
<td>2.00E+03</td>
<td>4.62E-04</td>
<td>5.25E-05</td>
<td>4.18E+01</td>
<td>-3.15E+02</td>
</tr>
<tr>
<td>3</td>
<td>3.00E+03</td>
<td>2.78E-04</td>
<td>3.16E-05</td>
<td>8.49E+01</td>
<td>-4.51E+02</td>
</tr>
<tr>
<td>4</td>
<td>4.00E+03</td>
<td>3.23E-04</td>
<td>3.67E-05</td>
<td>6.91E+01</td>
<td>-6.45E+02</td>
</tr>
<tr>
<td>5</td>
<td>5.00E+03</td>
<td>3.73E-04</td>
<td>4.23E-05</td>
<td>8.66E+01</td>
<td>-8.06E+02</td>
</tr>
<tr>
<td>6</td>
<td>6.00E+03</td>
<td>6.69E-04</td>
<td>7.60E-05</td>
<td>6.10E+01</td>
<td>-1.01E+03</td>
</tr>
<tr>
<td>7</td>
<td>7.00E+03</td>
<td>2.85E-04</td>
<td>3.24E-05</td>
<td>8.09E+01</td>
<td>-1.17E+03</td>
</tr>
<tr>
<td>8</td>
<td>8.00E+03</td>
<td>4.32E-04</td>
<td>4.91E-05</td>
<td>7.17E+01</td>
<td>-1.36E+03</td>
</tr>
<tr>
<td>9</td>
<td>9.00E+03</td>
<td>5.95E-04</td>
<td>6.76E-05</td>
<td>2.70E+01</td>
<td>-1.58E+03</td>
</tr>
</tbody>
</table>

**Total Harmonic Distortion = 1.438206E-02 Percent**
Condition: 20 ~ 20000 Hz, 4Ω Load, 2V Output

Analysis
Time Domain (Transient)
- Run to time: 2ms
- Start saving data after: 0ms
- Maximum step size: 100n
- Skip the initial transient bias point calculation (SKIPBP)

Parametric Sweep
- Global parameter
  - Parameter name: RL
  - Value list: 4, 8

Specifications: Frequency Response Evaluation Circuit

Options
- RELTOL: 0.01
- VNTOL: 1.0u
- ABSTOL: 1.0n
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 2000
- ITL4: 10
Specifications: Frequency Response Simulation Result

\[ V_{\text{OUT}} + 1 \text{dB} \ (8\Omega \ \text{Load @ 20kHz}) \]

\[ V_{\text{OUT}} - 0.4 \text{dB} \ (4\Omega \ \text{Load @ 20kHz}) \]
Note: $P_o [W] \text{ vs. } V_{in} [V_{peak}]$

$$V_{in} [V_{peak}] = \frac{1.4142 \times \sqrt{P_o \times R_{load}}}{G_v}$$

- $P_o [W] = \text{power output}$
- $R_{load} [\Omega] = \text{Load resistance}$
- $G_v = \text{Amplifier voltage gain}$
2. Waveforms Evaluation

Class D amplifier circuit are simulated and compared with measured waveforms from oscilloscope (Tektronix: TDS3054B)

PARAMETERS:
- $V_{OUT} = 2$
- $Gv = 15.85$
- $f_{in} = 1k$

VAMPL = $1.4142 \times V_{OUT}/Gv$

VOFF = 0

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3. Simulated vs. Measured Waveform (1/3)
3. Simulated vs. Measured Waveform (2/3)

Simulated

Measured

HO

LO

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3. Simulated vs. Measured Waveform (3/3)
4. Voltage gain of the amplifier – $G_V$

$$G_V = \frac{R_{FB}}{R_{IN}}$$

$R_{IN} = 2.4 \text{, } 3\text{kΩ}$

$R_{FB} = 47\text{kΩ}$

**Analysis**

**Time Domain (Transient)**
- Run to time: 1ms
- Start saving data after: 100n
- Maximum step size: 100n
- Skip the initial transient bias point calculation (SKIPBP)

**Sweep variable**
- Global parameter: RIN
- Value list: 2.4k, 3k

**Options**
- RELTOL: 0.01
- VNTOL: 1.0u
- ABSTOL: 1.0n
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 200
- ITL4: 10
4. Voltage gain of the amplifier – $G_V$
5. Self-Oscillating Frequency

Self oscillating frequency is design by setting the following items

- Integration capacitors.
- Integration resistor.

**Integration resistor:** R4+VR1

**Integration capacitors:** C4=C5

Analysis

Time Domain (Transient)
- Run to time: 1ms
- Start saving data after: 0.5m
- Maximum step size: 40n
- Skip the initial transient bias point calculation (SKIPBP)

Options
- RELTOL: 0.001
- VNTOL: 1.0u
- ABSTOL: 1.0n
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 200
- ITL4: 10
5. Self-Oscillating Frequency

Simulated

Measured

Self-oscillation frequency = 400kHz (Simulated)

Self-oscillation frequency = 400kHz (Measured)
6. Dead-time

<table>
<thead>
<tr>
<th>Dead-time Mode</th>
<th>R20</th>
<th>R21</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT1 (25ns)</td>
<td>3.3k</td>
<td>8.2k</td>
</tr>
<tr>
<td>DT2 (40ns)</td>
<td>5.6k</td>
<td>4.7k</td>
</tr>
<tr>
<td>DT3 (65ns)</td>
<td>8.2k</td>
<td>3.3k</td>
</tr>
<tr>
<td>DT4 (105ns)</td>
<td>-</td>
<td>&lt; 10k</td>
</tr>
</tbody>
</table>

Analysis
Time Domain (Transient)
- Run to time: 1ms
- Start saving data after: 0.5m
- Maximum step size: 40n
- Skip the initial transient bias point calculation (SKIPBP)

Options
- RELTOL: 0.001
- VNTOL: 1.0u
- ABSTOL: 1.0n
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 200
- ITL4: 10

V(DT) Voltage Divider
Dead-time DT1(25ns)
Dead-time DT3(65ns)

Spike voltages
(Decrease for longer dead time)
7. Turn-on transient

- Start-up sequencing is achieved through the charging of the CSD voltage (C7). Simulation will show how capacitors are charged to complete the sequence for each capacitance value.

Analysis
Time Domain (Transient)
- Run to time: 975ms
- Start saving data after: 100n
- Maximum step size: 100u
- ☑ Skip the initial transient bias point calculation (SKIPBP)

Options
- RELTOL: 0.01
- VNTOL: 1.0u
- ABSTOL: 1n
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 200
- ITL4: 10
Turn-on transient: C7 = 10μF

Class D Startup @ 0.976 second.
Turn-on transient: C7 = 5uF

Class D Startup @ 0.488 second.
Turn-on transient: $C7 = 3.3\mu F$

Class D Startup
@ 0.320 second.
8. Components stress

- This simulation shows how voltage and current are applied to each component at the maximum load condition (25W, 4ohm).
Components Stress Simulated Result for Diodes, FETs, Inductor, and 4ΩLoad
9. Power losses in the MOSFETs

The total power loss in MOSFET are given by:

\[ P_{TOTAL} = P_{SW} + P_{cond} + P_{gd} \]

---

**Analysis**

**Time Domain (Transient)**

- Run to time: 500us
- Start saving data after: 100n
- Maximum step size: 2n
- Skip the initial transient bias point calculation (SKIPBP)

---

Options

- RELTOL: 0.003
- VNTOL: 1.0m
- ABSTOL: 100n
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 200
- ITL4: 20

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Power losses FET1 (Standard Model)

FET1: ID and VDS are simulated and compared with scope (Tektronix: TDS3054B) waveforms. $P_{SW}, P_{cond},$ and $P_{gd}$ are calculated by PSpice.
Power losses FET2(Standard Model)

FET2: ID and VDS are simulated and compared with scope (Tektronix: TDS3054B) waveforms

$P_{SW}, P_{cond}, and P_{gd}$ are calculated by PSpice.
Power losses in the MOSFETs (Professional model)

The total power loss in MOSFET are given by:

\[ P_{\text{TOTAL}} = P_{\text{SW}} + P_{\text{cond}} + P_{\text{gd}} \]
Power losses FET1 (Professional Model)

FET1: ID and VDS are simulated and compared with scope (Tektronix: TDS3054B) waveforms. $P_{SW}, P_{cond}, and P_{gd}$ are calculated by PSpice.
Power losses FET2 (Professional Model)

FET2: ID and VDS are simulated and compared with scope (Tektronix: TDS3054B) waveforms

$P_{SW}, P_{cond}, \text{and } P_{gd}$ are calculated by PSpice.
FET: IRFIZ24N Qg Standard vs. Professional Model

- Gate charge characteristics in Professional model has more accurate results than standard model.

<table>
<thead>
<tr>
<th>VDD=44V, Id=10A, VGS=10V</th>
<th>Measurement</th>
<th>Simulation</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Model: Qg(nc)</td>
<td>13.400</td>
<td>12.543</td>
<td>-6.396</td>
</tr>
<tr>
<td>Professional Model: Qg(nc)</td>
<td>13.400</td>
<td>13.409</td>
<td>0.067</td>
</tr>
</tbody>
</table>
Simulated $P_{gd}$, Standard model compared to Professional model, shows some different results caused by different Qg characteristics of the models.

- Professional model requires more simulation time and might cause some convergence error.

※ Professional model requires more simulation time and might cause some convergence error.
10. Short circuit vs. switching output shutdown

- This simulation will show how the IRS2092 responds to a short circuit condition.

Short circuit at 2.25ms.

Analysis
Time Domain (Transient)
- Run to time: 4ms
- Start saving data after: 100n
- Maximum step size: 100n
- ✔ Skip the initial transient bias point calculation (SKIPBP)
Short Circuit vs. Switching Output Shutdown (Positive Side)

Delay between short circuit and switching output shutdown

Load (Speaker) current

CSD pin

VS pin

V(Speaker)
Short Circuit vs. Switching Output Shutdown (Negative Side)

Delay between short circuit and switching output shutdown

Load (Speaker) current

CSD pin

V(Speaker)

VS pin
11. Short Circuit Response

This simulation will show how the IRS2092 responds to a short circuit condition.

Short circuit at 1.75ms.
Short Circuit Response: C7 = 10uF
Short Circuit Response: C7 = 3.3μF
12. Capacitor models

- Capacitor models are needed for the simulation to include spike voltage.

Analysis
Time Domain (Transient)
- Run to time: 1ms
- Start saving data after: 0.5m
- Maximum step size: 40n
- ☑ Skip the initial transient bias point calculation (SKIPBP)

Options
- RELTOL: 0.001
- VNTOL: 1.0u
- ABSTOL: 1.0n
- CHGTOL: 0.01p
- GMIN: 1.0E-12
- ITL1: 500
- ITL2: 200
- ITL4: 10
Simulation Result (without Capacitor Model)

Simulated (without output capacitor models)

Self-oscillation frequency = 400kHz (Simulated)

Measured

Self-oscillation frequency = 400kHz (Measured)
Simulation Result (with Capacitor Model)

Simulated (with output capacitor models)

Measured

Self-oscillation frequency = 400kHz (Simulated)

Self-oscillation frequency = 400kHz (Measured)
### 13. Simulated Performance of the circuit with different FETs

<table>
<thead>
<tr>
<th>IRFIZ24N Key Parameters</th>
<th>IRFI4024H-117P Key Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V&lt;sub&gt;DS&lt;/sub&gt;</strong></td>
<td>55</td>
</tr>
<tr>
<td><strong>I&lt;sub&gt;D&lt;/sub&gt;</strong></td>
<td>14</td>
</tr>
<tr>
<td><strong>R&lt;sub&gt;DS(ON) typ. @ 10V&lt;/sub&gt;</strong></td>
<td>70 mΩ</td>
</tr>
<tr>
<td><strong>Q&lt;sub&gt;g typ.&lt;/sub&gt;</strong></td>
<td>13.4 nC</td>
</tr>
<tr>
<td><strong>t&lt;sub&gt;ON typ.&lt;/sub&gt;</strong></td>
<td>38.9 ns</td>
</tr>
<tr>
<td><strong>t&lt;sub&gt;OFF typ.&lt;/sub&gt;</strong></td>
<td>46 ns</td>
</tr>
<tr>
<td><strong>Q&lt;sub&gt;rr typ.&lt;/sub&gt;</strong></td>
<td>120 nC</td>
</tr>
</tbody>
</table>
Simulated Performance of the circuit with different FETs

<table>
<thead>
<tr>
<th></th>
<th>IRFIZ24N</th>
<th>IRF4024H-117P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency (@ 25W, 4Ω)</td>
<td>93.505%</td>
<td>94.578%</td>
</tr>
<tr>
<td>Distortion (@ 1kHz, 4Ω, 10W)</td>
<td>0.0144 %THD</td>
<td>0.0201 %THD</td>
</tr>
</tbody>
</table>

Efficiency and Distortion values are provided for comparison with different FET types.
Simulated Performance of the circuit with different FETs

IRFIZ24N

IRFI4024H-117P

FET1

FET2
<table>
<thead>
<tr>
<th>Simulation</th>
<th>Folder Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Efficiency Evaluation</td>
<td>Efficiency</td>
</tr>
<tr>
<td>2. THD Evaluation</td>
<td>THD</td>
</tr>
<tr>
<td>3. Frequency Response Evaluation</td>
<td>FrqRsp</td>
</tr>
<tr>
<td>4. Waveforms Evaluation</td>
<td>Waveforms</td>
</tr>
<tr>
<td>5. Voltage gain of the amplifier – $G_v$</td>
<td>Gv</td>
</tr>
<tr>
<td>6. Self-Oscillating Frequency</td>
<td>OSC</td>
</tr>
<tr>
<td>7. Dead-time Evaluation</td>
<td>DT</td>
</tr>
<tr>
<td>8. Turn-on transient</td>
<td>StartUp</td>
</tr>
<tr>
<td>9. Component stresses</td>
<td>Stress</td>
</tr>
<tr>
<td>10. Power losses in the MOSFETs (Standard model)</td>
<td>FET(STD)</td>
</tr>
<tr>
<td>11. Power loss in the MOSFETs (Professional Model)</td>
<td>FET(PRO)</td>
</tr>
<tr>
<td>12. Short Circuit vs. Switching Output Shutdown</td>
<td>Short</td>
</tr>
<tr>
<td>13. Short Circuit Response</td>
<td>ShrtRsp</td>
</tr>
</tbody>
</table>