MP741/7/8 Class D Audio Amplifier

POP Analysis and Solutions

Application Note

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ABSTRACT

INTRODUCTION ABOUT POP IN CLASS D AMPLIFIERS

The click and pop, which are undesirable audible transient sound and does not come from the system input signal, is generated when the amplifier system changes its operating mode (e.g. charging/discharging coupling capacitors or PWM start/stop).

ABOUT THIS APPLICATION NOTE

In the first part of this application note, we will introduce the improved startup and shutdown Pop elimination design and the de-pop performance of the MPS new generation Class D amplifier MP7741/7/8. The de-pop performance of the MPS new parts is comparable to that of the key competitions.

If you want to know the detailed analysis of the causes and corresponding solutions of startup/shutdown pop in MPS AAM™ products, and how to fix this issue completely in MPS new generation class D amplifier products with SE and BTL configuration, please see the second part and the third part of this application note.
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1. NEW GENERATION CLASS D AMPLIFIER MP7741/7/8 DE-POP PERFORMANCE

To better understand the root causes of a Class D amplifier pops, it is useful to have a look at MPS Class D audio system (MP7747 SE for example). The typical application schematic is shown in Figure 1. There are three external capacitors, the coupling capacitors $C_{IN}$, $C_{OUT}$ and the bootstrap capacitor $C_{BST}$, and the manner in which they charge/discharge during the start-up/shut down of the amplifier, that determines the degree of pop and click of the amplifier. As we known, the transient current through speaker may be heard as a pop due to the audible-frequency components.

![Figure 1: MP7747 Application Schematic](image)

Notes:

‘Enable Pop’ means the heard pop @ the class D audio amplifier is enabled (Enable = 0V -> 5V; VDD=set value);
‘Disable Pop’ means the heard pop @ the class D audio amplifier is disabled (Enable = 5V -> 0V; VDD=set value);
‘Power On Pop’ means the heard pop @ enable signal is ready and then power is on (Enable = 5V; VDD= 0V -> set value);
‘Power Off Pop’ means the heard pop @ enable signal is keep high enough and then power is declined (Enable = 5V; VDD= set value -> 0V).

Unless other notes, the test waveforms shown in this application note were tested under VDD=24V and 8Ω speaker.
‘SE’ means Single-ended.
‘BTL’ means Bridge Tied Load.

Degree of pops: large pop means a pop is audible in 1m distance, audible pop is audible in 50cm distance, slight pop is audible in 20cm distance, and very slight pop is audible in 0cm distance.
1.1 HOW TO ELIMINATE THE POPS

MP7741/7/8 integrates improved internal circuits and startup sequence:

1. Timer controlled ramp up source current instead of step-up/step-down current in MP7740/2/5.

The all MPS AAM™ class-D amplifiers integrate a source-current function to charge the DC block capacitors \( C_{OUT} \) and \( C_{IN} \) at start-up. The internally-generated current flow to the SW pin during start-up, which helps to eliminate turn-on pop. The source current of the all previous products is step, which may cause a small audible pop. Now in MP7741/7/8, the rising slew rate of the source current can be adjusted from the timer capacitor \( C_{TIMER} \), which can be controlled out of the audio band.

2. Lower sink current.

Sink current will be applied when the voltage of NIN is higher than the PIN. And the value of sink current determines the degree of the related pop. MP7741/7/8 decreases the sink current value to around 3mA, which is around 15mA in the old parts.

3. UVP function.

MP7741/7/8 integrates a programmable under-voltage protection (UVP) function, which can prevent pops during power downs by controlling the UVP node voltage. If the UVP pin is NC, the default VDD shutdown voltage (rising threshold) is 8.4V since there is an internal voltage divided circuit. For de-popping during power-down, the VDD shutdown voltage is easily adjusted by the external divider resistor, detailed analysis and application information, please refer to section 2.3 and section 3.2.

4. Additional External circuit.

Besides the improved internal designs, we still need to add a few external components to help to eliminate the startup/shutdown pop completely. Please see the below figure, with the \( C_{BST} \) pre-charge circuit and \( C_{OUT} \) pre-charge circuit, the MP7741/7/8 can eliminate the enable/disable pop completely. If the applications do care the pop performance, these external circuits are highly commended.

Figure 2: MP7747 External Start Up Pop Elimination Circuit for SE
1.2 DE-POP PERFORMANCE COMPARISON

We can evaluate pop performance in an amplifier by capture the current through a speaker:

- The higher peak to peak current results in larger pop amplitude.
- The fast rising/falling edge in the transient current contains sensitive audible-components, which can be heard by human ear easily.

1. With internal circuit design improvement and additional externally components, MPS new generation class D amplifier products MP7741/7/8 achieve impressive de-pop performance both in SE and BTL configuration applications. Figure 3 is the comparing test results of MP7748 SE and BTL EVBs during enable/disable transient.

![Figure 3: MP7748 SE/BTL Enable/Disable Waveform](image1)

2. Comparing with competitor’s part (TPA3123D2 from TI) in SE configuration, there is almost no pop can be found during the MP7748DF changing its operating mode. Figure 4 shows the measured speaker current waveforms (I_SPK) from MP7748 SE and TPA3123D2 SE amplifier when enable/disable. This waveform clearly shows that the MP7748DF SE amplifier produce much lower peak to peak current (trough speaker) than TPA3123D2.

![Figure 4: MP7748 and TPA3123D2 Enable/Disable Waveform](image2)
3. Comparing with competitor’s latest part (TPA3110D2 from TI) in BTL configuration, MP7748 has the similar pop performance when enable/disable. Figure 5 is the scope capture of comparison of MP7748 BTL and TPA3110D2 when enable/disable.

![Figure 5: MP7748 BTL and TPA3110D2 Enable/Disable Waveform](image)

4. Comparing with former generation part MP7782 in BTL configuration, MP7748 has the much better pop performance when enable/disable. Figure 6 is the scope capture of comparison of MP7748 BTL and MP7782 BTL when enable/disable.

![Figure 6: MP7748 and MP7782 Enable/Disable Waveform](image)
2. ANALYSIS OF POPS AND CORRESPONDING SOLUTIONS FOR SE

2.1 ENABLE POP

2.1.1 Internal Startup Scheme and External Circuit For Pop Elimination

For Single-Ended Class D amplifier, the coupling capacitor \( C_{\text{INT}} \) and \( C_{\text{OUT}} \) must be charged until the threshold voltage is reached at start-up. This is done so that the output signal can have a high output swing in both the positive and negative directions without one side being clipped before the other. And at start-up, the bootstrap capacitors should also charged up. If the bootstrap capacitor is not charged, the SW cannot go high.

So before the normal operation, the class D amplifier needs to pre-charge the coupling capacitors \( C_{\text{IN}} \) & \( C_{\text{OUT}} \) and the bootstrap capacitor \( C_{\text{BST}} \), as shown in Figure 7. The detailed start-up sequence of MP7741/7/8 for start-up pop elimination is shown in the Figure 8.

![Figure 7: Start up sequence](image-url)
Enable

Both FETs OFF

Turn on BST current source (source current to BST)

Yes

NIN<PIN?

No

Turn on HS current source (source current to SW)

NIN>PIN?

Yes

Turn on LS current source (sink current to SW)

No

Turn off HS current source

BS-SW>4V?

Yes

Yes

BS-SW>4V & NIN > PIN

High Frequency Burst

Normal Operation

Figure 8: Detail operations of start up sequence

Improved from the MP7740/2/5 start up operation, MPS new generation class D amplifier products MP7741/7/8 start up source current can be adjusted to low slew rate by external $C_{\text{TIMER}}$ (e.g. 2.2μF), so pop elimination can be achieved with the $C_{\text{BST}}$ pre-charge circuit and $C_{\text{OUT}}$ pre-charge circuit (Figure 2), the detailed speaker current is shown in the right part of Figure 9.
Without external de-pop circuits, slight pop still can be heard within very short-range (about 20cm distance between the human ear and speaker). When the external de-pop circuits added (see figure 2), no sound can be heard from the loudspeaker.

### 2.1.2 Why We Need Extra External De-pop Circuits

Original MP7747 start up waveforms are shown in Figure 10, the transient current through speaker may be heard as a pop due to the audible-frequency components. Two sounds of pop can be heard from the speaker. Detail cause and solution please refer to Table 1.

### Table 1: Pops Cause and Solution

<table>
<thead>
<tr>
<th>Cause</th>
<th>Solution</th>
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<tbody>
<tr>
<td>No.1 Pop BST charge Current</td>
<td>Add the BST pre-charge circuit</td>
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</table>
| Start up source rise up or sink current | For start up source current: set $C_{\text{TIMER}} > 1\mu\text{F}$  
For start up sink current: set $V_{\text{COUT}} < V_{\text{DD}}/2$ to escape the start up sink current |
| No.2 Pop Start up source current end $C_{\text{OUT}}$ discharge current | Set $C_{\text{TIMER}} > 1\mu\text{F}$  
Add the $C_{\text{OUT}}$ pre-charge circuit |
2.1.2.1 No.1 Pop _ Bst Charge Current

1. Cause Analysis

As the MP7747 start up sequence shows, the amplifier charges the $C_{\text{BST}}$ firstly once enable, as the Figure 10. With $1\mu F$ $C_{\text{BST}}$, the $C_{\text{BST}}$ charge current is high $di/dt$ ($A/\mu S$) and high amplitude ($A$). The current frequency is within the audio band, so it can be heard as a pop.

Test condition: $VDD=24V$; $EN=0V->5V$; $R_{\text{SPEAKER}}=8\ \Omega$; Input AC grounded; $C_{\text{BST}}=1\mu F$; without $C_{\text{BST}}$ pre-charge circuit

2. Solutions for the Pop Caused by BST Charge Current

To escape this pop, it is better to pre-charge the $C_{\text{BST}}$ with low frequency current before enable, e.g. adding the $C_{\text{BST}}$ pre-charge circuit (Figure 11). This circuit can help to charge the $C_{\text{BST}}$ when power is on, and it is recommended to set low charge rate by a large resistor (e.g. $20\text{k} \Omega$).

With $C_{\text{BST}}$ pre-charge circuit (need to add three external components), the pop caused by BST charge current can be reduced to un-audible level (Figure 12).

![Figure 10: C_{BST} charge current](image)

![Figure 11: C_{BST} Pre-Charge Circuit](image)
2.1.2 No.1 Pop _ The Start-Up Source Current

1. Cause Analysis

According to the start up sequence of MP7741/7/8, the amplifier needs to charge the coupling capacitors \( C_{\text{OUT}} \) & \( C_{\text{IN}} \) to \( V_{\text{DD}}/2 \) firstly after enable. Pop may occurs when the charge current with high slew rate and amplitude.

Improved from MP7740/2/5, MP7741/7/8 start up source current is controlled by the external timer capacitor \( C_{\text{TIMER}} \). With larger \( C_{\text{TIMER}} \), the slew rate of start up source current would be smaller:

\[
T_{\text{RISE}} (\text{S}) = \frac{C_{\text{TIMER}}}{6.25 \times 10^{-6}} \quad (1)
\]

E.g. \( C_{\text{TIMER}} = 2.2 \mu\text{F} \), the rise time \( T_{\text{RISE}} \) of source current from 0 to 20mA is would be 0.352 S. Figure 13 shows the relations of start up source current and \( C_{\text{TIMER}} \) voltage.

2. Solutions for the Pop Caused by Start Up Source Current

It is recommended to use the \( C_{\text{TIMER}} \) larger than 317nF. So with 2.2\( \mu\text{F} \) \( C_{\text{TIMER}} \), the start up pop is very low frequency and out of audible frequency band, which can't be heard even the human ear is 20cm distance to the speaker. Figure 14 shows the captured waveform.
2.1.2.3 No.1 Pop _ The Start-Up Sink Current – Occurs At Some Specially Conditions

1. Cause Analysis

As the start up sequence, if NIN>PIN, the SW node will sink current to discharge the NIN voltage. This sink current also has high di/dt (A/µS), so it can be heard.

2. Solutions for the Pop Caused by Start Up Sink Current

To eliminate the pop caused by this sink current, MP7741/7/8 set the sink current to lower amplitude (just 3mA, Figure 15) than MP7740/2/5 internally. Besides, it is better to escape the sink current by setting the C\text{OUT} voltage smaller than V\text{DD}/2. (For this external circuit, please refer to Figure18)
2.1.2.4 No.2 Pop _ Start-up Source Current End

1. Cause Analysis

As mentioned above, the MP7741/7/8 start up source current is related with $C_{\text{TIMER}}$ voltage. After MP7741/7/8 enters into the normal operation, the $C_{\text{TIMER}}$ voltage will be reset to zero, at the same time the source current starts to reset (Figure 16).

![Figure 16: Start Up Source Current](image)

2. Solutions for the Pop Caused by Start up Sink Current

Once the PWM starts, the source current will ended with very low discharge rate and very low discharge amplitude (Figure 16). The generated pop is very slight even the listener stands 0cm distance to the speaker. Therefore, no special solution is needed.

2.1.2.5 No.2 Pop _ COUT Discharged Current

1. Cause Analysis

According to the start up source current loop, when NIN voltage is charged up to $V_{\text{DD}}/2$, the output coupling capacitor $C_{\text{OUT}}$ voltage is already higher than $V_{\text{DD}}/2$, because $V_{\text{COUT}} = V_{\text{NIN}} + V_{\text{RF}}$. $V_{\text{RF}}$ is the voltage drop on feedback resistor. Before NIN is charged to $V_{\text{DD}}/2$, SW node (DC block capacitor) already exceeds $V_{\text{DD}}/2$.

Thus a problem comes: the output capacitor will be over charged when the NIN voltage just equals to PIN voltage. Under this condition, at the moment of 50% duty PWM start, a large current will go through the speaker to discharge the output coupling capacitor. Therefore, a large pop noise is generated. This current is proportional to the overcharge voltage, as is shown in Figure 17 (CH4). The smaller source current is, the smaller $C_{\text{IN}}$ charge current and the smaller $V_{\text{RF}}$ is, which also results in smaller start up pop.
2. Solutions for the Pop Caused by $C_{OUT}$ Discharged Current

Adding a $C_{OUT}$ pre-charge circuit (Figure 18) can help to charge $C_{OUT}$ voltage to about VDD/2 when VDD is turned on, and the $C_{IN}$ voltage is also closed to VDD/2. Under the condition above, the start up condition NIN=PIN is achieved soon by the start up source up current when enable. Therefore, the discharge transient current is limited to small amplitude, which helps to reduce the pop (Figure 19).

![Figure 18: C_{OUT} pre-charge circuit](image)

![Figure 19: Start Up Source Current with C_{OUT} Pre-charge Circuit](image)
2.2 DISABLE POP

Refer to the disable waveform in Figure 20, there is no audible pop when the amplifier is disabled. The very small current ripple on the output is caused by oscillation of inductors (output inductor, the speaker equivalent inductor) and capacitors (output block capacitor).

![Figure 20: Disable Waveform](image)

2.3 POWER OFF POP

Without proper UVP setting, a MP7741/7/8 Class D amplifier will keep operating until the $V_{DD}$ drops to 8.8V. For a typical 24V power supply case, an abnormal current burst can be found in the output of the amplifier. The phenomenon is related to different voltage drop rate between $V_{COUT}$ and $V_{PIN}$. This case is even worse when the amplifier keeps its operation while the $V_{DD}$ is under 50 percent of its original value.

MP7741/7/8 series class D amplifiers integrate programmable UVP function, which can be used to avoid the power off pop by controlling the UVP node voltage. The corresponding circuit is shown in the Figure 21.

![Figure 21: UVP Circuit](image)
If the UVP pin is not connected, the default \( V_{\text{DD}} \) shutdown voltage (rising threshold) is 7.6V, which is related to the internal voltage divided circuit. The \( V_{\text{DD}} \) shutdown voltage can be flexibly adjusted by controlling UVP pin voltage with two external resistors (RH and RL in figure 21). To set \( V_{\text{UVP}} \) equal to 70 percent of \( V_{\text{DD}} \) is recommended. Please refer to Equation 2 for detail calculation.

As the waveforms shown in Figure 23, the power off pop is much improved with proper UVP circuit setting when compared with that with improper UVP as shown in Figure 22.

### 3. ANALYSIS OF POPS AND CORRESPONDING SOLUTIONS FOR BTL

#### 3.1 ENABLE/DISABLE POP

The Start up sequence in BTL configuration is similar with the SE application described above, so we will analyze enable/disable pop in detail to the following cases:

- BTL configuration with differential input.
- BTL configuration with single-ended input.

No matter which type of input was used, matching the input impedance is the key rule for eliminate pops. Refer to Figure 24 and Figure 25, components in the red path determine the inverted amplifier input impedance, the blue path determines the non-inverted amplifier input impedance.

\[
V_{\text{UVP}} (V) = 4x \frac{R_H + R_L}{R_H}
\]
3.1.1 Root Cause Analysis for Enable Pop

Take the SE input BTL application for example. Once the input impedance is not match well (the value of $R_{\text{source}}/R_{s1}$ is far away from $R_{s2}$), a large start-up pop may occurs when the BTL amplifier is enabled. Figure 26 shows the enable on pop waveforms using a single-ended audio source with 10KΩ input.
impedance mismatch. Different charge rate of NIN1 and NIN2 lead to abnormal PWM during the BTL amplifier starts on, thus a large pop is occurred.

![Figure 26: MP7748DF BTL application with 10KΩ mismatched SE input impedance waveforms](Image)

### 3.1.2 Solution For Enable Pop

As shown in Figure 24 and Figure 25, normally, the impedance of the two phases (HOT and COLD) in a differential audio source are equal, so 1% tolerance resistors can meet the impedance matching requirement for the two inputs. For a singled-ended audio source with a residual resistance $R_{source}$, the total resistance of $R_{source} \parallel R_s$ should be equal to $R_{s2}$.

In most of the applications, the $R_{source}$ is much lower than the $R_s$. In these situations, what we need is to short $R_{s2}$ with jumper or replace $R_{s2}$ with a 0Ω resistor.

MP7748DF BTL amplifier achieves no enable pop when the input impedance is well matched (Figure 27).

![Figure 27: MP7748DF BTL application with well-matched SE input impedance waveform](Image)

### 3.1.3 Root Cause and Solution For Disable Pop

1. **Causes**

   Disable pop is slight in MP7748DF BTL amplifier (the left side of Figure 28). The pop is not only related to the RC oscillation when the PWM shut down, but also related to the mismatch EN voltage falling threshold between the two amplifiers in MP7748DF. A slight pop occurs when SW2 last about 10uS switching after SW1 fully shut down (the right side of Figure 28).
2. Solution

As is discussed in SE amplifier part above, improve the slight pop caused by RC oscillation is not necessary. Discharging the EN voltage of BTL amplifier rapidly is recommended. With fast EN voltage falling rate, the mismatched shut down time will be decreased (Figure 29). This solution success in reducing the disable pop by push the pop frequency contents to higher sonic band.

3.2 POWER OFF POP

3.2.1 Cause Analysis

One slight pop can be heard with certain distance (like 50cm to speaker) during the BTL amplifier power off. The root cause for power off pop is the different UVP falling thresholds of two amplifiers. With the \( V_{DD} \) drops near to the preset value of UVP, one amplifier may already UVLO while the other amplifier still keeps switching, then the unwanted abnormal PWM generates the power off pop (Figure 30).
3.2.2 Suggestions for Minimize the Power off Pop

We can not eliminate power off pop completely because the internal UVP falling threshold of two amplifiers can not be matched precisely, but the right external UVP setting can help to minimize power off pop. Please refer to part 2.3 in this application note for the right UVP setting.

4. CONCLUSION

In this application note, we have explored in details the root causes of pops in new generation class D amplifiers of MPS. We can easily achieve pop-free level performance with new generation class D amplifiers of MPS by following the solutions given in this application note.

5. REFERENCES


Figure 30: MP7748DF BTL Application Power Off Pop Waveforms