Introduction

Pop and click, or rather, the absence of it, is a characteristic that makes a lot of impact in the world of audio amplifiers. This is especially true for those destined for headphone-equipped applications (such as mobile phones and MP3 players).

Pop and click are the names given to the popping noise that may be heard through the headphones when you switch on or off portable audio equipment or mobile phones. The noise is generated by a voltage difference at across the output stage of the amplifier at switch-on or switch-off before it reaches its idle (or equilibrium) state.

But what does “zero” pop and click really mean? In this article, we will look in detail at what causes pop and click and at the performance of a new STMicroelectronics audio amplifier, the TS4990.

What causes pop and click?

To better understand how pop and click is generated, it is useful to look at a typical audio amplifier application schematic, as shown in Figure 1.
In the audio amplifier schema shown in Figure 1, we can see that there are two capacitors external to the audio amplifier (STMicroelectronics’ TS4990 in this case): \( C_{in} \) and \( C_b \). It is these two capacitors, and the manner in which they are charged upon start-up of the amplifier, or discharged at turn-off, that determines the degree of pop and click heard.

These two capacitors charge (and discharge) at different rates—they have different time constants. This difference in time constant causes a temporary potential difference between the \( C_{in} \) line and the \( C_b \) line, and a resulting equalization that causes the loudspeaker membrane to vibrate, and a popping noise to be heard. However, note that depending upon the frequency of vibration, this pop & click may or may not be audible by the human ear.

What is important, firstly, to realize, is that with the application configuration shown above, there will always be a difference in potential between the \( C_{in} \) and the \( C_b \) lines; this because the speed at which capacitors charge or discharge is due to both their value (in Farads), as well as their application “surroundings”. But the amount of potential difference and whether it is translated into an audible noise is controllable by choosing the right amplifier, and the right values for \( C_{in} \) and \( C_b \).

In a typical audio amplifier schema, as shown in Figure 1, the \( C_{in} \) capacitor and the \( C_b \) capacitor serve different purposes:

- The \( C_{in} \) capacitor in series with \( R_{in} \) forms a high-pass filter which is used to filter out signals below a certain frequency, called the lower cut-off frequency. The value of a -3dB
lower cut-off frequency, $F_{cl}$, is found with the following relation:

$$F_{cl} = \frac{1}{2\pi \times R_{in} \times C_{in}} \quad \text{(Hz)}$$

In audio amplifiers for mobile phones, a typical lower cut-off frequency is 100Hz. For high fidelity audio amplifiers, the lower cut-off frequency is about 20Hz which corresponds to lower range of frequency audible by the human ear.

- The $C_b$ capacitor acts as a filter for the internal bias voltage of the audio amplifier. The audio amplifier will not work until the $C_b$ voltage reaches the threshold $0.5V_{cc}$.

In determining the values of $C_{in}$ and $C_b$, there is a compromise to be made between start-up time for the amplifier, the lower cut-off frequency and the PSRR of the amplifier. We will look at each of these factors in turn in order to optimize our application, using the TS4990 audio amplifier as an example.

At start-up, $C_b$ charges at a constant rate until the threshold voltage of $0.5V_{cc}$ is reached. At the same time, $C_{in}$ is also charging, but at an exponential rate because it is in series with the resistance $R_{in}$. The schematic in Figure 2 shows this relationship.

**Figure 2: Charging of capacitors $C_{in}$ and $C_b$ at start-up**

By looking at Figure 2, we can see that to minimize pop and click, $C_{in}$ must be charged to the threshold voltage ($0.5V_{cc}$) before $C_b$ reaches this voltage, and the amplifier becomes operational. If $C_{in}$ is at a lower voltage than the $0.5V_{cc}$ when the audio amplifier becomes operational (as shown by the dotted line in Figure 2) there will be a potential difference in the lines which will be transferred as energy across the loudspeaker, as pop and click.
Therefore, to minimize pop and click, the time constant of the $C_{in}$ line must be shorter than the start-up time for $C_b$, or:

$$\tau_{in} \ll t_b$$

where $\tau_{in}$ is the time constant of the $C_{in}$ line, and $t_b$ is the start-up time for $C_b$. $t_b$ depends on the value chosen for $C_b$. $\tau_{in}$ is derived from the following relation:

$$\tau_{in} = (R_{in} + 2k\Omega) \times C_{in} \ (s)$$

where $R_{in}$ must be $\geq 5k\Omega$ and $2k\Omega$ is the correction factor for the time constant.

As mentioned previously, the choice of $C_b$ is a compromise between start-up time for the amplifier, the lower cut-off frequency and the PSRR of the amplifier. The curves shown in Figure 3 give start-up times ($t_b$) relative to the value of $C_b$. However, $C_b$ also determines the PSRR performance of the audio amplifier, which must be taken into account for good overall performance.

**Figure 3: Start-up time versus bypass capacitance**
A final constraint is that to optimize the performance of the TS4990, \( \tau_{in} \) must not reach the \( \tau_{in} \) maximum value for a given \( C_b \) (see Figure 4).

**Figure 4: Maximum \( \tau_{in} \) for a given value of \( C_b \)**

![Figure 4: Maximum \( \tau_{in} \) for a given value of \( C_b \)](image)

By following the previous rules, the TS4990 can reach near zero pop and click even with high gains such as 20 dB.

**A performance calculation using the TS4990**

With the above relations, we can simulate the situation in a typical application scheme using some typical values given in Table 1.

**Table 1: Typical amplifier application scheme values**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{in} )</td>
<td>22k( \Omega )</td>
</tr>
<tr>
<td>( F_{cl} )</td>
<td>100Hz</td>
</tr>
<tr>
<td>Start-up time</td>
<td>100ms</td>
</tr>
<tr>
<td>( V_{cc} )</td>
<td>3.3V</td>
</tr>
</tbody>
</table>

We see that for a typical application scheme, with an \( R_{in} \) value of 22k\( \Omega \) and a 100Hz –3dB lower cut-off frequency, we arrive at:

\[
C_{in} = \frac{1}{2\pi \times 22k \Omega \times 100Hz} = 73nF
\]
Note, however, 73nF is a very small capacitance, equivalent to the minimum necessary capacitance to assure a lower cut-off frequency of 100Hz, which is the maximum lower cut-off frequency. The nearest normalized capacitance is 68nF, which results in a lower cut-off frequency equal to 107Hz.

This means that the time constant of the \( C_{\text{in}} \) line will be:

\[
\tau_{\text{in}} = (22k\Omega + 2k\Omega) \times 68nF = 1.6ms
\]

Recall the relation:

\[
\tau_{\text{in}} \ll t_b
\]

Let’s assume that we wish a start-up time for the \( C_b \) capacitor (\( t_b \)) that is roughly two orders of magnitude greater than \( \tau_{\text{in}} \), or about 100ms.

To achieve a 100ms start-up time, at 3.3V, we can see using the graphs in Figure 3, that we will require a normalized \( C_b \) value of about 1\( \mu \)F. This is a reasonable value for \( \tau_{\text{in}} \), as at lower than 1\( \mu \)F, THD+N increases at lower frequencies and the PSRR worsens. Similarly, if \( C_b \) is higher than 1\( \mu \)F, the benefit to THD+N at lower frequencies is small, but the benefit to PSRR is substantial.

Now using the graph shown in Figure 4, we can see that the maximum value of \( \tau_{\text{in}} \) at \( C_b=1\mu F \) is 30ms. Our actual value of \( \tau_{\text{in}}=1.6ms \) — well below the maximum value, and giving a result very close to zero pop and click.

The excellent results possible with the TS4990 can be seen by comparing the graphs in Figure 5, where (a) shows the “pop” peak in an older generation audio amplifier and (b) shows the pop peak in the TS4990.
Conclusion

In this article, we have explored what determines, and how to minimize, pop and click. We have seen that by using an audio amplifier such as the TS49990 that contains pop and click reduction circuitry, we can easily achieve the conditions necessary for minimum pop and click, whilst keeping a correctly filtered audio signal.