Pop & Click in Audio Amplifiers

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*.

Figure 1: Typical audio amplifier application using the TS4990 audio amplifier
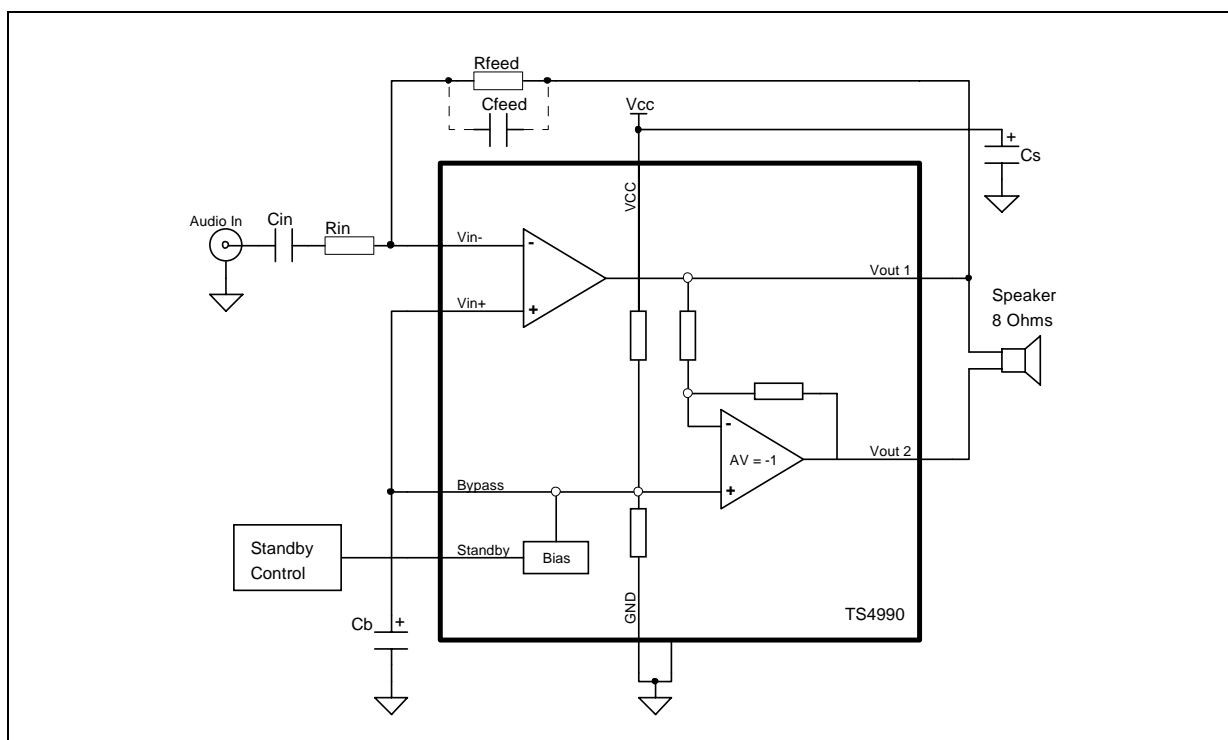
In the audio amplifier schema shown in *Figure 1*, we can see that there are two capacitors external to the audio amplifier (STMicroelectronics' TS4990 in this case): C_{in} and C_b. It is these two capacitors, and the manner in which they are charged upon start-up of the amplifier, or discharged at 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:

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

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 0.5Vcc 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
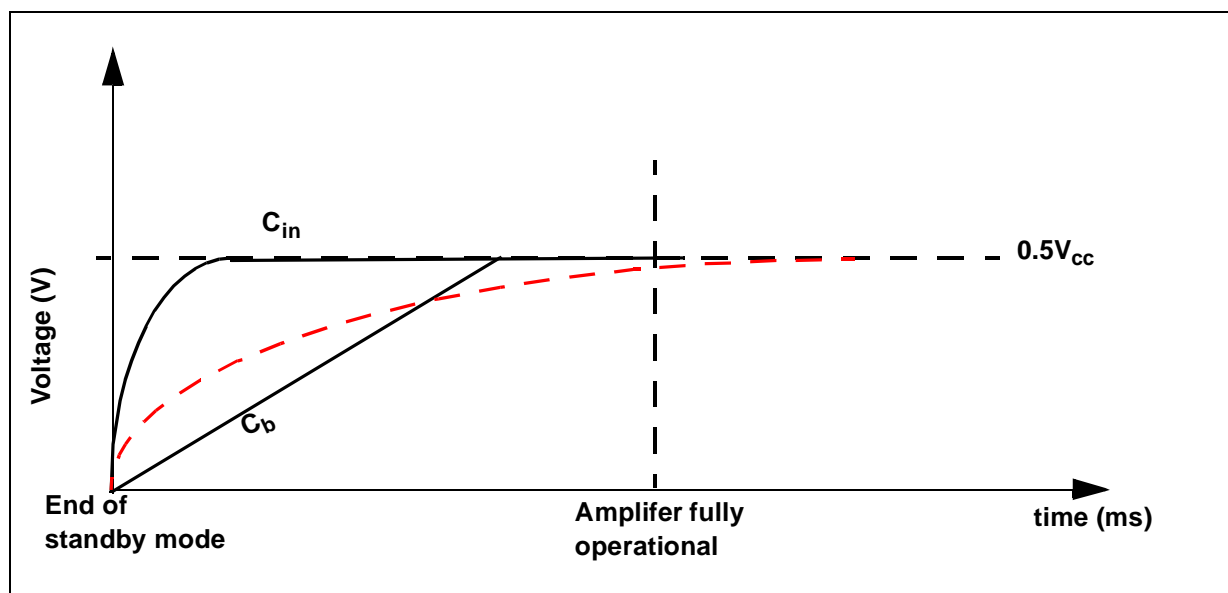
By looking at *Figure 2*, we can see that to minimize pop and click, C_{in} must be charged to the threshold voltage ($0.5V_{cc}$) before C_b reaches this voltage, and the amplifier becomes operational. If C_{in} is at a lower voltage than the $0.5V_{cc}$ when the audio amplifier becomes operational (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 τ_{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. τ_{in} is derived from the following relation:

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

where R_{in} must be $\geq$ 5kΩ and 2kΩ 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
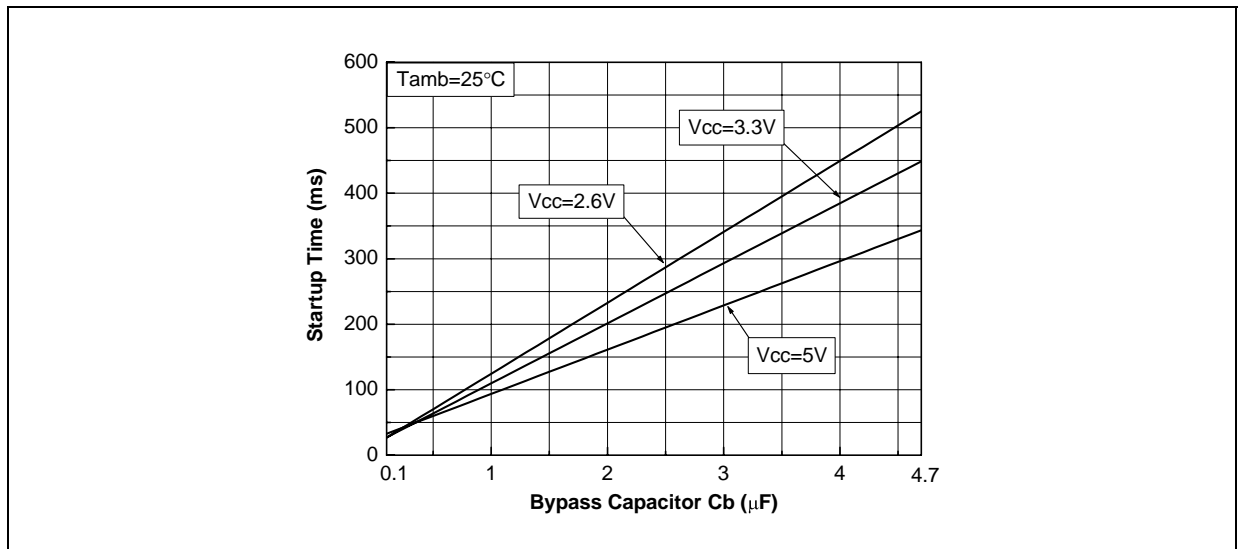
A final constraint is that to optimize the performance of the TS4990, τ_{in} must not reach the τ_{in} maximum value for a given C_b (see *Figure 4*).

Figure 4: Maximum τ_{in} for a given value of C_b
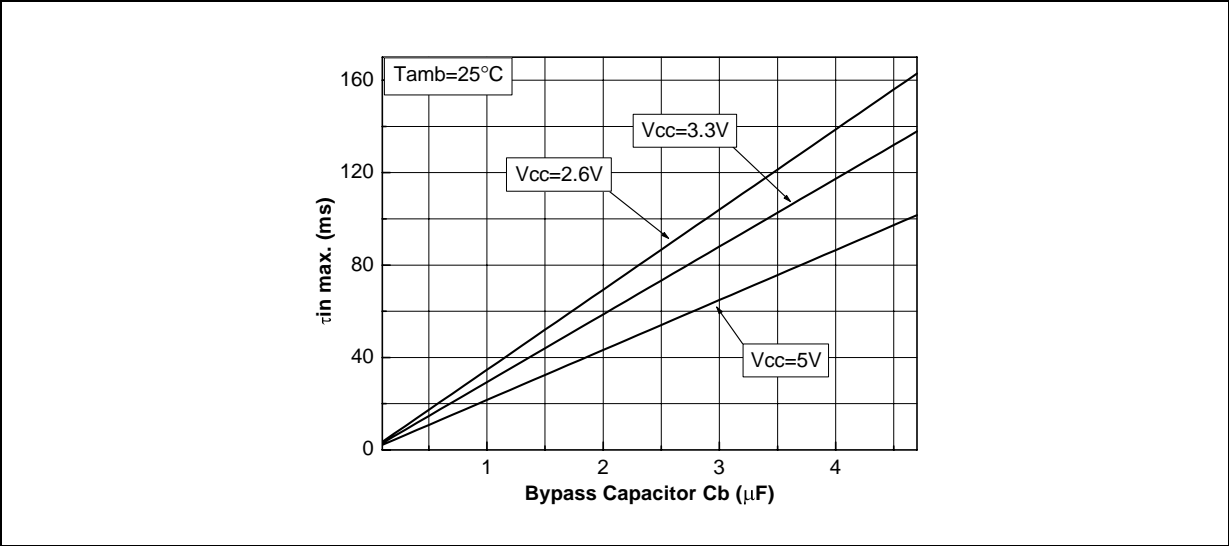
By following the previous rules, the TS4990 can reach near zero pop and click even with high gains such as 20 dB.

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

Parameter	Typical Values
R_{in}	22kΩ
F_{cl}	100Hz
Start-up time	100ms
V_{cc}	3.3V

We see that for a typical application scheme, with an R_{in} value of 22kΩ 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_{in} line will be:

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

Recall the relation:

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

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 τ_{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 1µF. This is a reasonable value for τ_{in}, as at lower than 1µF, THD+N increases at lower frequencies and the PSRR worsens. Similarly, if C_b is higher than 1µF, 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 τ_{in} at C_b=1µF is 30ms. Our actual value of τ_{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.

Figure 5: (a) Peak measures pop in older generation audio amplifier; (b) shows measure of pop in TS4990
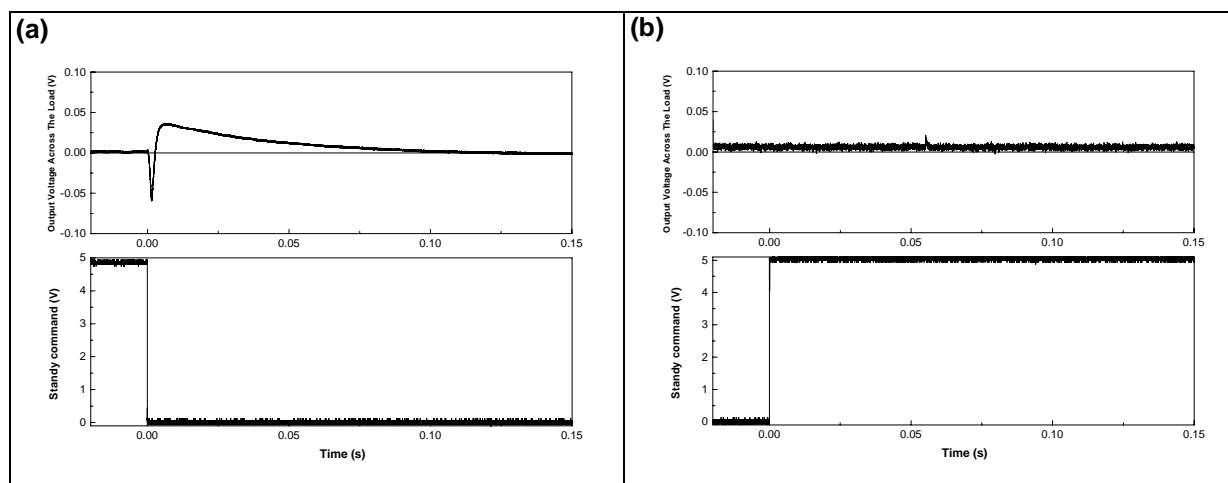
Conclusion

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.