Apex Inkjet Printhead Driver Power Dissipation

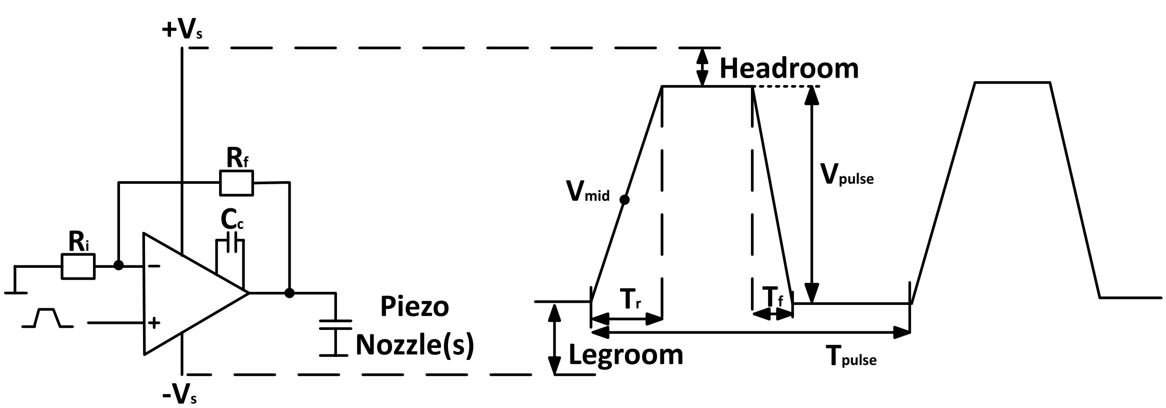
INTRODUCTION

Printing industries are rapidly converting from conventional techniques, like offset lithography and rotogravure, to digital technology like inkjet. The printheads of many industrial inkjet printers use piezoelectric technology. In the printheads of so called 'drop-on-demand' (DoD) inkjet printers the piezoelectric nozzles produce ink drops when driven by electric pulses. Since the nozzles behave like electric capacitors and the amount of nozzles in a printhead being fired varies continuously, the amplifier driving the printhead 'sees' a very dynamic, capacitive load. Apex Microtechnology's power operational amplifiers are very well suited to drive DoD inkjet printheads as they meet the power requirements of and can be tuned to this specific application by external components. This application note describes a way to derive the internal power dissipation of an Apex power op amp driving a DoD inkjet printhead.

THE AMPLIFIER AND THE FIRE PULSE

DoD piezoelectric printheads usually contain a large, even number of nozzles, often a power of 2, that can be in a single or in multiple rows. The head also contains digital circuitry through which each individual nozzle can be set to eject a drop at the next fire pulse or to stay inactive. The active nozzles are all in parallel when the driver amplifier produces a fire pulse to make them all eject drops simultaneously. Single nozzle capacitance, depending on manufacturer, can vary wildly, but usually is in the range of 150pF to 2nF.
A typical amplifier circuit and fire pulse would look like figure 1.

Figure 1: Typical Amplifier Circuit and Fire Pulse



HEADROOM AND LEGROOM

Since power operational amplifiers exhibit a voltage drop across the conducting output transistor, which depends on the output current, they cannot swing rail to rail. In order to achieve a certain output voltage swing, the amplifier needs to be powered off of rails providing enough headroom at the topside and legroom at the bottom side. The supply rails of the power operational amplifier should be chosen such as to accommodate the largest fire pulses.

SLEW RATE

Slew Rate is the rate of change of the output voltage of the amplifier per unit of time. In figure 1:

$$SR = \frac{V_{pulse}}{T_r (or T_f)}$$

with V_{pulse} being the amplitude of the fire pulse and T_r and T_f being the times it takes the amplifier to produce the rising and falling edges of the fire pulse respectively. For the purpose of this application note it is assumed T_r=T_f, but this can be different in practice.

$V_{DRIVE,MIN}$ AND $V_{DRIVE,MAX}$

$V_{drive,min}$ and $V_{drive,max}$ are the voltage extremes of the fire pulse, with $V_{drive,min}$ being the bottom and $V_{drive,max}$ being the top value. For the purpose of this application note it is assumed that subsequent pulses have the same amplitude, but in practice, when grey scale printing is being achieved through a technique called multi-pulsing the printhead, individual pulses within pulse trains can have different amplitudes, thus manipulating the drop size.

V_{MID}

V_{mid} is the voltage of the fire pulse, halfway between its minimum and maximum drive voltages. See remark about multi-pulsing under $V_{drive,min}$ and $V_{drive,max}$. If subsequent pulses have different amplitudes, their midpoints are different, too.

T_{PULSE}

T_{pulse} is the fire pulse's period.

$$\frac{1}{T_{pulse}} = f_{pulse}[Hz]$$

CALCULATION OF INTERNAL POWER DISSIPATION

Total power dissipation in the power operational amplifier consists of two components: 1) Quiescent Power Dissipation and 2) Output (Stage) Power Dissipation.

1. Quiescent power dissipation is caused by the quiescent current draw of the power op amp. This current is used internally to bias the various stages of the amplifier. It also flows when the amplifier is idling. The quiescent power dissipation can be calculated as:

$$P_Q = I_Q \cdot V_{SS}$$

with I_Q being the quiescent current and V_{SS} the total voltage across the amplifier or $+V_S$-$-V_S$. This means that even if the amplifier is doing nothing, it may already need to be cooled down by mounting it on a heatsink!

2. Output (stage) power dissipation is caused by the conducting output stage transistor, dropping a certain voltage from the supply rail to produce the required output voltage, and the output current that flows through this transistor.
   The output current is:

$$I_o = C \cdot \frac{dV}{dt}[A]$$

The voltage across the conducting output stage transistor varies during the rising and falling edges of the fire pulse signal. Since the current is (assumed to be) constant, it can be assumed constant as well at the midpoint between the voltage extremes of the pulse.

The AVERAGE output stage power dissipation during the rising edge of the fire pulse is:

$$P_{OUT,r} = (V_S - V_{MID}) \cdot I_o[A]$$

and during the falling edge is:

$$P_{OUT,f} = (V_{MID} - -V_S) \cdot I_o[W]$$

There is only power dissipation during the falling and rising edges of the fire pulse, when the drive voltage is constant there is no output current and hence no power dissipation. This is a simplification; in reality output current can (and will!) swing, yielding power dissipation. Because this power dissipation should be (kept) small in comparison to the power dissipation during the falling and rising edges of the fire pulse, and for the purpose of this being an explanatory application note only, it is assumed there is only power dissipation when the capacitive load is (dis)charged, so during the rising and falling edges of the fire pulse.

Total average power dissipation over time is:

$$P_{OUT,tot} = \frac{T_f \cdot P_{OUT,f} + T_r \cdot P_{OUT,r}}{T}$$

with T_f being the duration of the falling edge, T_r the duration of the rising edge, and T being the pulse period time.

This can be rewritten as:

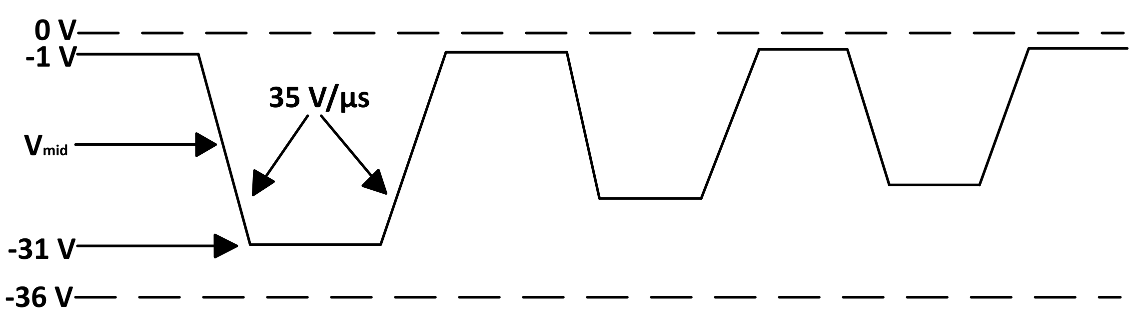
$$P_{D,tot} = (T_f \cdot P_{OUT,f} + T_r \cdot P_{OUT,r}) \cdot f_{pulse}$$

with f_{pulse} being the fire pulse frequency.

EXAMPLE

Figure 2 shows a typical fire pulse for a certain type of printhead. Note that the fire pulses are reversed with respect to ground; rather than having positive amplitude, the depicted fire pulse is negative.

Figure 2: Typical Fire Pulse



ASSUMPTIONS

- The printhead to be driven has 2048 nozzles, each with an equivalent electrical capacitance of 200pF, so the entire head has a typical capacitance of 2048*200pF=410nF.
- All nozzles are continuously being fired (which in practice is hardly ever the case, maybe only when varnishing…)
- The maximum slew rate to be applied is 35V/us.
- The maximum pulse amplitude to be presented to the print head is -31V.
- The main positive supply voltage is 0V, and the main negative supply is -36V (because 36V power supplies are rather easy to get, and -36V provides a nice legroom for the -31V pulses).
- The maximum pulse base line value is -1V.
- Many Apex power op amps feature a boost function that allows the output to swing closer to the supply rails. Using such a device the positive output stage supply voltage pin(s) can be connected to ground, so a high-power positive supply isn't needed. Only a low-power supply is needed to raise the voltage on the auxiliary positive supply (+Vb) pin 5~15V above the positive output stage supply to bias input and intermediate stages in such a way that the output stage can be driven further towards the rails. Without this, the positive supply of the output stage would have needed headroom like 6 to 8V, but by supplying +Vb with a voltage like +12V, the top output transistor can be driven closer to the supply rail (in this case at ground). If the amplifier's output needs to be driven all the way to 0V, a (high-power) positive supply *IS* needed for +Vs.
- For the purpose of this example, +Vb is 12V, -Vb=-Vs as -36V already provides enough legroom.
- The printhead is being driven with equal -1 to -31V pulses, so the midpoint of these is -16V.
- The pulse repetition rate is 200 kHz.
- The Apex amplifier of choice is MP111, which features a total supply voltage of 100V max, output current of 15A continuous and 40Apeak, 170W of internal power dissipation capability, 130V/us slew rate, 500 kHz power bandwidth and a quiescent current draw of 157mA max.

The output current is:

$$I_o = C \cdot \frac{dV}{dt} = 410 \cdot 10^{-9} \cdot \frac{35}{10^{-6}} = 14.35A$$

The AVERAGE output stage power dissipation during the falling edge of the fire pulse is:

$$P_{OUT,f} = (V_{MID} - -V_S) \cdot I_o = (-16 - -36) \cdot 14.35 = 287W$$

The AVERAGE output stage power dissipation during the rising edge of the fire pulse is:

$$P_{OUT,r} = (V_S - V_{MID}) \cdot I_o = (0 - -16) \cdot 15.35 = 229.6W$$

Total output stage power dissipation becomes:

$$P_{OUT,tot} = (T_f \cdot P_{OUT,f} + T_r \cdot P_{OUT,r}) \cdot f_{pulse} = (0.857 \cdot 10^{-6} \cdot 287 + 0.857 \cdot 10^{-6} \cdot 229.6) \cdot 200 \cdot 10^3 = 88.55W$$

Unlike explained earlier, because of the use of the V_{boost} option in this example, quiescent power dissipation is:

$$P_Q = I_Q \cdot V_{BB}$$

with V_{BB} being the total voltage supplied across the $+V_B$ and $-V_B$ pins, or $V_{BB}=+V_B - -V_B$.

Quiescent power dissipation becomes:

$$P_Q = I_Q \cdot V_{BB} = 0.157 \cdot 48 = 7.54W$$

Total internal power dissipation becomes:

$$P_{D,tot} = P_Q + P_{OUT,tot} = 88.55 + 7.54 = 96.1W$$

This amplifier needs serious cooling!

CONCLUSION

This application note provides a fairly simple way of assessing an Apex power operational amplifier's internal power dissipation when driving piezo-technology DoD inkjet printheads. It should be noted that the method provides a slightly inflated number, as in reality printheads are hardly ever driven with all nozzles ejecting ink with every fire pulse. Also, in (grey-scale) multi-pulse situations subsequent pulses usually do not have equal amplitude, and only in 20% of the pulse trains 3 pulses are evoked, in 80% of pulse trains less than 3 are evoked.

In other words: the heatsink selection (see Application Note #11, *"Thermal Techniques"*) based on the power dissipation as calculated above will be a bit over-rated, which is good for a lower operating temperature and higher reliability.