Power Amplifier Drives Multiple Inkjet Heads

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Suitable for piezoelectric transducers, high-current linear power amplifiers are playing an ever-expanding role in the development of new inkjet printer applications.

The desktop inkjet printer is an engineering marvel. Able to place millions of tiny ink droplets precisely on a page, it creates a page of crisp type and vivid images rivaling silver-halide photography, which has been solidly entrenched for more than a century. Not so well known is the role inkjet printing is beginning to play in other applications—food, beverage and medical packaging as well as large format applications such as billboards and banners. It is here that power operational amplifiers, such as the Apex Microtechnology MP111FD, are fulfilling a crucial role in the design of inkjet printers (Fig. 1).

The piezoelectric technique of inkjet printing employs a crystal that flexes whenever a voltage pulse is applied to the piezo transducer, thereby forcing a droplet of ink out of the nozzle. Fig. 2 illustrates this sequence.

Each time a voltage pulse is applied to the piezoelectric material, it deforms, forcing a tiny droplet 50 to 60 microns in diameter onto the surface to be printed. When the voltage returns to zero, the material is restored to its original shape, drawing ink into the reservoir and thus preparing it for the application of the next drop. This cycle

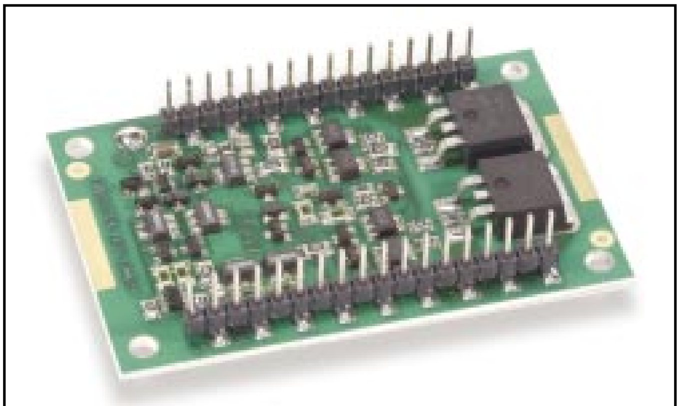

Fig. 1. *The Apex MP111FD operational power amplifier delivers 50-A pulses and the high slew rates required to track the waveforms that drive transducers in inkjet printers.*

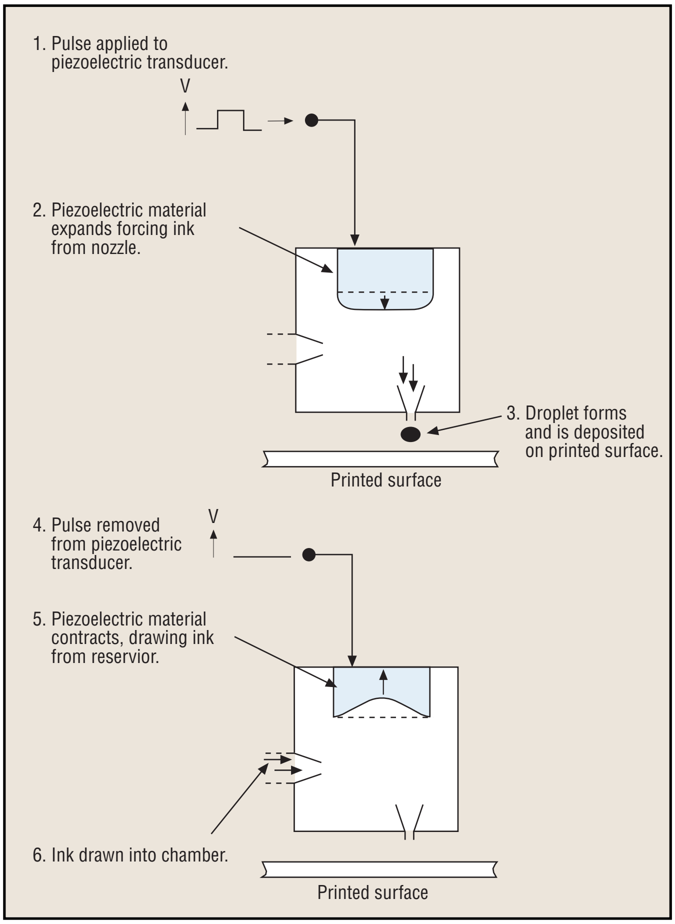

Fig. 2. *The basics of piezoelectric inkjet printing. There are no valves in the piezoelectric transducers. Instead, the natural surface tension of the entry and exit orifices behaves as a valve and is overcome by the pressure developed each time the piezo transducer expands and contracts.*

repeats many times per second, each time the print head makes a pass across the page.

Multiplexing the Nozzles

A representative printing head configuration might employ a single power amplifier to drive 128 nozzles. A variation of time-division multiplexing is employed. We say variation because it departs somewhat from the conventional system of time-division multiplexing, which normally connects to just one node at a time. In this case, the power amplifier may be connected to any number of ports at any one instant—from 0 to 128.

Depicted in Fig. 3 are 128 MOSFET switches that connect the piezoelectric jet nozzles in the printhead to the power amplifier. Consequently, at any instant, the voltage on each piezo driver is either 0 V or 48 V, depending on whether that nozzle is on or off. As shown in the figure, each nozzle is turned on by grounding the piezoelectric transducer via the MOSFET switch element corresponding to the nozzle it drives. However, the high-voltage piezo driver remains connected at all times to all of the high sides of the 128 nozzles via a bus.

The MOSFET switches control the entire ensemble digitally. The switches allow the negative return of each piezo transducer to either float—in which case the companion nozzle does not dispense a droplet of ink—or to be grounded, so as to dispense a droplet of ink. At any instant, the printhead carrying all 128 nozzles is emitting anywhere from 0 to 128 ink droplets as governed by the program instructions delivered to the bank of MOSFET switches. Perhaps numbers 12, 84 and 128 nozzles are selected, at any instant. If so, they are all driven at that moment by the piezo transducer.

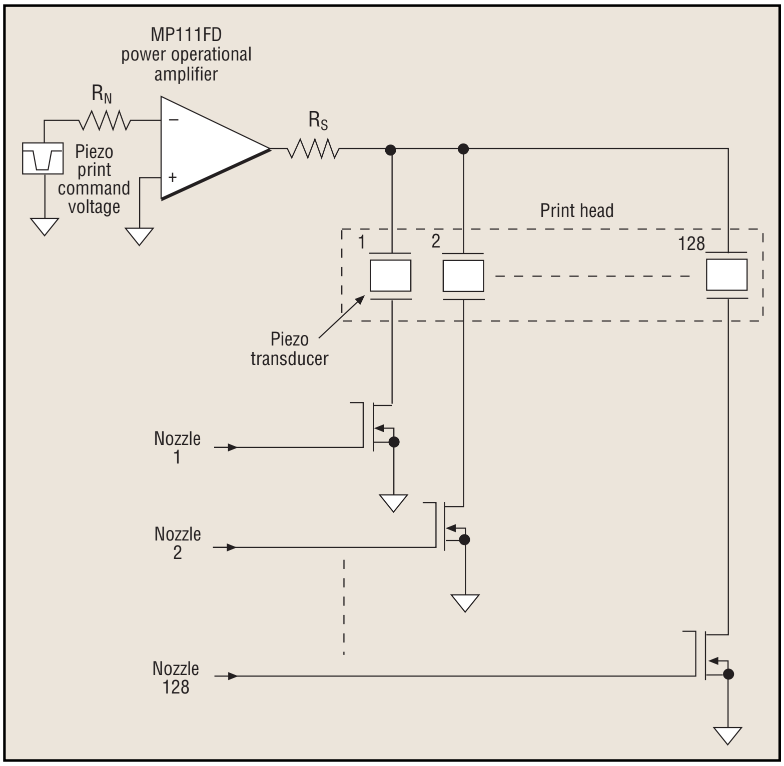

Fig. 3. *Simplified diagram using MOSFETs to multiplex the piezo transducers. The transducers form the printhead, which is fabricated from a single piece of ceramic endowed with piezoelectric characteristics.*

Different Waveforms for Different Inks

Various waveforms have been devised for printing various kinds of inks. These waveshapes are developed empirically and are then stored in a computer so that the optimal waveshape for each ink and its specific application can be retrieved at a later time.

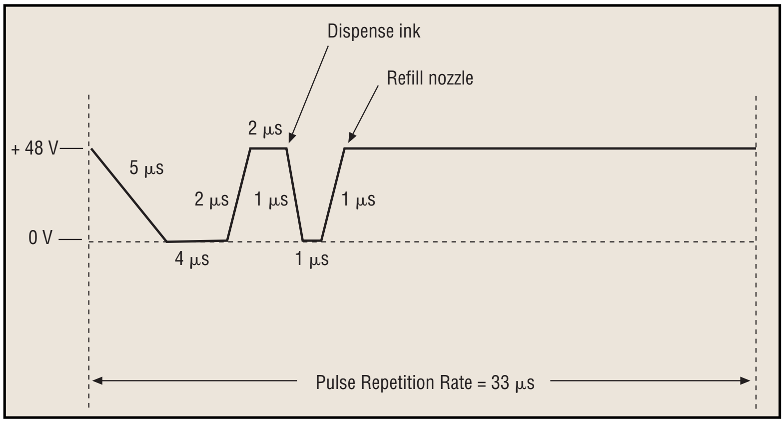

Fig. 4. *This waveform was devised to optimize performance for a specific printhead.*

The simplest is a trapezoidal waveform, which has a controlled ramp on the up slope and a ramp with a slightly different slope on the down side. These slopes are well controlled but not necessarily symmetric. The rise on the up slope is likely to be faster, whereas on the down slope a longer fall time is necessary. This ensures sufficient ink will flow from the ink magazine to the nozzle chamber to supply ink for the next droplet to be dispensed. A representative waveform is shown in Fig. 4.

Common to all designs is a waveform that must be devised that is tailored to the specific characteristics of the ink to be dispensed. Principal governing factors are the viscosity of the ink, and the shape and size of the droplet to be delivered to the printing surface and the mechanism of the printhead itself.

For some inks, it maybe necessary to double-pulse the piezo transducer to overcome oscillations that might hinder satisfactory ink delivery. Depending on the ink employed, such double-pulsing can counteract oscillations that would otherwise occur when the droplet leaves the jet.

The power amplifier must be designed to deal with any arbitrary waveshape that may be required for a given printing solution. In other words, there is no single circuit that will fulfill all piezoelectric ink-driver design objectives. That is why an understanding of all the design issues is essential to developing driver circuits.

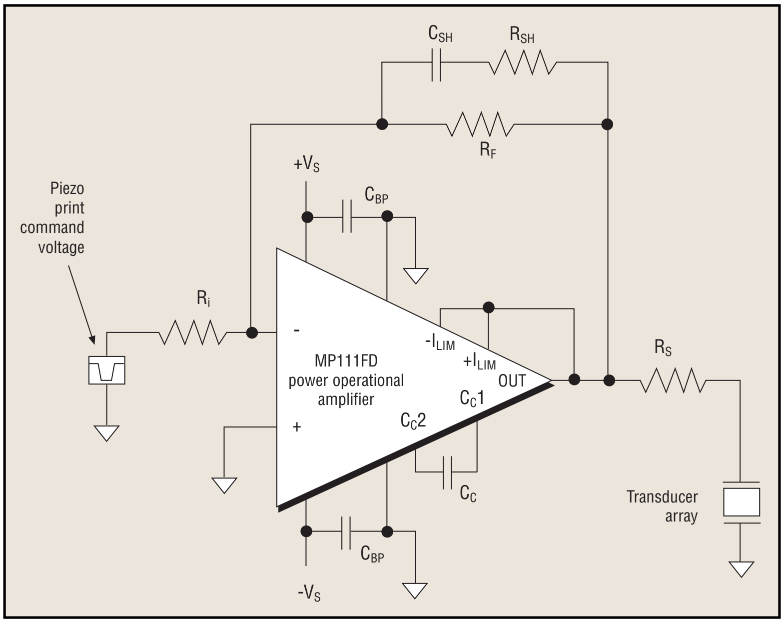

Fig. 5. *Simplified diagram of the MP111FD power amplifier and companion passive components.*

Determining Design Parameters

Because piezo elements are almost purely capacitive and therefore dissipate virtually no power, disposing of the heat is of paramount importance. Almost all the buildup of power is dissipated in the power amplifier module. This must be safely transferred as heat from the amplifier module, via thermally efficient heatsinking, in such a way that the operating temperatures within the power amplifier remain safely below its rated safe operating temperature.

The Apex MP111FD power operational amplifier is particularly suited for driving piezoelectric transducer arrays. It is a 100-V device with a 500-kHz power bandwidth and a 50-A pulse capability. Fig. 5 shows a simplified drawing of the MP111FD power operational amplifier in an inkjet transducer application with the companion passive components identified.

Next, we examine the essential steps in designing the piezo transducer circuit. The first step is choosing power supply voltages. An unbalanced source voltage would be best. Assuming a 50-V pulse is to be delivered by the power amplifier, then a +62-V and a –12-V source would be appropriate. This will assist the charge-discharge cycle because the capacitive load presented by the array of tranducers must be driven back to 0 V during each pulse cycle.

As the capacitor approaches 0 V, the –12-V potential will ensure that the output transistor of the power amplifier will still have sufficient potential to drive the capacitor back to 0 V. This minimizes the power dissipation in the amplifier and also contributes to signal fidelity.

The next step is selecting passive component values. Assuming a gain of 10, the value of R_I would be 100 Ω, R_F is 1 kΩ and capacitor C_C is 33 pF to 47 pF.

Once those values are selected, the designer must address stability issues. Because the load is highly capacitive, a resistance R_S may need to be placed in series with C1 to improve the stability of the amplifier circuit. You will have to experiment, but typical values for R_S will range from 0.1 Ω to 0.5 Ω, depending on the capacitance of the printhead. Without $R_{S,}$ there may be considerable overshoot in the output waveform, which could affect the droplet shape and the overall performance of the system.

The next task is bypassing the power supply terminals. Because the slew rate of the power amplifier is quite high, there is a tendency for the power supply to droop if no precautions are taken. It is recommended that two 1-µF ceramic capacitors of the leadless surface-mount type, C_{BP}, be connected directly to the $+V_S$ and $–V_S$ pins of the power amplifier.

After bypass caps are added, it is necessary to enhance dynamic response. To do so, connect a series network comprising a 10-pF capacitor C_{SH} and a 1-kΩ resistor R_{SH} in shunt with resistor R_F, as shown in Fig. 5. This will improve the dynamic response of the power amplifier. Adjust these values slightly to optimize the response.

Another step is minimizing distortion. As the amplifier slews, it forces energy back into the signal source. To minimize distortion that might otherwise occur, it is essential the signal source exhibit a low dynamic impedance of 1 W or less.

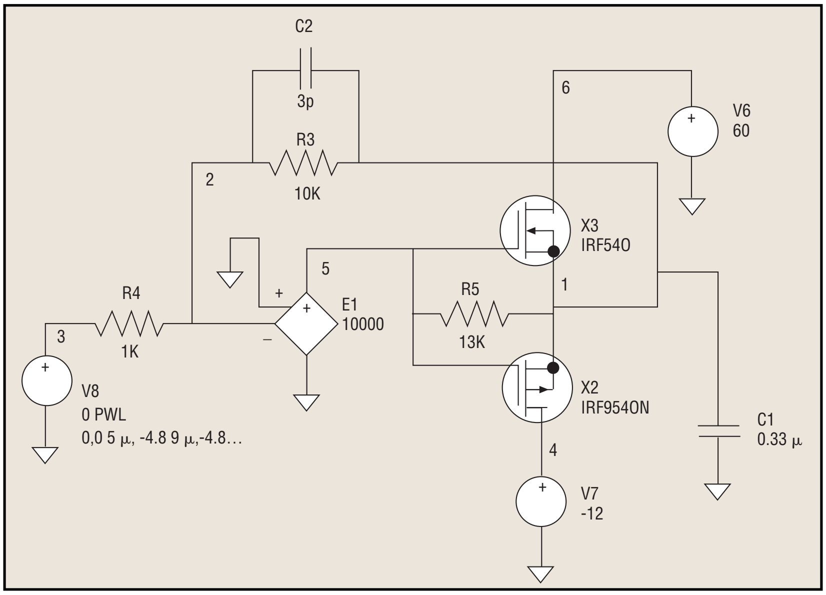

Fig. 6. *Spice representation of the transducer drive circuit. Note that capacitor C1 represents the printhead transducer.*

Selecting a Heatsink

It is essential to hold the junction temperatures within the power amplifier module below 175°C. Determining the proper heatsink is a three-step procedure. First, the average power consumption is determined. Then, the thermal resistivity in °C per watt of the heatsink is calculated. Finally, the thermal resistivity of the heatsink selected is checked to ensure it provides sufficient margin. That is, it will hold the junction temperatures to a value well below 175°C.

● *Determining power dissipation*. Once the waveform for a particular ink is determined, a simplified circuit can be devised to perform a SPICE simulation and thereby determine the power that will be dissipated within the amplifier. Fig. 6 shows a simplified SPICE circuit that represents the MP111FD power operational amplifier circuit. In this example, the amplifier is assumed to be driving four inkjet printheads simultaneously.

Each printhead will be assumed to have 256 nozzles for a total of 1024 nozzles. The total capacitance of the four heads is 1 µF. However, only every third nozzle is driven at any instant. Therefore, the maximum capacitance in this analysis is reduced to 0.33 µF. This is the load capacitance identified as C1 in Fig. 6.

A piece-wise linear waveform is developed by V8 that duplicates the selected waveform, as illustrated in Fig. 4. The results of the SPICE simulation are depicted by the three graphs in Fig. 7.

Plot 1 depicts the amplified output voltage waveform V(1). Plot 2 is the current pulse train I(C1) applied to the load capacitor C1, whereas Plot 3 shows the average power dissipated in the amplifier versus time:

$$\text{Average Power} = \text{AVG}\ \{[(V1)-V(6)]*[I(V6)]+[(V(1)-V(4)]*[I(V7)]\} \quad \text{(Eq. 1)}$$

Plot 3, as governed by this equation, is the average of the voltage across each output transistor multiplied by the current through each transistor at each instant in time. The result at the end of the period is the average power that the heatsink must dissipate due to the load. It is this average power, 68 W, which is of interest in determining the heatsink requirement.

Because the pulse rate frequency is 30 kHz, its period is 33.33 µs. Notice that in Plot 2 the current pulses end after 16 µs. The remainder of the period is dead time. Therefore, the time interval for the average is greater than the time over which instantaneous energy is being delivered. Therefore, 68 W is the average power that must be dissipated by the amplifier over the full period.

● *Determining heatsink requirements.* By referring to the data sheet for the MP111FD, the ac thermal resistance is determined to be 0.65°C/W. To calculate the temperature rise of the junctions of the output transistors above the case temperature, multiply the thermal resistance of the MP111FD by the average power dissipated:

$$0.65°C/W * 68\ W = 44.2°C \quad \text{(Eq. 2)}$$

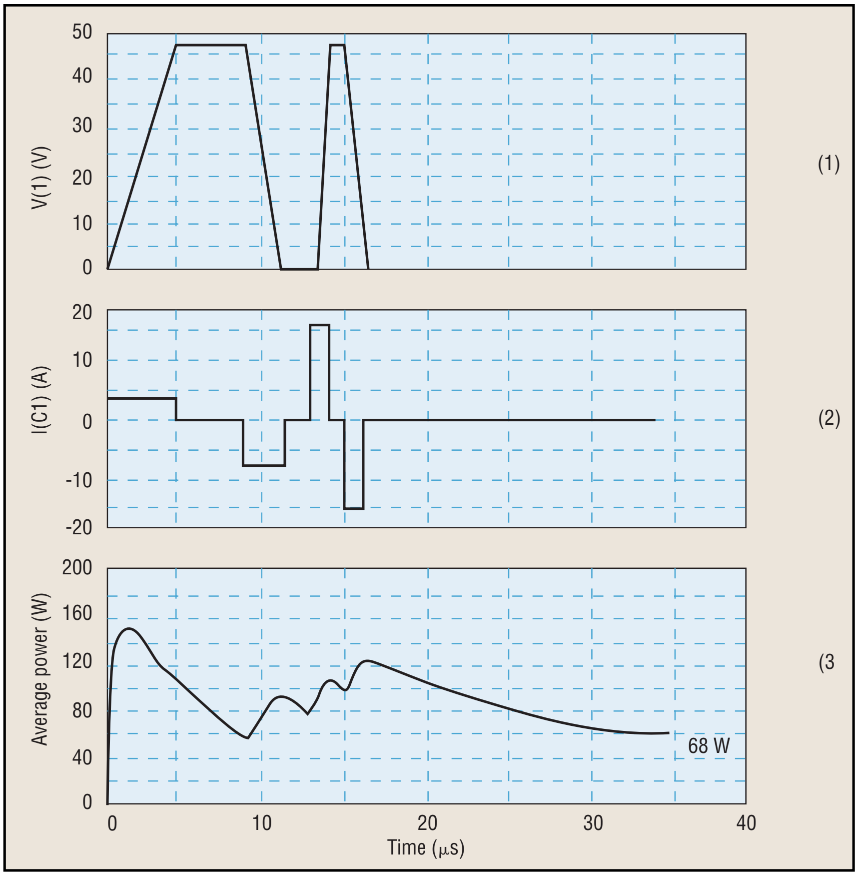

Fig. 7. *SPICE: (1) amplified output voltage V(1); (2) current pulses I(C1) applied to capacitor C1; (3) average power dissipated in the amplifier versus time.*

To determine the permissible case temperature, assume that a normal ambient temperature within the printer will be 30°C. The maximum operating case temperature of the MP111FD is 85°C. Thus, subtract the ambient from the maximum operating temperature to determine the permissible case temperature rise:

$$85°C - 30°C = 55°C \qquad \text{(Eq. 3)}$$

Therefore, the permissible case temperature rise is 55°C.

Although the load, C1, dissipates 68 W of power in the amplifier, the heatsink will have to dissipate the quiescent power dissipation of the amplifier as well as the power delivered by the pulse train.

The quiescent power dissipation of the MP111FD with the operating conditions given is approximately 11 W. This quiescent power is due to the operating power supply voltages and the quiescent current in the amplifier. Therefore, the actual amount of power that must be dissipated is the sum of the two, or 79 W. The thermal resistance of the heatsink required is governed by this equation:

$$(X°C/W) * (79\ W) = 55°C \qquad \text{(Eq. 4)}$$

Where X is the required heatsink thermal resistance in °C/W; 79 is the total amplifier dissipation in watts; and 55 is the permitted temperature rise of the amplifier in °C.

Solving equation 4 for X yields a thermal resistance of 0.696°C/W. Thus, any heatsink having a thermal resistance of 0.696°C/W or less will be acceptable in this application.

- *Confirming the maximum junction temperature.* Although a maximum junction temperature of 175°C is allowed, for long-term reliability, a lower temperature would be better. Check that a heatsink with a thermal resistance of 0.696°C/W will hold the junction temperature of the output transistors below 175°C.

As previously mentioned, the 68 W of power dissipation due to the load causes a temperature rise of 44.2°C in the output transistors. The total junction temperature with the selected heatsink is then the sum of the maximum case temperature and the temperature rise in the output transistors:

$$85°C + 44.2°C = 129.2°C \qquad \text{(Eq. 5)}$$

Where 85°C is the case temperature with the selected heat sink and 44.2°C is the temperature rise of the output transistors due to the load. Because a junction temperature of 175°C is the maximum allowed, there will be a margin of 45.8°C—acceptable for the heatsink in this application.

If the power module is to be located near the printhead and the ink is heated, the operating ambient will be well above room temperature of the traditional 25°C. In this case, liquid cooling or forced air may be required.

Note that for illustration purposes, the quiescent current in the output stage and some other fine details have been neglected. However, Apex has an online power design spreadsheet that can easily help you with all the details of arriving at a heatsink thermal resistance for your particular application. Log on to www.apexmicrotech.com and look for "Circuit Design Software" under the "Support" icon.

As we have shown, devising a drive circuit for inkjet circuits requires tailoring a waveform that will optimize the delivery of the ink droplets delivered by a particular printhead. Then, by following the sequence of steps described, the designer will be able to configure a driver circuit that will provide the necessary current pulse train and preserve the fidelity of the waveform delivered to the printhead, while addressing the resulting thermal issues.

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Reference

Power Operational Amplifier MP111FD Data Sheet, www.apexmicrotech.com.