High Quality, High Speed, Next-Generation Inkjet Technology with Scalability from Serial Printheads to Lineheads

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Abstract

Digital printing technologies are demonstrating strong growth due to their on-demand capability, which enables short run, varied-lot printing with rapid turnaround. Key growth segments in which piezo inkjet technology is recently increasing its presence are commercial, industrial and business printing, which demand professional quality and high productivity. Piezo inkjet technology uses mechanical energy rather than heat for ejection, enabling various types of ink to be used – from non-aqueous UV inks to water-based pigment inks.

Thus far, we have developed MACH printheads with 120-180 npi/row nozzle resolution by enhancing the process of precision machining bulk piezo and ink channel components [1-5]. Using a different approach, we dramatically raised the nozzle resolution with TFP (Thin Film Piezo) technology in 2007 [6]. TFP's high displacement piezo, with a thickness of around 1 μm, made it possible to increase the nozzle resolution up to 360 npi/row. We have since utilized TFP as our flagship technology in large format printers.

Now, with a next-generation actuator chip, we have succeeded in broadening the application of TFP technology into a wider range of printing segments, from desktop serial printers to industrial linehead presses. In this paper, we explain this next-generation inkjet technology, which achieves high output quality, high speed printing and improved scalability through the miniaturization of the core chip.

Introduction

Inkjet technologies are expanding their presence in the digital printing field. Unlike analog printing, digital is an on-demand technology which does not require the preparation of physical master copies for the printing process. This simplifies and shortens the printing process, and makes inkjet suited to low-volume, high-variety jobs. The same inkjet technologies that brought photo quality printing to the home are expanding into the commercial, industrial, and business printing markets, which demand even higher image quality and productivity. As piezo inkjet technologies use a mechanical ejection mechanism rather than heat to fire ink, they can handle many kinds of inks and media, ranging from resin-rich water-based inks for photographs, documents and garments, to UV curing ink for labels, and functional material inks for flat panel displays. This means piezo inkjet is a highly flexible technology suitable for industrial, business, and home printing applications.

Previously, we developed the MACH series printheads which, with a nozzle density of 120-180 npi/row, brought quality photo printing to the home. MACH heads use an electrical signal to actively control the movement of a piezo element and this enables firing of a variety of ink drop sizes, thereby achieving both high quality and high speed printing [1-5].

Then, in 2007, we achieved even higher quality printing with the development of the high-displacement TFP (Thin Film Piezo) technology. Employed in our flagship large format printers, TFP printheads achieved a nozzle resolution of 360 npi/row [6].

In the last few years, we have also leveraged the ability of the piezo mechanism to fire non-aqueous solvent inks and its superior durability to develop industrial printers that use resin and sublimation inks to print on a range of media including films and fabrics.

And now, with the aim of opening up new markets and bringing our state-of-the-art printhead technology to a wider range of customers, we have accelerated the evolution of our TFP technology and named it "PrecisionCore." PrecisonCore includes all printheads using TFP. We refer to the conventional type as the "TFP print chip" and the new type as the "MicroTFP print chip." In addition to boasting high print quality and speed, the key elements of the new MicroTFP print chip developed for PrecisionCore have been reduced in size, allowing the print chip to be used in applications ranging from serial printheads for desktop printers to lineheads for industrial presses. In this article we will explain about the technology used to achieve the image quality, print speed, and small size of the MicroTFP print chip.

Head Scalability, Chip Performance & Structure

The compact and highly scalable MicroTFP print chip enables high quality, high speed printing in all types of printers. First, we will explain about PrecisionCore's scalability and platform structure.

Platform Chips for Serial and Line Configurations

The modular design of the MicroTFP print chip means it can be freely deployed in a wide range of head configurations in everything from high speed serial heads to lineheads (Figure 1).

The length of the nozzle row in the MicroTFP print chip is 1.33 inches, which in a serial printer reduces the number of passes required thereby making them faster. In addition, the width of the chip was shrunk to 6.8 mm and this in turn reduces the width of the head when used in a line configuration. The nozzles on the chip can be separated into black and color and the combinations and configurations of these chips bring faster speeds and more compact form factors to any kind of printer.

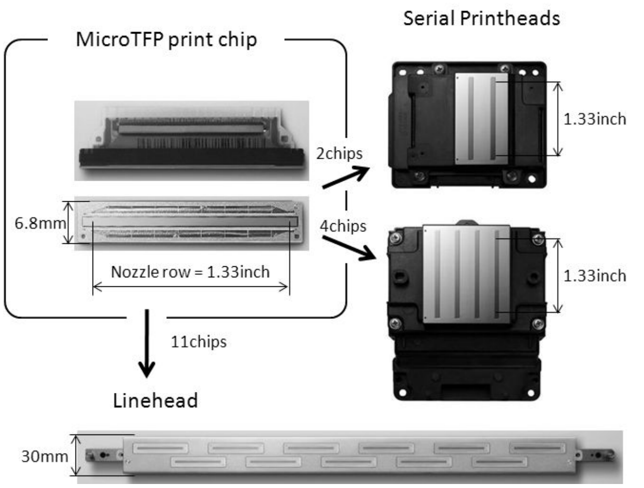
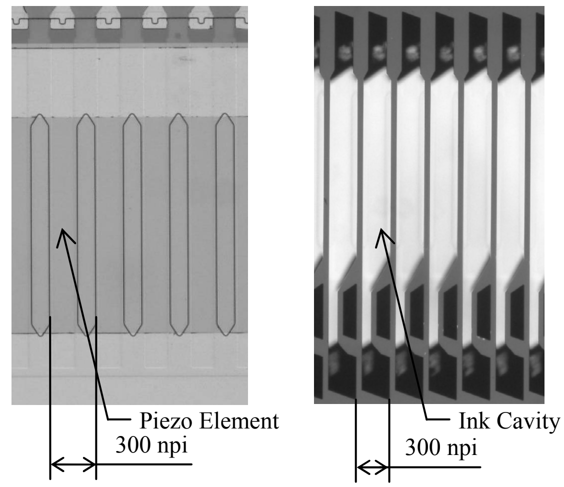


Figure 1: *MicroTFP print chip (platform) and PrecisionCore printheads (serial printheads using 2 chips and 4 chips for business desktop printers on right; linehead using 11 chips for a label press, bottom.)*



a) TFP actuator, upper view   b) Ink cavity, lower view

Figure 3: *Microscope images of MicroTFP actuators and ink cavities.*

The Structure of the MicroTFP Print Chip

Figure 2 is a schematic of the PrecisionCore ink discharge section. All of the key components – the thin film piezo element, the ink cavities, and the ink flow channels – are precisely formed from silicon using MEMS manufacturing processes. The upper limit of nozzle resolution from mechanical processing is around 180 npi/row but PrecisonCore's higher nozzle density means it achieves 300 npi/row, with 2 rows per print chip for a total of up to 800 nozzles. PrecisionCore print chips therefore fit more nozzles per row than chips produced with traditional mechanical manufacturing, enabling native 600dpi performance.

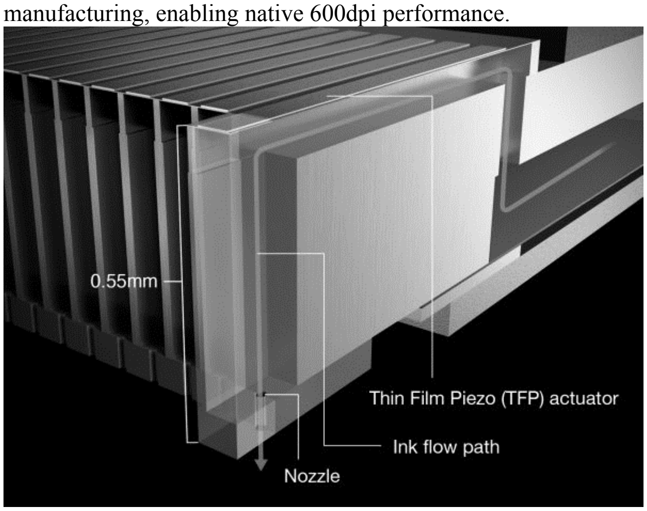


Figure 2: *Schematic of the MicroTFP print chip key components – the piezo actuator, cavity channel, and nozzle*

Figure 3 shows microscope images of the precisely formed Thin Film Piezo element and the ink cavities, which are manufactured using a combination of Epson's own original piezo material technology and MEMS production processes.

High Quality Printing with Precise Dots

The nozzles of our printheads are able to produce round and repeatable dots. These precise dots are very important for realizing high quality printing. Both TFP and MicroTFP print chips have this feature.

Circular and Repeatable Dots

The left of Figure 4 shows perfectly formed nozzles approximately 20 μm in diameter. These nozzles are also produced using MEMS fabrication techniques and formed to less than 1 μm variance in position and diameter. Furthermore, the length and straightness of the nozzles mean the ink droplets fly straight and result in highly accurate dot placement. They are also able to produce various dot sizes by controlling the voltage applied to the piezo actuator.

The right of Figure 4 shows dots produced by a MicroTFP print chip. It shows almost perfectly round, repeatable dots approximately 40 μm in diameter. These precise dots achieve high print quality ranging from finer, sharper text and ruled lines for business documents to smooth gradation for photographs.

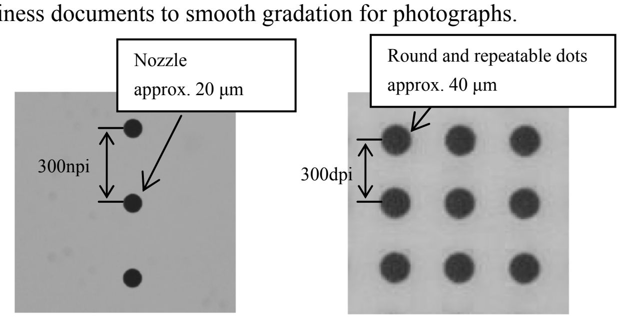


Figure 4: *Circular nozzles achieve accurate and repeatable dots.*

Improvement of Print Quality

PrecisionCore inkjet technology improves print quality with high-resolution and precise dots. Figure 5 shows 600 x 600 dpi sample text on plain paper. On the top is PrecisionCore / MicroTFP output and below that is output from an Epson laser printer. Higher resolutions like this call for smaller dot sizes and the smaller dots decrease bleeding. As a result, fine text becomes sharper and equivalent to that of a laser printer.

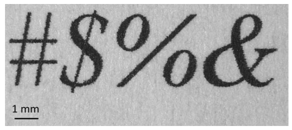
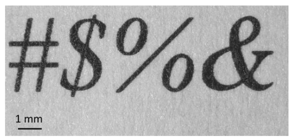
Printhead	Resolution	Sample Text
Inkjet printer / MicroTFP print chip	600 x 600 dpi	
Epson laser printer	600 x 600 dpi	

***Figure 5**: 12-point text printed by a MicroTFP print chip inkjet and a laser*

High Speed Printing with Smaller Print Chips

In this section, we explain how we achieved the high speed and smaller size of the new MicroTFP print chip.

There are two methods to improve inkjet print speed. The first is to increase the number of nozzles and the second is to improve the ink ejection capacity of the nozzles themselves (increase ejection frequency and dot volume). The easy way to increase nozzle number is to use multiple heads or nozzle rows. However, these methods increase printhead size, which in turn increase printer size and production costs. Hence, it is important to fit a large number of nozzles in a small area and increase the total nozzle number without increasing the head size.

We have succeeded in improving printing speeds in configurations ranging from serial printheads to lineheads. The longer nozzle row length of 1.33 inches decreases the number of passes needed by serial printheads to print one page, increasing print speeds. Also, the width of the MicroTFP print chip has been reduced to 6.8 mm by shrinking down key elements of the print chip, which enables the development of high-speed lineheads for a variety of applications.

We will explain three technologies employed to shrink the MicroTFP print chip below.

Shorter TFP for Improved Displacement

The first technique used to shrink down the MicroTFP print chip was to increase the displacement of the actuator and reduce its length. In a piezo head the ejected ink volume depends on the volume the piezo actuator can displace. In other words, how much it can deform. To make a dot of the same volume, an actuator that has greater displacement can be made shorter. With the MicroTFP print chip we succeeded in doubling the displacement of the actuator compared to conventional TFP and thereby shrinking the length of actuator to half its size.

There are three ways to improve displacement of the piezo actuator. The first is to increase the piezoelectric constant. The second is to increase the electrical field strength with a thinner actuator or stronger voltage. And the third is to decrease the stiffness of the vibrating plate. For the MicroTFP print chip, we improved the displacement by modifying the structure of the TFP layer to decrease the stiffness of the vibrating plate. Okumura et al. have shown that reducing the thickness of the vibrating plate by 75% increases displacement by approximately 12 times [6].

Figure 6 shows actuator and ink cavity cross-sections of the TFP and MicroTFP print chips. In the conventional TFP print chip, there is a humidity barrier to prevent insulation breakdown between the top and bottom electrodes. The top electrode works as an independent positive electrode and the bottom one works as a common negative electrode. However, the humidity barrier decreases the displacement because it increases the stiffness of the vibrating plate.

With the new design, the top electrode of the MicroTFP print chip functions as both electrode and humidity barrier. The top electrode covers the top and side of the piezo element and works as a common negative electrode. The bottom consists of independent positive electrodes. By eliminating the separate humidity barrier we decreased the stiffness of the vibrating plate and thereby improved displacement while maintaining protection against insulation breakdown.

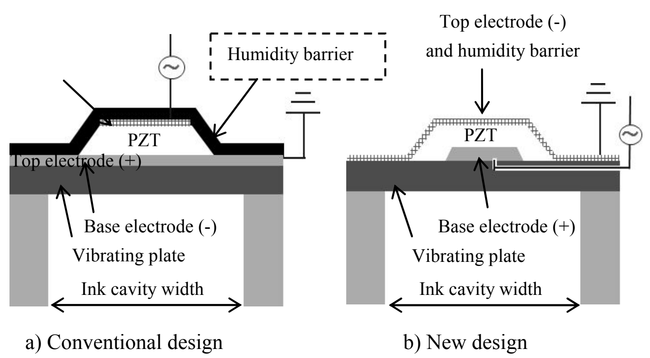


***Figure 6:** Actuator structure schematic*
(TFP print chip on the left; MicroTFP print chip on the right.)

Figure 7 shows the comparative FEM (finite element method) simulation result of displacement, and the simulation conditions are shown in Table 2. The graph indicates the relationship between the cavity width and the displacement. The displacement of the new TFP layer construction is greater than the conventional type, which has a separate humidity barrier.

Table2: Simulation Condition of Actuator Displacement

Piezo Elements Thickness	approximately 1 [μm]
Applied Voltage	30 [V]

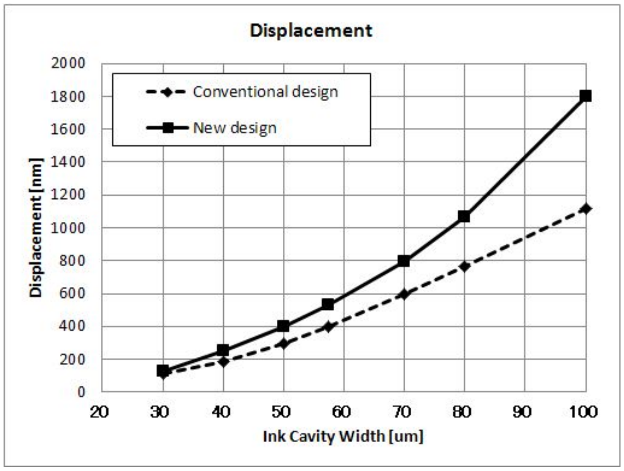


Figure 7 *Graph shows estimation of cavity width vs. displacement. New electrode construction with reduced humidity barrier increases displacement.*

Figure 8 shows the schematics of displacement for both the TFP and MicroTFP print chips. We improved the displacement of the MicroTFP print chip to around double that of the TFP print chip. The displacement of the MicroTFP print chip at 30 V current is 800 nm.

Consequently, we were able to halve the length of the MicroTFP print chip actuator compared to that of the conventional TFP print chip, as shown in Figure 9.

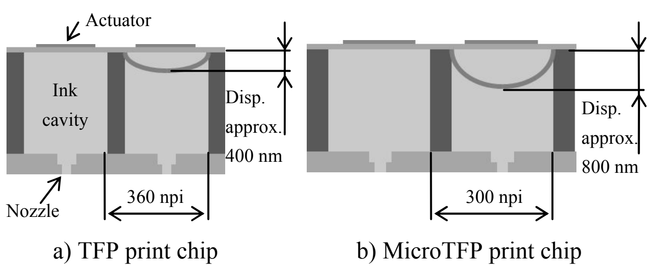


Figure 8: *Schematics show displacement of the TFP and MicroTFP print chip. Displacement of the MicroTFP print chip is twice that of the conventional TFP print chip.*

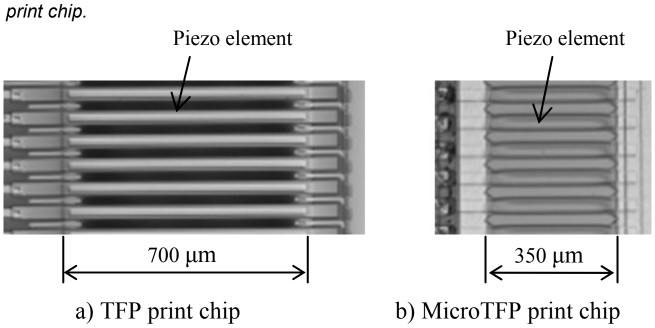


Figure 9 *Microscope images of the piezo elements from above. The MicroTFP print chip actuators are half the length of conventional TFP.*

Fine-pitch COF Mounting Technology

The second technique used to shrink the MicroTFP print chip was fine-pitch COF (chip on film) mounting technology, which we used to reduce the mounting area. Figure 10 shows 3D models of the MicroTFP and TFP print chips.

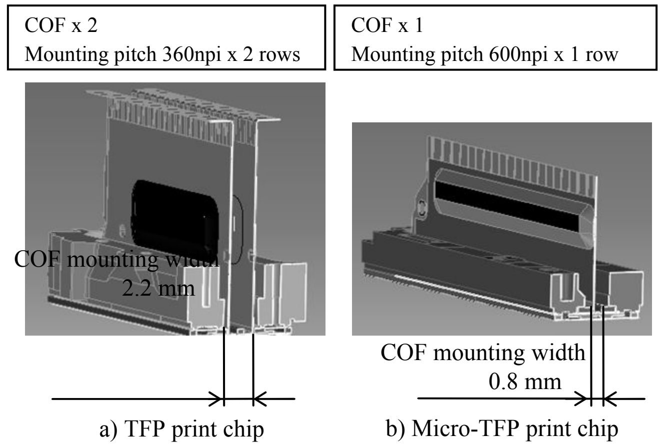


Figure 10: *3D models of the TFP and MicroTFP print chips. The number of COF was reduced in the MicroTFP print chip to reduce its width.*

In our print chips electrical signals are transmitted to the actuator through COF. In our conventional TFP print chip the electrical signals are transmitted through two COF for two nozzle rows (360 npi/row x 2), and the width of the mounting area is 2.2 mm. In our MicroTFP print chip, we halved the COF number from two to one, thereby reducing the mounting area by 1.4 mm, to 0.8 mm.

For the MicroTFP print chip, we chose to use NCP (non-conductive paste) technology to realize fine pitch and narrower segment mounting. Previously we had used ACP (anisotropic conductive paste) for mounting, which connects segments through conducting particles. However, it is difficult to trap the conducting particles with fine pitch and narrower segments. We therefore chose NCP mounting technology because it directly connects each segment and does not need to trap the conducting particles on narrower segments. Figure 11 shows the pitch of COF segments and cross-sections of the segment mounting area for ACP and NCP. Generally, NCP needs an extremely flat mounting plane compared to ACP because NCP cannot offset the impact of height variability between segments with the conducting particles. We therefore developed highly flat fine pitch mounting technology to successfully reduce the size of the mounting area.

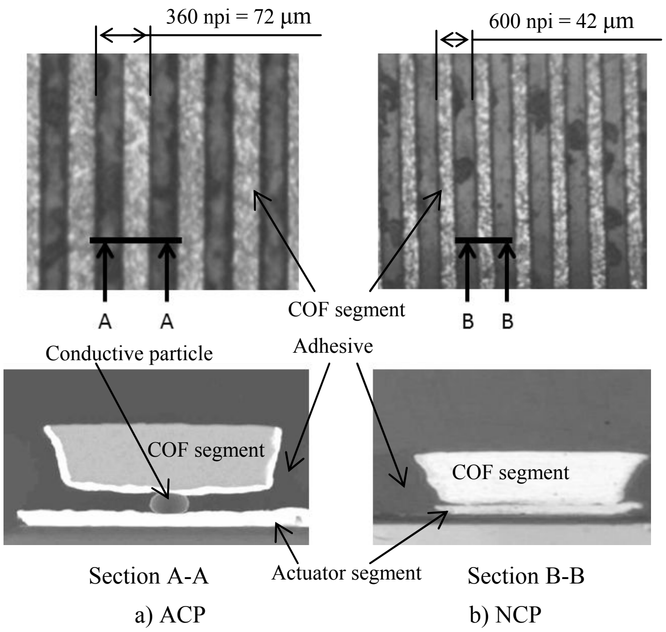


Figure 11: *These photographs show the segments which connect the signal from COF to actuator. The top images show the COF segments and the bottom images show cross-sections of mounted segments.*

Small, Low Resistance Reservoirs

The third technique used to shrink the MicroTFP print chip was design of smaller ink reservoirs with low fluid resistance.

The reservoirs of the MicroTFP print chip were designed tall and narrow to match the small width of reservoir and achieve low fluid resistance at the same time. Figure 12 shows a schematic cross-section of the MicroTFP print chip.

The fluid resistance of the rectangular reservoir area is given by (1), below. The fluid resistance rises in proportion to the short side length and varies as the cube of the long side length.

In our conventional printheads, the reservoir is long in the horizontal because the reservoir is designed into the actuator and ink cavity plate. For the MicroTFP print chip, we redesigned the reservoir to be long in the vertical. The reservoir is constructed from the silicon channel plate and plastic case parts, which allowed us to reduce the width of the reservoir from between 1.6 and 2.0 mm to 0.7 mm (length "B" in Figure 12).

Additionally, the reservoir is designed to be able to circulate ink differently by changing the case shape. This means the reservoir design is adaptable to various types of ink supply systems.

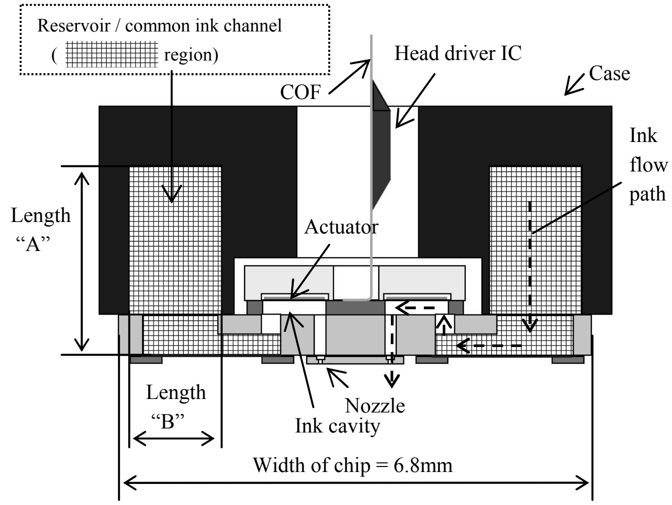


Figure 12: *This cross-section schematic of the MicroTFP print chip shows the reservoir design.*

$$R = (4\mu L) / (AB^3 \times X) \quad (1)$$

$$X = (16/3) - ((1024/\pi^5) \times (B/A) \times (\tanh(\pi A/2B) + (1/3^5) \times \tanh(3\pi A/2B) + \cdots)$$

where the following notations are used:

- A ,B length of sides, $A \geq B$
- L depth of rectangle
- μ liquid viscosity

Conclusion

We successfully developed a scalable next-generation actuator and MicroTFP print chip using TFP (Thin Film Piezo) technology. The chip can be adapted to a wide range of applications from desktop serial printheads to industrial press lineheads by arranging the small actuator chips in various configurations. The next-generation actuator achieves high quality printing with circular repeatable precise dots and high speed printing with increased numbers of nozzles thanks to optimized chip design.

The width reduction of the chip was achieved with higher actuator displacement, fine pitch COF mounting technology, and newly designed compact, low fluid resistance reservoirs.

Volume production of this next-generation actuator chip will make it possible to deliver affordable high quality, high speed printing to a wider range of printing segments from commercial and industrial to business.

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Author Biography

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