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Development of Dual-Line Wide-Format 1200 dpi Thermal Printhead

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Abstract. *The wide-format dual-line 1200 dpi thick film thermal head was developed utilizing the following technologies: (a) an alternated conductive lead circuitry inside the thermal head is devised in that it does not use diodes for the prevention of reverse current; instead, it adds a secondary power supply to redirect the reverse current. (b) The heater nib line of the printhead is produced stably and accurately using the direct dispensing system which, based on the air microtechnology, feeds back the air pressure and controls the linear actuator to follow the surface of a substrate. (c) The 1200 dpi printhead is combined of two identical 600 dpi nib lines with half-pitch offset in the nib line direction and separated by a distance of 32 nib lines in the printing direction. Although the printhead is not made of a 1200 dpi single nib line and may be classified as a quasi-1200 dpi printhead in a more strict sense; however, it does exhibit a 1200 dpi-like performance and, for the convenience of presentation, it is still called a 1200 dpi printhead in this article. Several wide-format (up to 54 in. width) products based on the 1200 dpi thermal printhead have been designed and are capable of printing half-tone images of up to 133 lines per inch. © 2009 Society for Imaging Science and Technology.*
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INTRODUCTION

The concept of thermal printing was introduced in the 1960s; the development phase in utilizing thick film technology as serial printheads started in early 1970s and the line thermal printheads followed in late 1970s.[1] In the early days, the direct thermal printing technology was mostly used in facsimile applications and later expanded for its use in engineering plotters and, in some cases, in grayscale image recording due to the advantages of low cost, free of maintenance, and high printing speed. In most applications, thermal sensitive papers are used whereas for the prepress image-setters, the main media are thermal sensitive film. The 1980s and 1990s have seen a full blossoming of the thermal transfer technology using the color ribbon as the transfer media and resulting in a full range of high resolution machines for full color printing and copying. Meanwhile, very high quality black-and-white direct imaging systems were also introduced.[2]

In the early days low-resolution, such as 200 dpi or at most 400 dpi, thermal heads would usually suffice. As the printing applications move upward to graphic and other high end markets, high resolution thermal heads become a necessity and 600 dpi is the basic requirement. To move upward further, 1200 dpi thermal heads are becoming more desirable. However, there have been challenging technical difficulties involved. For example, two major issues: heater durability and high density integrated circuit (IC) assembly, have been addressed in the development of 600 and 1200 dpi thin film printheads.[3]

This article describes the development of a wide-format 1200 dpi thick film thermal head and the innovations evolved during the course of development. The conventional alternated conductive system used in a thick film printhead is briefly discussed; then the innovative alternated conductive lead system without diodes is explained in detail. To satisfy the need of developing a high resolution nib line, the direct dispensing system based on the air microtechnology is applied. Finally, the technical details of forming a 1200 dpi printhead by means of combining dual 600 dpi nib lines are discussed.

CONDUCTIVE LEAD SYSTEMS USED IN THICK FILM PRINTHEADS

There are two technologies in manufacturing thermal printheads: thin film and thick film. In thin film technology, a film is coated by physical vapor deposition (for example, sputtering) or chemical vapor deposition. Then a conductor pattern and heater elements of high electrical resistance are formed with photolithographic technology. Thin film technology achieves a better printing quality due to its smaller variation in resistance of heater elements and thus in size of heated dots. Printers utilizing a thin film head may express photograph-like continuous-tone image quality.

On the other hand, in thick film technology, a conductive film is coated by screen printing and heated in furnace. Then a conductor pattern is formed with photolithographic technology. The heater resistive line is deposited in the form of paste, usually screen-printed across the width of the printhead on top of the complex conductor pattern. It is then heated in a furnace to develop the required character-

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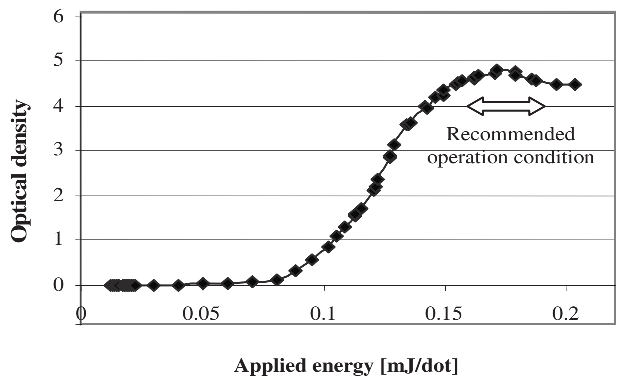

Figure 1. Optical density as a function of the applied energy for a typical film.

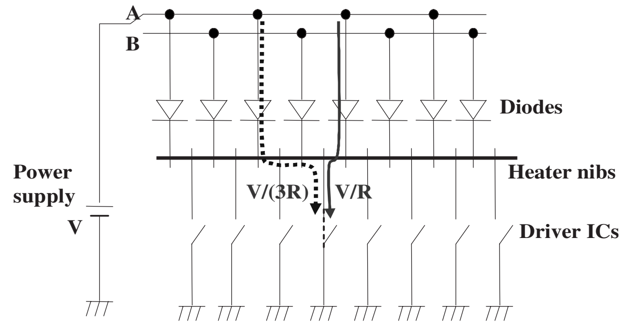

Figure 2. Conventional alternated conductive lead system.

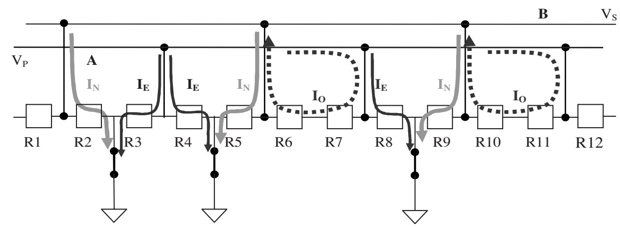

Figure 3. Current flow in diode-less alternated conductive system.

istics. Thick film head is more desirable where heavy use and harsh environment are present.

The print characteristic of a thick film printhead usually exhibits an S-like curve for the relationship between the optical density on the printed media and the applied energy. Shown in Figure 1 is the print characteristic for a typical case where film is the printed medium.

Note that the proper applied energy for the film being tested is in the range of 0.15–0.18 mJ/dot so that the saturation optical density can be achieved. Also note that the threshold applied energy, beyond which the media can get energized and the printed dot visible, is rather large, about 0.08–0.09 mJ/dot and almost half of the saturation energy. In the range between the threshold and saturation, the energy curve is very steep, nonlinear, and thus not easy to control. Therefore, most applications for a thick film printhead are for half-tone imaging.

The conductor pattern used in conventional thick film printheads is called "alternated conductive lead system"[4] and was utilized to develop a 1100 mm (44″) 400 dpi thermal head on a single substrate in 1994.[5] The alternated conductive lead system will be discussed in the next section.

Conventional Alternated Conductive Lead System

In the conventional alternated conductive lead system, the downstream driver ICs and the upstream conductive circuits are shared by pairs of neighbor nibs. The heating of nibs is controlled by switching between different paths from the power supply and by turning on or off the individual driver IC based on the data bit being 1 or 0. Each conductive path is connected to a diode to prevent the reverse current from flowing back to the other path.

A simplified circuit diagram of the alternated conductive lead system is shown in Figure 2. While the external controller sends data to be printed to the register in the driver IC, the power supply is connected to the conductive path A (A-phase) or to the conductive path B (B-phase) alternatively.

The diodes in the conductive circuit path prevent the reverse current from flowing back to the other conductive path. This can be illustrated in the simplest case that only one driver IC is switched on, as shown in Fig. 2. The current flowing through the supposedly energized nib is V/R, while the current flowing through the three neighbor nibs on the left side is only $V/(3R)$. Since on each of these three nibs, which are not intended to be energized, the current is only one-third of that through the supposedly energized nib (i.e., V/R), it generates on each of these three neighbor nibs only one-ninth of the power of that on the energized nib.

For manufacturing purpose, it is necessary to embed diodes into arrays with multiple elements mounted. However, if A- and B-phases are not dissociated completely, the leakage may occur between arrays. This requires extreme precaution during the developing of the printhead.

By utilizing the alternated conductive lead system, only one half of conductive circuits and driver ICs need to be budgeted, easing the density requirement of pattern formation. Therefore, wide conductor lines can be used to achieve reliable performance and also the benefits of ease of part inspection and correction/repair.

Diodeless Alternated Conductive Lead System

For thermal heads utilizing the conventional alternated conductive lead system, diode arrays are required. However, for high resolution thermal heads the space allowed for mounting the diode arrays becomes small, which in turn requires forming a deep diffusion zone during the manufacturing process. Therefore, the addition of diode arrays may present problems in technical implementation as well as in manufacturing cost.

These considerations have led us to the invention[6] in which the diodes are removed and a secondary power supply is added. The invention is depicted in the following illustrations. Shown in Figure 3 is a connection diagram for the generalized case that one single driver IC and an adjacent pair are switched on.

Instead of using diodes on the upstream conductive paths, a secondary power supply V_S is placed at the other

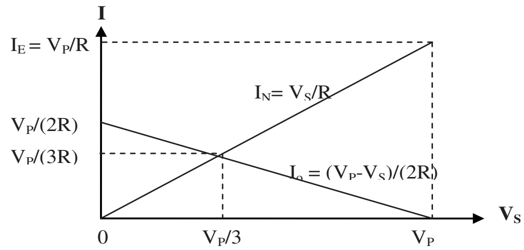

Figure 4. Relationship of I_E, I_N, and I_O versus V_S.

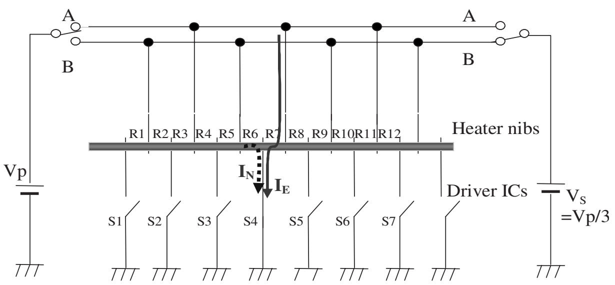

Figure 5. Current flow of diode-less alternated conductive system with only one nib on.

side of the main conductive path and at any time is switched to the path not connected to the primary power supply V_P. Illustrated in Fig. 3 is the case that V_P is switched to A and V_S ($<V_P$) to B and that three drive ICs are turned on to have the nibs R3, R4, and R8 energized.

With the assumption that all the nibs are of the same resistance (denoted by R), the current going through each nib can be classified into three categories:

For the nibs, R3, R4 R8, to be energized

$$I_E = V_P/R, \tag{1}$$

for the neighbor nibs, R2, R5, and R9,

$$I_N = V_S/R \tag{2}$$

For all other nibs (R1, R6, R7,R10, R11, R12,...),

$$I_O = (V_P - V_S)/(2R). \tag{3}$$

The relationship of currents I_E, I_N, and I_O versus V_S for a fixed V_P are plotted in Figure 4. Note that a higher V_S generates a larger I_N but a smaller I_O and that the balance point is at $V_S=V_P/3$ where $I_N=I_O=V_P/(3R)$. This relationship means that if the secondary power supply is selected to be of one-third of the primary one, all the nonenergized nibs would have the same current, one-third of that on the energized nibs, no matter what data pattern is applied on the driver ICs.

Based on these analyses, a diodeless alternated conductive lead system is designed so that the secondary power supply $V_s=V_p/3$ is always connected to the conductive path which the primary power supply is unconnected. A simplified circuit diagram is shown in Figure 5.

The design principle may also be illustrated from a different point of view by analyzing the need for diodes in a conventional alternated conductive system. Consider the fictitious case that V_S is removed (i.e., voltage on path B V_B is determined by the circuit configuration in Fig. 5). When the driver IC S4 is turned on to provide a current path to energize the heater nib R7 with the current of $I_E=V_P/R$, the current flowing into the neighbor nib $R6$ (which is not supposed to be energized) can be expressed as

$$I_N = V_B/R = (V_P - V_B)/(2R) + N_R(V_P - V_B)/(2R). \tag{4}$$

The first term in the right-hand side represents the current flowing through the path A-R4-R5-R6-S4 and the other term accounts for the N_R reverse currents such as A-R3-R2-R6, A-R11-R10-R6, etc. The values of V_B and I_N can be solved from the above equation as

$$V_B = V_P(1 + N_R)/(3 + N_R), \tag{5}$$

$$I_N = V_B/R = I_E(1 + N_R)/(3 + N_R). \tag{6}$$

For $N_R=0$ (the case of every other driver IC being on), $V_B=V_P/3$ and $I_N=I_E/3$. However, for a very large N_R (i.e., in the case of very few switched-on driver ICs), it results in an undesirable situation of $V_B \sim V_P$ and $I_N \sim I_E$. That is why diodes are required in the conventional alternated conductive lead system, as shown in Fig. 2, to block the N_R reverse currents so that the maximal I_N is $I_E/3$. In the case that every driver IC is switched on, $I_N=0$.

For a diode-less conductive system, the selection of $V_S=V_P/3$ forces $V_B=V_P/3$ as shown in Fig. 4. This effectively limits the current flowing into nib 6 to $V_P/3R$, as in the case with the diodes in the circuit. Thus it can be seen that the secondary power supply V_S serves two functions: a sink path for the primary power supply V_P to flow out (such as V_P-R3-R2-V_S, V_P-R8-R9-V_S, etc.), as well as a source path for the current to flow into the driver IC (such as V_S-R6).

IMPLEMENTATION OF DIODELESS ALTERNATED CONDUCTIVE SYSTEM

As compared to the conventional alternated conductive system with diodes, the diodeless system using a secondary power supply is easier to control. This is because the conventional system is influenced by the structure of diode arrays and the associated semiconductor characteristics. With the elimination of diodes, these variations do not exist. Thus, the specification of parts can be relaxed, and the work of parts inspection is unnecessary, resulting in reduced labor cost.

Note that $V_P/3$ is always applied to the heater resistance nibs and, when the temperature on the nib elements becomes high, the small energy generated may cause thermal reaction on the printing media and result in an unwanted imaging effect. Therefore, the switching of power supplies needs to be synchronized very precisely with the strobe signal of driver IC, as shown in Figure 6.

Shown in Figure 7 is the circuit diagram for the real implementation of the power supplies V_P and V_S ($=V_P/3$).

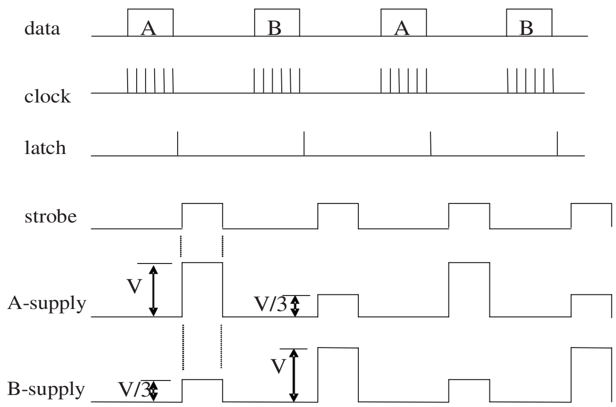

Figure 6. Thermal head control timing for the diode-less alternated conductive system.

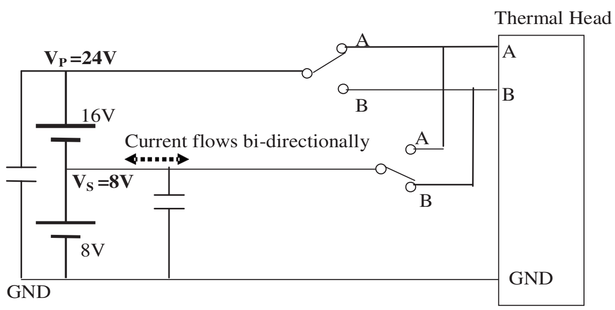

Figure 7. Power supply circuit for the diode-less alternated conductive system.

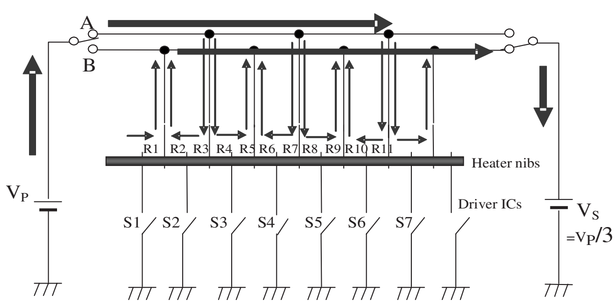

Figure 8. Flow of current inside thermal printhead when not printing.

Note that for cost and efficiency considerations, an 8 V power supply is used for V_S and stacked up with a 16 V power supply to provide a 24 V V_P. The path of current flowing in/out depends on the ON/OFF state of the driver ICs inside a thermal head.

The flow of the current inside the thermal head when not printing is shown in Figure 8. In that case, all the currents are flowing from V_P through all the nibs into V_S with the magnitude of $V_P/(3R)$ on each nib. On the other hand, when printing one full nib line (i.e., with all the heater elements on) both V_P and V_S act as current sources. Therefore, proper attention should be paid to the timing response and capacity matching in the selection of power supplies and implementation of the power switching circuit.

In the test prints shown in Figure 9, only one nib element was printed repeatedly, and it can be seen that the influence of V_S on the neighbor nibs is negligible.

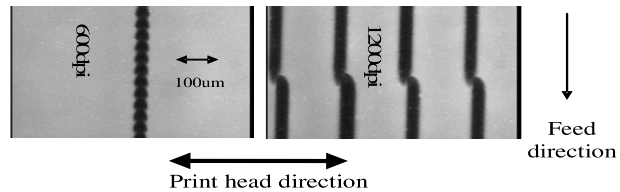

Figure 9. Enlargement of one-element printing.

FORMATION METHODS OF A HEATER NIB LINE

For low-resolution thermal heads, the pattern formation of conductive path and nib line can be achieved by means of screen printing. The lower limit of width for which a heater resistance nib line can be formed reliably is about 0.15 mm (150 μm).

For a single-line 400 or 600 dpi thermal printhead, the pitch is 63.5 or 42.3 μm, which is the maximal width of the dot formed. For a proper aspect ratio (width:length) of 1:1.5 for the dot formed, the length should be no more than 100 μm in 400 dpi or 65 μm in 600 dpi. In consideration of the fact that at either flank edge of the nib line the heating effect is usually negligible due to its thinness, the length of the dot formed is much smaller than the width of nib line. However, the maximal requirement of dot length still places a restriction on the width of nib line. In the case of 400 dpi, generally good printing quality can be obtained by using 160–200 μm linewidth, and for 600 dpi, 120–140 μm.

For thermal heads of higher resolution, the conductor pattern density requirement becomes more demanding, especially for 1200 dpi heads, and it makes the manufacturing process more difficult. For our 1200 dpi printhead made of dual 600 dpi nib lines and explained in detail later, although the width of nib line is not proportionally smaller, it still should be in the range of 90–110 μm. Furthermore, forming a nib line of narrow width with stability and consistency is more challenging due to the fact that the influence of the surge of a substrate on the thickness and width of a nib line becomes more detrimental.

New Formation Method Using a Microdispensing System

To form a heater resistance nib line, two methods are available. One is screen printing; the other is the direct drawing system using a dispenser. As mentioned above, since 150 μm is a minimal achievable width by screen printing, it becomes unsuitable for forming a 600 or 1200 dpi head. Therefore, we have turned to the use of a microdispensing system which can detect the surge of a substrate and draw a heater element line more stably and accurately.[7–9]

A dispensing system is usually composed of a surface-following subsystem and a discharging device. It detects the surge of a substrate, usually using a touching stylus or a laser device, and moves up/down following the surface curvature while the discharging device dispenses fluid. The use of a touching stylus, however, is problematic to our application since it may create scratches on a conductive pattern when touching the substrate. A laser device, though offering the advantages of free of contact, presents technical complications for incorporation into our system, however.

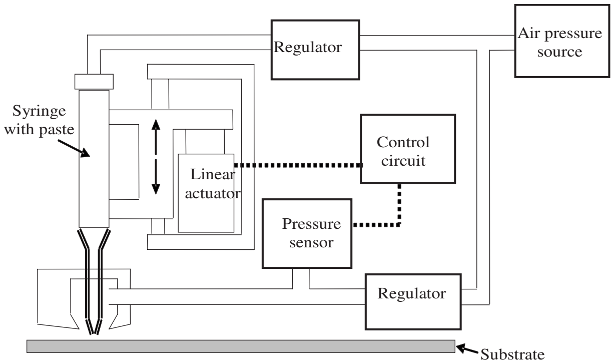

Figure 10. Block diagram of microdispense system.

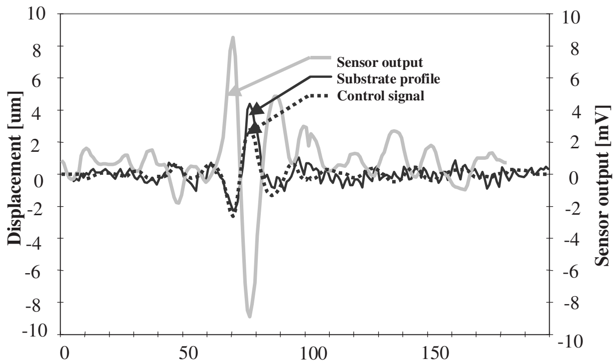

Figure 11. Microdispense system control and output data.

Our approach is to devise a microdispensing system which has the desirable surface-following capability and can draw the nib line on the substrate accurately. The block diagram of the microdispensing system is shown in Figure 10.

In the system, a pressure sensor is used to detect the change in backpressure at the tip of the nozzle due to the variance in the gap between the nozzle and the substrate. The sensed pressure is used as the feedback signal to control a linear actuator so that the variance in the gap can be minimized. The sensed and control signals are shown in Figure 11 for a test substrate with a surge.

A capillary of the type used for wire bonding has been adopted in our dispensing system. The production quality has been improved that a narrow width of down to 80 μm can be formed stably.

To demonstrate the improvement of the microdispensing system over the screen printing method, two 54″ 600 dpi nib lines (32,255 nibs per line) are formed separately by these two methods. It is aimed to have a nominal nib width of 170 μm and a nominal resistance of 3000 Ω per nib. The test results are shown in Figure 12 and in Table I for comparison. Note that the results shown are for the nib lines before trimming. In the screen printing method, it has been noted that when a wider heater nib line is formed, the width exhibits a wave-like variation which appears to be under the influence of the screen mesh. For the nib line being formed in this manner, the maximum width deviation, (max-min)/average, is about 7%, whereas it is no more than 2% for the

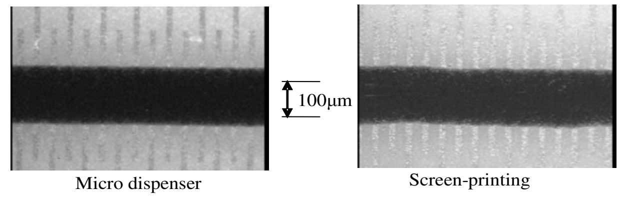

Figure 12. Enlargement of nib lines formed by microdispensing system and screen printing.

Table I. Comparison of nib lines formed by microdispensing system and screen printing.

		Microdispenser	Screen printing
Nib line formed	Averaged width, μm	170.80	169.80
	(max-ave)/ave, %	0.71	3.10
	(min-ave)/ave, %	−1.06	−3.96
Resistance	Average, Ω	3228	3626
	Variation $3-\sigma$, %	14.8	31.5

microdispenser approach. Moreover, the resistance variation in the latter is less than half in the former, i.e., 14.8% versus 31.5%.

FORMATION OF DUAL-LINE 1200 DPI THERMAL PRINTHEAD

As mentioned above, the heater nib line can be formed stably by means of an air pressure microdispensing system. Formation of a heater nib line of narrow width can be realized through the optimal adjustment of operational parameters such as output pressure, drawing speed, selection of a nozzle and paste viscosity, etc. It has also been proven that the design is achievable via the use of the alternated conductive lead system without incorporating diodes in the circuit.

The formation of a 1200 dpi thermal head is comprised of two identical 600 dpi nib lines. The approach is an extension of the pioneering feasibility study,[10] which formed a quasi-600 dpi thermal head by combining two identical 300 dpi nib lines. The design and formation procedure of 1200 dpi thermal heads are as follows:

- Draw two 600 dpi heater resistance nib lines, with the gap set to 0.677 mm (32 × 1200 dpi lines).
- Since 1200 dpi is formed by two 600 dpi nib lines, a wide conductive path for dot and heat separation is formed.
- Arrange the 1200 dpi pattern to be a symmetrical conductive path, using commercial driver ICs with a shift register and a latch, so that two directions of data transfer are performed simultaneously into each heating nib line.
- Communalize power supplies for both nib lines.

The conductive path diagram is shown in Figure 13 and the enlarged view of heater resistance nibs is shown in Figure 14.

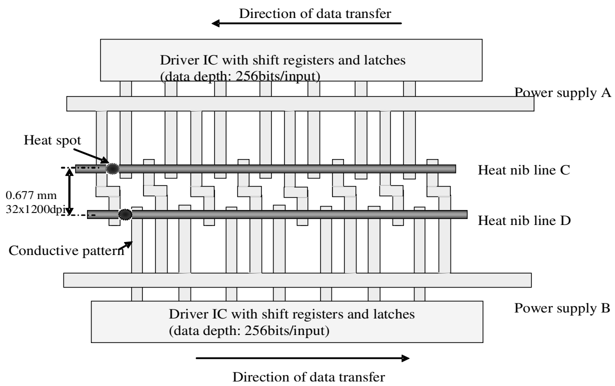

Figure 13. The conductive path diagram of 1200 dpi thermal head.

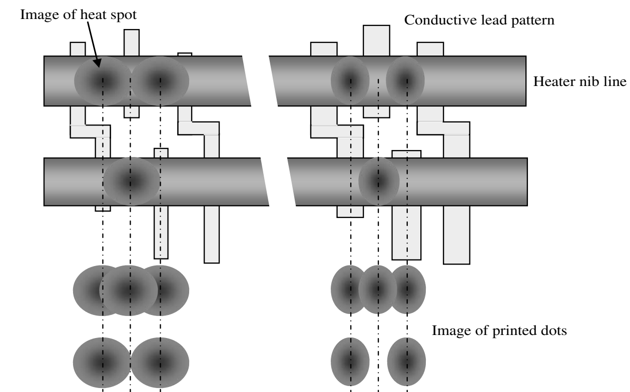

Figure 14. Form of nib pattern with narrow and wide conductive paths.

Note that for the case of a narrow conductive path, as shown in the left side in Fig. 14, each 600 dpi nib line may produce round-shaped dots suitable for 600 dpi imaging; but an image of 1200 dpi may lose the clarity it deserves due to interlacing of two 600 dpi nib lines. Therefore, a wide conductive lead pattern should be used as shown in the right side.

IMPLEMENTATION AND TEST PRINTINGS OF A 1200 DPI 54″ THERMAL HEAD

Listed below are the specifications of a 1200 dpi 54″ thermal head:

- Effective printing width: 1365 mm (54 in.).
- Platen diameter: 70 mm max.
- Data depth in the shift register: 256 bits.
- Number of data input ports: 126.
- Typical heater resistance value: 3000 Ω.

For a 1200 dpi printhead of 54 in. long, mechanical stability and electrical/electronic efficiencies are two important factors requiring thorough consideration in realizing the real system implementation. In order to provide the mechanical rigidity for the printing system, a big platen is required. Data depth in the shift register is set to 256 bits to minimize the data transfer time for high-speed printing as well as for the implementation of micropulse control and history control.

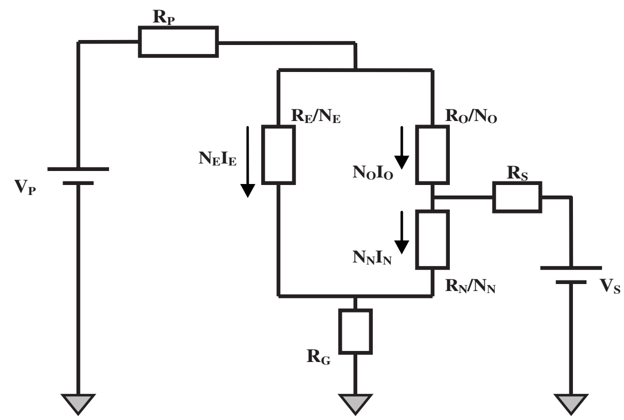

Figure 15. Conceptual circuit diagram of the printhead system including the resistances of power supplies, conductive paths, and wiring cables.

For the implementation of electrical power sources and wirings, careful attention needs to be paid in consideration of different operational conditions. Shown in Figure 15 is a more realistic circuit diagram for the operation of the printhead at any time instant in either phase A or B.

N_E, N_N, and N_O in Fig. 15 represent the numbers of energized nibs, neighbor nibs sharing the same driver ICs with energized ones, and the rest of nibs, respectively. Similarly, R_E, R_N, and R_O are the corresponding average resistances. R_P, R_S, and R_G represent the lumped resistances accounting for the internal resistance of the power supplies as well as the combined resistance of conductive path on the printhead and the wiring cables. Note that in the ideal case, R_P, R_S, and R_G are usually very small and thus negligible. This ideal case of $R_P=R_S=R_G=0$ is the foundation upon which Eqs. (1)–(3) hold and which the design of the diodeless alternated conductive system is based.

Note that at any time during printing, the sum of N_E, N_N, and N_O equals the total number of nibs in the nib line. For a 600 dpi 54″ nib line, it is about 32,400. Also note that any of N_E, N_N, and N_O may be large, depending on the data pattern in the image to be printed, and that any of the equivalent impedance R_E/N_E, R_N/N_N, or R_O/N_O may be as small as to 0.1 Ω. Therefore, R_P, R_S, and R_G should be made as small as possible. For such purpose, the metal bar is used inside a thermal head to minimize the wiring/conductor resistance and the accompanying voltage drop. The cross-sectional structure including the platen of the thermal head assembly is shown in Figure 16.

The printed samples using 1200 and 600 dpi thermal heads are shown in Figure 17. The character "R" is an enlargement from the original six-point font. Not surprisingly, the curve and the slanting line are expressed more smoothly in 1200 dpi. Similarly, printings of a step tablet in grayscale (half-toned dots) are also shown, and gradation can be expressed continuously at 133 lines per inch when using 1200 dpi thermal head.

Another factor to be considered in the system implementation is the finite current capacity of real power supplies. As the number of energized nibs increases, so does the current drawn from the power supply. It may result in dif-

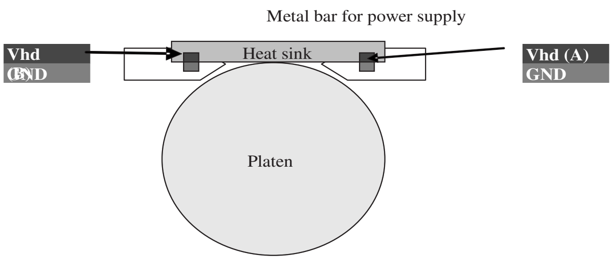

Figure 16. Cross-sectional structure of thermal head.

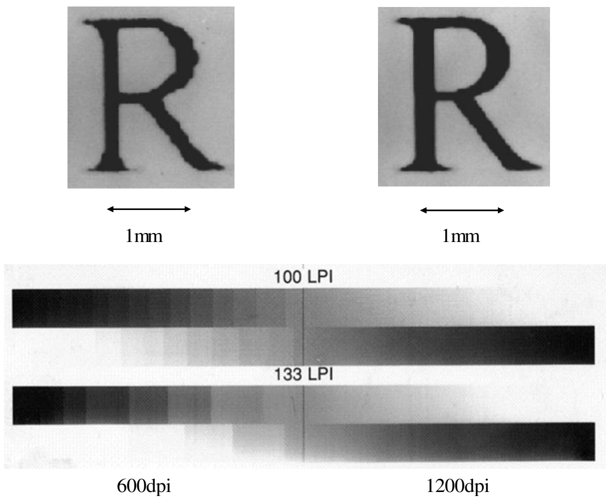

Figure 17. 600 and 1200 dpi printing samples.

ferent amounts of current flowing through the energized nibs between the cases of high black-rate and low black-rate printings. Our solution is to implement in the system firmware a "black-rate control" scheme that adjusts the internal pulse control by utilizing the black-rate information for each data scanline to be printed. Printing samples of different black rates are shown in Figure 18.

CONCLUSION

Development of a wide-format (up to 54″) 1200 dpi thermal printhead was realized by utilizing the following innovative approaches.

The diodes which are usually required in the conventional alternated conductive lead system are eliminated. Instead, a secondary power supply is added, resulting in a simpler circuitry inside the thermal head and making the manufacturing of the thermal head of high resolution more feasible. By means of the microdispensing system, which uses the air backpressure for feedback to achieve accurate surface following, the uniform heater resistance line can be formed stably by minimizing the influence of the surge of a substrate. The narrow-width nib line, which cannot be formed using the conventional screen printing method, can be achieved and the exothermic domain also made small. The 1200 dpi printhead is then realized by combining two identical 600 dpi nib lines with half-pitch offset in the nib line direction and separated by a distance of 32 nib lines in the printing direction. Although the printhead is not made

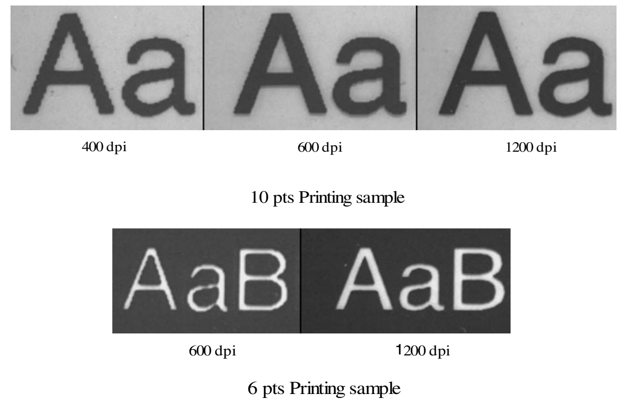

Figure 18. Printing samples of different black rates.

of a genuine 1200 dpi single nib line and may be classified as a quasi-1200 dpi printhead in a more strict sense; however, it does exhibit a 1200 dpi-like performance.

Further improvements, however, are still in order especially in the areas of glaze structure and coating method. A recent article[11] based on narrow-format thin film thermal heads has studied the effect of different glaze structures on heat storage, heat response, print quality, and productivity. Similar studies are being carried out on our 1200 dpi thick film thermal heads. For durability improvement of thermal heads, different coating methods and protection layers are being pursued as well.

The wide-format 1200 dpi thermal head is of the conventional flat type. While sufficing for use on film imagesetters and paper plotters, its performance may be further improved on systems requiring ribbon peel-off, such as direct-to-screen applications, by utilizing corner-edge thermal heads. This is another area being explored.

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