# Testing Unpackaged Thermal Ink Jet Printing Devices

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## Abstract

There are stages in the refinement of new imaging processes in which the use of unique test equipment and study tools is required to isolate problems related to performance and fabrication steps. A juncture had been reached in our thermal inkjet program wherein an evaluation of the panting device for both electrical function and print quality before final packaging was required. Nondestructive testing is necessary so that these printing devices can be tested repeatedly and subsequently packaged by mounting them onto a substrate with appropriate circuit boards wire bonds, and ink manifolds to form finished thermal inkjet printheads. This study describes test equipment designed to test electrically, print test, and evaluate fully the imaging properties of unpackaged thermal inkjet printing devices. The use of this test equipment and related testing procedures has accelerated process development times significantly and is playing a key role in quality control functions in the product manufacturing environment. Test equipment, techniques and results are discussed.

## Introduction

The task of taking a new marking process to the market place requires the same basic approach regardless of the technology. Usually materials, hardware, testing procedures, and process understanding evolve together. At some stage in this development effort, a key requirement will be the use of unique equipment and study tools to isolate problems and process steps.

One approach that has been taken to further thermal inkjet technology is to fabricate the thermal inkjet printing devices via the use of both thin and thick films and fabrication technologies commonly used in silicon-based integrated circuit manufacture. A channel wafer is made by patterning and orientation-dependent etching of a 0.020"-thick silicon wafer with multiple unit repeat patterns to form the ink inlet openings, ink reservoirs, and the inkjet channels.[1] A heater wafer is made using silicon IC technology and patterned with the thermal transducers and integrated electronics (logic and driver circuitry) with a mirror image repeat pattern of the channel wafer layout.[2] After an automated inspection of the channel wafer and an electrical evaluation of the heater wafer, the finished printing device is assembled by aligning the channel wafer and heater wafer and bonding them together into a sandwiched pair.[3] This sandwiched pair is then precision diced to form thermal inkjet printing devices. At this point in the printhead fabrication process, the printing device can be functionally tested, both electrically and in terms of actual print quality, before final packaging, using hardware and techniques that are described in this study. It is required that the testing be nondestructive so that these printing devices can be tested, modified (front face treatments, etc.), retested, and subsequently packaged by mounting them onto a substrate with appropriate circuit boards wire bonds, and ink manifolds to form finished thermal inkjet printheads.

## The Printing Device

An example of a printing device to be tested is shown in Figure 1. It is a 128jet, 300-spi version with individual channel widths of 65 µm and channel heights of 45 ,um. The printing device (or die module) is diced from a bonded wafer set.[4] Its dimensions are approximately 0.5 inch long, 0.1 inch deep, and 0.040 inch high. The visual features include a series of 0.008-inch square contact pads along the exposed edge of the heater substrate at the rear of the device; ink inlet holes at the top of the device, which are covered with an electroformed screen;[5] and the triangular nozzles located on the face of the printing device. For convenience, these printing devices are stored in “waffle packs” and handled with vacuum pickup tools.

## The Need for Testing

The ability to test printing device electronics and print performance before packaging is necessary to sort out both process- and packaging-related problems. For present purposes, packaging is defined as the incorporation of a printing device into a completed printhead with heat sink, circuit board, ink manifold, and connector(s), as shown in Fig. 2. Additionally, an image evaluation system was required that would reduce the printing device

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performance down to a single print quality grade level. Specialized test equipment with unique capabilities is required to test electrically, print test, and evaluate quantitatively the resultant print samples from an unpackaged device. With respect to the device print testing equipment, for example, the electrical test requires reliable but nondamaging contact to the device pads. If the contact pads are damaged in the testing phase, then subsequent wire bonding in the printhead stage may not be possible. Custom electronics and associated software are also required to enable printing of test patterns, as well as computer control over the test system's mechanical functions. In addition, the printing capability requires automated liquid handling (device priming, ink supply while printing, and rinsing of ink after use), temporary sealing of the ink supply to the top of the device, relatively simple loading and unloading of the device, and a smooth paper drive system with high resolution encoder for precision printing.

After the printing cycle, a reliable measuring system is needed to quantify the printing results. The measuring system must be capable of measuring the precise locations of individual spots for specific test patterns and then comparing actual with idealized spot placement and size. A goal is to reduce the evaluation of printing devices to a single quality rating number.

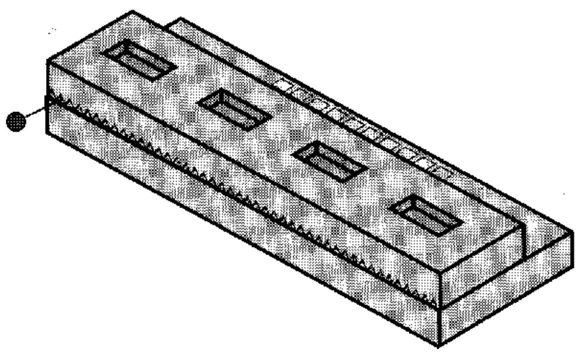


*Figure 1. Printing Device—The printing device has a fully functional printing capability. At a minimum, it requires only ink and electrical power to the contact pads to print.*

## The Die Probe Print Test Station

A Die Probe Print Test Station (DPPTS) was developed to enable the capability of functionally print testing Thermal Ink Jet (TIJ) printing devices in an efficient and nondestructive manner before they are fully assembled into printhead structures (see Fig. 3). This capability permits actual print quality evaluation before the printing devices are packaged, saving resources and increasing packaging yields. Use of the test station has also proved to be a valuable tool in process development activities, providing fast turnaround print quality evaluation at the die module level. The test station is under computer control and uses a commercial wafer probing system as a base unit around which custom fixturing and electronics have been assembled. The resultant test system facilitates print testing of individual TIJ printing devices in a semiautomated mode according to the following sequence:

1. Manual loading of printing device onto a vacuum chuck.
2. Alignment of printing device under a custom probe card and establishment of electrical contact.
3. Performance of electrical diagnostic test on the printing device (optional).
4. Priming of the printing device with ink.
5. Lowering of the print drum into position, selection of print test pattern(s), and actual performance of print tests.
6. Retraction of print drum after print testing is complete, and movement of the printing device to the unloading position.
7. Rinsing the ink from the printing device.
8. Unloading the printing device/loading the next device to be tested.

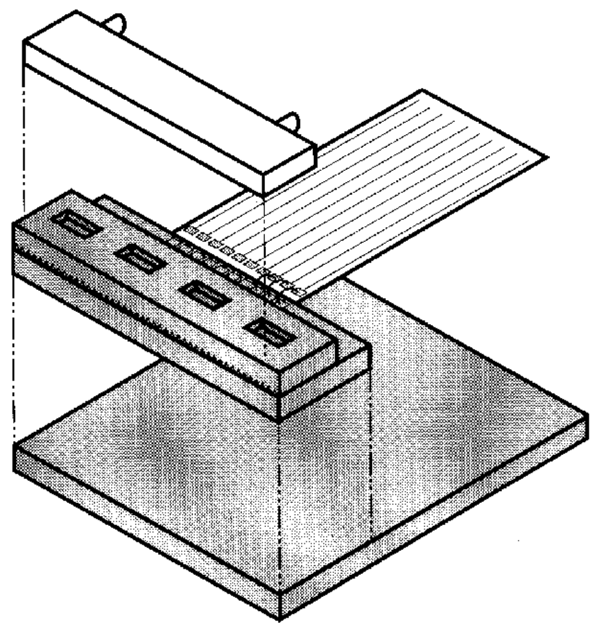


*Figure 2. Packaged Printhead—Additional parts are added to the panting device to enable it to function in a printer.*

Although the DPPTS is set up to test 128jet printing devices, almost any other TIJ design can be accommodated by a change of probe card and several small components on the printing device stage. Below is a brief description of each of the major subsystems and components of the DPPTS.

The base subsystem of the DPPTS is a Rucker & Kolls (R & K, Santa Clara, CA) 1032 wafer probing unit. This is a semi-automatic commercial wafer probing system that has been popular in the integrated circuit industry for many years, but is no longer in production. The wafer stage and probe card support structure have been extensively modified to accommodate the special requirements of TIJ print testing, but the standard prober controls are still used to control stage motion and probe contact to the individual TIJ printing devices. The precise (x, y, z, 0) motion and programmable overdrive inherent in the Rucker & Kolls system permit precise probe/printing device alignment and minimal probe contact damage to printing device bonding pads.

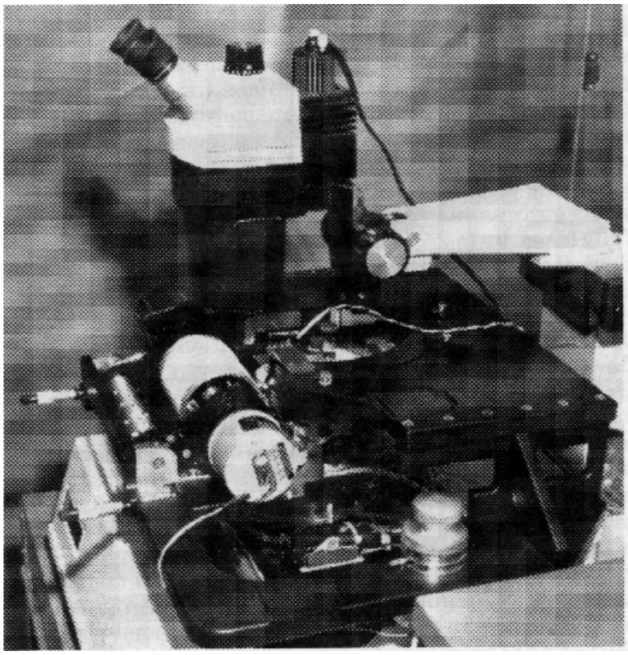


*Figure 3. The Die Probe Print Test Station—This is the unit designed to test electrically and print unpackaged thermal ink jet printing devices.*

The primary function of the probe card is to provide heater and logic supply voltages to the printing device, as well as printing signal information. The custom probe card used with the DPPTS differs from more conventional wafer probe cards in that the probes are arranged at the end of the card rather than around a circular opening in the center of the card. The probes on the card are of the ceramic blade type with BeCu probe tips. Probe cards with as many as 33 probe tips have been successfully used to test earlier matrix-addressed TIJ printing devices, although the present TIJ printing devices with integrated logic require far fewer probes for printing.[4] The printing device stage has been custom fabricated to hold the device securely in position (vacuum holddown), allow precise positioning in x, y, z and 0 orientations for electrical (probe) contact, and provide both ink supply and prime/wash functions for the device to enable print testing before packaging (see Fig. 4). The printing device stage incorporates the prime and ink manifold arm assemblies, which are fitted with custom molded gaskets. These assemblies are actuated by keyboard commands that control solenoid valves and air cylinders and cause the appropriate motion of the arm assemblies as required. The ink manifold arm provides a leak-proof seal to the inlet holes in the channel plate and thus provides a means of delivering ink to the TIJ device. In a similar manner, the prime manifold arm provides a seal to the nozzle face of the device to permit vacuum priming of the device before printing. Both arms are connected to a fluid-handling system (described below) that permits the operator to prime the device with ink supply ink to the device while printing, or rinse the ink from the device with water (or other cleaning fluid) when print testing is complete. The printing device stage is mounted on the original wafer stage of the R & K prober, and advantage is taken of the precise x, y, z and 0 motion capabilities to position the device accurately relative to the electrical probes and subsequently make contact to the device with minimal damage to the bonding pads. The capability for operating the device at some elevated temperature (e.g., 40-60°C) has also been incorporated in the die module stage. For example, by inserting miniature rod-type heater elements and a thermocouple into the predrilled holes of the device hold-down chuck and using a Macor R spacer plate, controlled elevated temperature operation of the TIJ device can be achieved. It should also be noted that the design of the printing device stage and print drum assembly (discussed below) is such that the device can be reprimed as often as necessary without making repeated probe contacts to the device, thus avoiding unnecessary damage to the bonding pads. Critical components of the device stage assembly were machined from stainless steel, and peripheral material is black anodized aluminum.

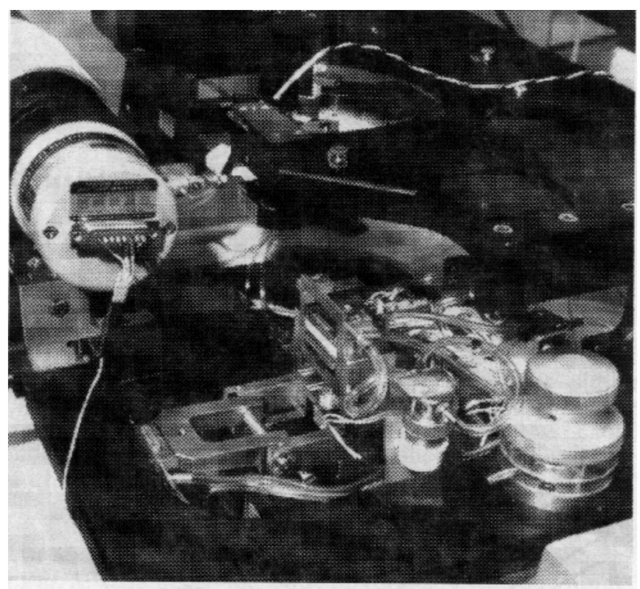
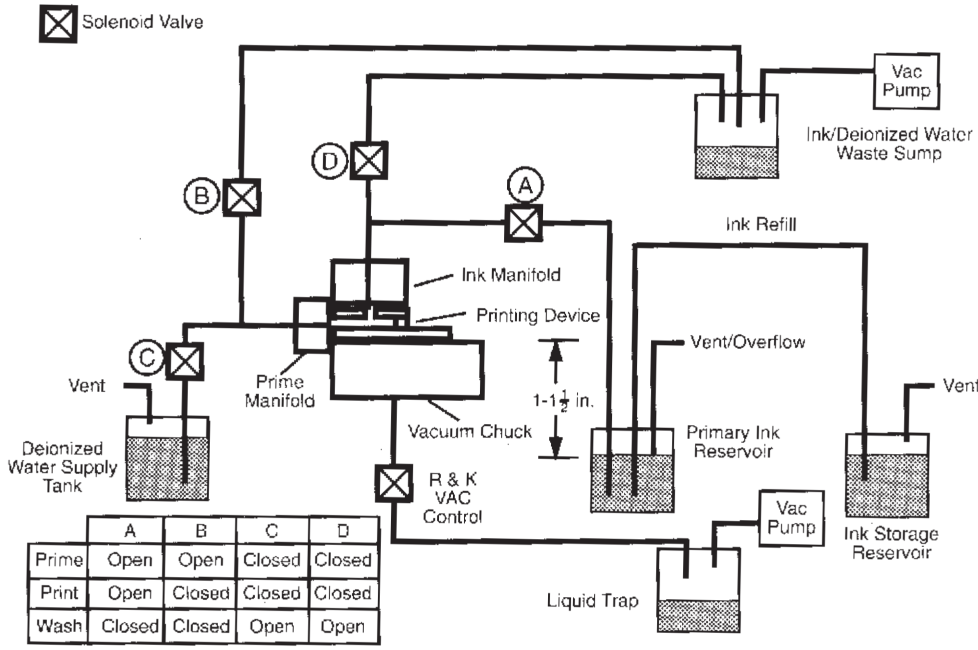


*Figure 4. Die Probe Print Test Station Chuck—This chuck has been designed to ink, prime, print, and then wash the printing device with DI water.*

To print test functionally at the die module level, it is necessary to be able to prime the device with ink, as well as to supply ink continuously to the device at the desired pressure level. Also, it is desirable to be able to rinse the ink from the device once the print testing is complete. In conjunction with the specially designed ink and prime manifolds of the printing device stage (described above), a fluid handling system incorporated in the DPPTS permits the operator to perform such




| | A | B | C | D |
|---|---|---|---|---|
| Prime | Open | Open | Closed | Closed |
| Print | Open | Closed | Closed | Closed |
| Wash | Closed | Closed | Open | Open |

*Figure 5. Die Probe Print Test Station Fluid Handling System Schematic.*

operations automatically]y with a command from the keyboard. The fluid-handling system is shown schematically in the diagram of Fig. 5. Extended prime or wash cycles are achieved by repeating the keyboard command. The ink and prime manifolds on the printing device stage are connected through small diameter flexible tubing and solenoid valves to ink and deionized water supplies, as well as to a waste sump and a separate vacuum pump.

The prime and ink manifold arms contain small custom-molded RTV gaskets, which provide the leak-tight seals to the TIJ printing device. The gaskets seem to hold up well, but can be easily replaced, if necessary. The ink manifold gasket is simply a press fit into the precision machined groove of the manifold. The priming manifold gasket, which is more robust, is held in place by a retainer plate that is secured to the prime manifold arm by four small screws.

The primary ink reservoir is positioned right on the printing device stage, and ink pressure to the TIJ device can be adjusted by manually changing the height of the reservoir and/or the ink level in the reservoir. The DPPTS has typically been operated using negative ink pressures of approximately 1 to 11 inches, so that channel refill is by capillary action and "weeping" of ink from the nozzles is avoided. Level control and refill of the primary ink reservoir as ink is consumed by priming and printing operations is accomplished automatically through use of a liquid-level sensor in a secondary reservoir that gravity-feeds the primary reservoir. Detection of low ink level in the secondary reservoir by the sensor activates a pump that refills the secondary reservoir from an ink storage tank.

The print drum assembly consists of a shaft-mounted aluminum drum (10 inch circumference), a variable-speed drive motor/gearbox, and a 3000-spot/rev encoder. The assembly can be raised or lowered about a pivot point to place the drum either in printing position (close to the printing device) or out of the way to facilitate priming and stage movement operations. The movement of the drum assembly is accomplished through use of a miniature compressed air cylinder and associated control valves, which are activated by keyboard command. The drum rotates at operator-selectable speeds corresponding to process speeds ranging from 2 to 20 inches/sec (600 Hz to 6 kHz printing frequencies) at 300 spi in the process direction. Strips of paper (approx. 2.8 inches wide x 9.8 inches long) are temporarily attached to the print drum,.. using a special double-sided adhesive tape. The tape (available from the 3M Company, St. Paul, MN as product no. 928) is very thin (a 0.001 inch) and has a high-tack adhesive on one side and a low-tack ("Post-it™ Note") adhesive on the other side. A special applicator gun is used to apply the tape across the width of the print drum with the high-tack adhesive side down. Paper strips can then be easily applied to, and removed from, the drum for print-testing purposes. Approximately 30-50 sheets of paper can be used before a new piece of tape must be applied to the drum. Typically, five strips of print test patterns can be printed on one sheet of paper as the drum is manually repositioned along the shaft after each print strip. The distance between the paper surface and the printing device nozzle face is adjustable through use of built-in micrometer heads on either side of the print drum assembly.

To activate the printing cycle, a single keyboard command sequentially opens the priming manifold arm and lowers the print drum into position in front of the printing device stage. A second keyboard command initiates print drum rotation; after the drum has achieved constant surface velocity, a preselected print pattern is automatically printed and the drum stops rotating. The print cycle is repeated (to make up to five patterns) after manually positioning the drum to subsequent positions along the shaft. A second print strip can be made through similar keyboard commands. When printing is complete, another keyboard command sequentially raises the print drum and closes the priming manifold arm. At this point, the paper strip can be replaced and the printing device reprimed or ink can be rinsed from the device before unloading.

The optical system on the DPPTS consists of a binocular zoom microscope with integral illumination, mounted on a heavy-duty motorized slide assembly for precision positioning. The primary purpose of the viewing optics is to permit precision alignment of the probes to the printing device bonding pads. A cross-hair reticle in one of the eyepieces facilitates probe card positioning and alignment when a new probecard is installed in the system and is also helpful in setting the rotational (0) position of the printing device stage. The microscope is moved to the left or right by pushing the appropriate buttons on the front cover of the Rucker & Kolls probing unit.

The custom designed printer electronics package for the DPPTS, which is located in a metal enclosure separate from the Rucker & Kolls probing unit, contains all of the control and printer electronics for the DPPTS, as well as 5-V and 12-V power supplies for the integrated TIJ device logic and solenoid valve activation. A separate (operator adjustable) dc power supply for TIJ heater voltage is also housed in the enclosure. Operator interaction with the system is via a PC (or, optionally, a terminal).

The electrical diagnostic test (optional) is enabled by keyboard command and allows the operator to check out the electrical functionality of the device before print testing. In addition to the DPPTS, a current probe/amplifier and oscilloscope are required. When activated by the keyboard command, current pulses to the device (according to a preselected data pattern) are displayed on the oscilloscope. Such diagnostic testing is often helpful in the development stages of new device designs to identify and isolate electrical problems internal to the device, as well as to verify routinely good electrical probe contact before print testing. Additionally, such diagnostic testing can also be used to help analyze specifically the electrical failure mode(s) of the device being evaluated without actually print testing.

## The Cognex® Print Quality Evaluation System

The Cognex® Computer Vision System is used for quantitative analysis of the print test samples generated on the DPPTS. The system is composed of a video camera with magnification optics, a computer-controlled motorized sample stage, the Cognex® computer, and a video monitor, which is used to view the magnified test print pattern (see Fig. 6). A keyboard, PC, and monitor are used to input commands to the system and to display analysis data. This unit has been enhanced by extensive use of custom internally generated software. Measurement of the print samples is achieved by placing the print sample under the viewing optics and ensuring that the sample is held flat. Usually a ninth tone pattern is analyzed and the width of the printed pattern is scanned by the computerized optical system.

When the alignment of the test pattern is complete, the data acquisition phase can begin. At keyboard command, the Cognex® steps across the test pattern, frame by frame, marking the location of each printed spot, along with its dimensions. All of the positional and dimensional data are placed in memory for subsequent analytical calculations, which will give the desired information on print quality. Each spot is accurately marked with a cross hair, while the outside dimensions of the spots, from which spot diameters or spot aspect ratio calculations are made, are precisely recorded. When the operator is satisfied that the data has been accurately acquired, a keyboard command initiates computational analysis of the data. Print quality results are displayed on the monitor and are also automatically printed out on a desktop printer.

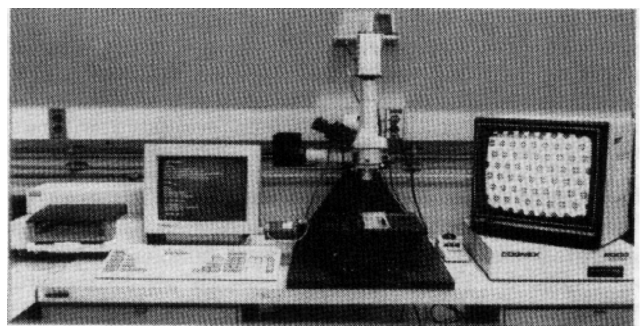


*Figure 6. Overall View of the Cognex® Image Evaluation System.*

The hard copy of the print quality analysis is divided into roughly three parts. In the first section, information on the average spot placement accuracy and average spot diameter is given, along with the standard deviation values. In the second section, signal-to-noise ratios are calculated for both spacing and spot diameters. The final section gives histogram-type information and also assigns an overall print quality grade to the device, based on user-specified rating criteria. In general, print quality analysis for a given test pattern typically requires only a few minutes to complete and gives consistent quantitative information on the print quality performance of the device.

## Application

Earlier in this paper, it was stated that the ability to print test unpackaged devices would enable initial testing of these devices, followed by device modification/optimization, and then retesting of the devices to determine what changes in performance (if any) had been made. An example of this sequence is shown in Fig. 7. The

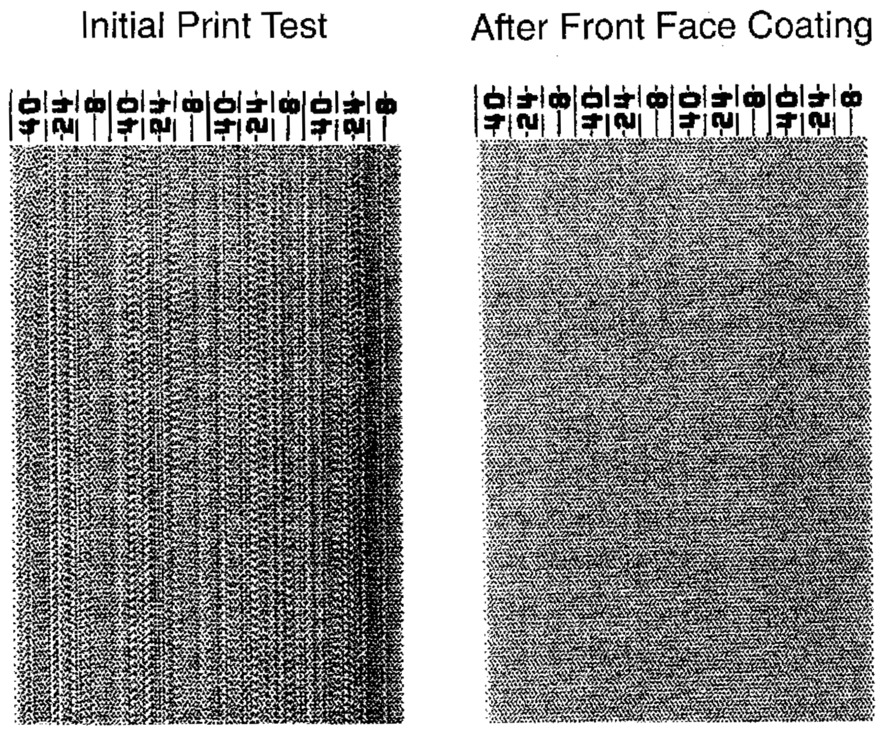



*Figure 7. Quartertone pattern printed on the Die Probe Print Test Station before and after coating the front face with F*DLC.*

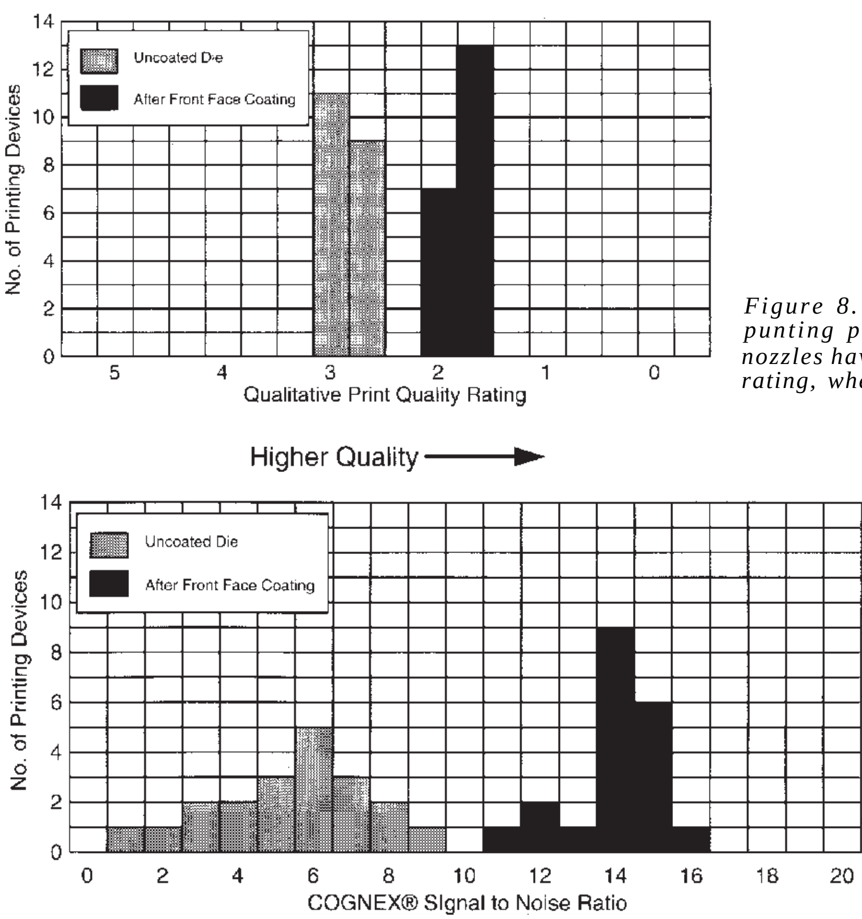



*Figure 8. Histogram showing "before and after" punting performance of punting devices in which nozzles have been coated with F*DLC. (a) is qualitative rating, whereas (b) is Cognex® quantitative rating.*

treatment of the front faces of the printing devices with various hydrophobic coatings is but one example of modifications that can be given to unpackaged printing devices. With the application of a fluorinated diamond-like carbon (F*DLC)[6] coating to the front face of the printing device, the ink wetting properties are greatly changed. The wetting properties significantly affect the jet directionality and, therefore, final print quality performance. The Cognex® system is used to establish efficiently very reliable print quality measurements in terms of signalto-noise ratios, which give us a (relative) quantitative assessment of the quality of these printing devices.

Before using the Cognex® system, a qualitative print quality rating scheme that was used was based on a visual inspection of the printing device performance. In Fig. 8(a) we see the ranking of two sets of data: one for uncoated devices (devices without front face coatings) and the second set for devices coated with F*DLC on the front face. Clearly, the coating process improves the quality of the prulthead, but because the data is qualitative and subjective in nature, it may not be precise. Figure8(b) shows data for the same printing devices and same treatments as used in (a), but Cognex®-generated signalto-noise ratios (derived from error analysis of spot placement and spot size data) are plotted instead to achieve a quantitative evaluation of the relative print quality. Additionally, Fig. 8 clearly shows the advantage of using the F*DLC front face coating as a means of improving the print quality performance on these devices.

## Conclusions

In conclusion, the DPPTS and associated Cognex® print quality analysis system have provided thermal inkjet technology programs at Xerox with a powerful test capability. Research, development, and production environments have all benefited from an efficient, nondestructive means of evaluating the bottom-line performance of thermal inkjet printing devices at the earliest possible stage of the fabrication cycle.


## Acknowledgments

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