Thermal Printing for the 21st Century

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Abstract

Portable rental car transactions with receipts, faxed documents, drivers' licenses, and bar code labels on hot steel slabs at 600°C ...are all printed with thermal printers. Notwithstanding the predictions of thermal printing's obsolescence for the last 10-15 years, the author explores some of the attributes of this technology which explain its robust nature, and its applicability well into the 21st century.

Evolution of thermal printing

FAX machines and weighing scales at deli counters clearly dominated the early days of thermal printing applications. Quite naturally, people tried to use this new printing process for printing labels for in-store and shelf labeling, and document applications, but soon became aware of the weaknesses of the new printed image, i.e. either fading or darkening, depending upon the dye chemistry used in the thermal paper. Thermal transfer printing very quickly supplanted direct thermal for situations which required more durable images, such as retail hang tags, theater tickets, or labels exposed to sunlight. Widespread acceptance of thermal printing technologies was sporadic until 1982, when the US Department of Defense mandated that suppliers to the DoD must use Code 39 barcode labels on all products sold and shipped to the US Armed Forces, the so-called "LOGMARS" program. Almost overnight, thermal printing technologies supplanted other printing technologies, notably formed font and dot matrix printing, for bar coded product identification labels, particularly in those instances requiring many different SKU's for a given manufacturer's products. The simplicity of use, ease of media selection, quick replacement of exhausted consumable supplies, and relatively low capital cost were key factors in these "technology substitutions". Within a year, thermal transfer printers moved from theater tickets to printing labels for identification of the hundreds of thousands of different part numbers acquired by the US Government. Clearly, the driving force for the explosive growth of thermal printing as an integral component of product identification was driven by the mandated requirements of barcode technology implementation.

Notwithstanding this momentum, the DoD experienced problems with the long term durability of the labels. Oftentimes, a product which complied with this new identification requirement, was received into the logistics networks, yet could not be scanned months later, due to label failure. Eventually, MIL-L-61002 evolved which described the acceptance criteria for the durability of the barcode identification, and hence, its continued usefulness. Once again, the technical attributes of thermal printing (most notably thermal mass transfer printing) enabled manufacturers to quickly comply with these additional requirements, thereby establishing an infra-structure to allow continued growth of thermal transfer printing in a wide variety of applications. Examples include barcode labels for identification of products facing long term exposure outdoors (rain, snow, UV deterioration); labels for identification of printed circuit boards (300°C temperatures, and harsh cleaning chemicals); for aerospace and aircraft (wire marking, exposure to kerosene, hydraulic fluids); for logistics labels in warehouses; for labels on products to be submerged underwater permanently; labels to withstand cryogenic temperatures; and many more.

In hindsight, the evolution of thermal printing processes is directly related to its success in solving increasingly difficult product identification problems. Specific attributes of this printing process make it unique from others. Arguably, clear understanding of these attributes suggests well-defined product identification applications for many years to come.

Printing process attributes

Experienced product identification practitioners are aware of the tradeoffs which usually accompany the printing technology of choice for a new application. Typically, these issues regarding image resolution, print density (cpi), throughput, variable information, batch vs. demand (as the identification relates to off-line or real-time labeling), cost/print, media adaptability, image durability, multi-color, connectivity (again, if real time labeling is required), capital cost, portability, and ruggedness of the printer in the environment in which it will be used. Other trade-offs may arise in more specialized situations. Clearly, the printed image must be compatible with the receiver's surface of the product, tag, ticket, or label. Particularly in the case of product identification "on the factory floor", the printing technology chosen is driven by the manufacturing environment and processes which the identified product will encounter during its manufacture, as will be discussed further below.

The sense of urgency for compliance with the LOGMARS mandates saw adaptation of thermal printing systems for low volume batches of LOGMARS labels, with many sets of different SKU numbers required, unlike the high volume production runs for UPC labeling of retail products. Thermal transfer printers were used, in registration with the fixed graphics output of hot stamping label presses, in order to provide variable information for the printed labels. This soon gave way to multi color thermal transfer ribbons, coated with panels of the primary colors (Cyan, Magenta, and Yellow), for use on a thermal printer with a single print head. Simultaneously, multi-head printers appeared on the scene, with each thermal head using only one of the primary colors, then stepping the label into the next print station for the next color, in very tight registration, similar to the well-known multiple print stations used in flexographic and other printing technologies.

As thermal printing gained widespread acceptance, printer manufacturers tried to differentiate their products with incremental gains in printing density (from 100 dpi to 300, followed by 600), print speed (from 1 ips, to 2 ips, to 6 ips, etc), and width (2" wide, 3" wide, 4,5,6 inches wide, and beyond). However, other printing technologies were poised to "obsolete" the thermal printers in specific applications related to multiple colors and absolute throughput. It seemed that thermal printing was so versatile that it was becoming "a jack of all trades but master of none". Yet, several of its attributes suggest that thermal printing's technological future still beckons as a viable and vibrant product identification technology.

Unique Characteristics of Thermal Printing

"Digital Printing" processes for product identification include dot matrix impact, ink jet, "laser printing" (using dry toner in the office environment), "wet toner" (such as the HP/Indigo process), and direct thermal and thermal transfer printing. Direct printing on product surfaces (instead of printing on a label to be affixed to the product's surface) would also include ink jet printing, laser etching by ablation/color change of the product's surface, and even 'dot peen' impact indentation of a product's surface.

Laser etching (by ablation or color change) is the only other printing process than thermal, which heats the 'receiver's' surface as an integral part of printing. This characteristic, plus thermal printers' ease of use, portability, low acquisition cost, and robust media contribute to its continued and future acceptance for product identification in real time environments. The following case studies will demonstrate this assertion.

Dye sublimation for security cards

Thermal transfer printers are widely used to print driver's licenses, myriad ID cards, and even passports. The thermal printer simultaneously heats the dye-containing ribbon, and the surface of the receiver, which causes the dye to sublime into the surface of the receiver. Again, the unique attributes cited above, have resulted in the technology's domination of this niche application when compared to other technologies, including 'instant photographic' ones.

Circuit board identification

Identification of circuit boards has clearly demonstrated the versatility and utility of thermal printing. In a typical board manufacturing process, the board's circuitry is produced on the surface of the plastic board substrate, by one of several processes (depending on the type of board manufacturing employed). Components are then placed onto the appropriate circuit interconnection points, and this "newly populated" board is heated to temperatures up to 300°C to allow the soldering/interconnections between components and circuitry to occur. The circuit boards are cooled, and then cleaned with one or more different saponifiers, cleaners, and solvents to remove any residue from the board. In many cases, additional components and subassemblies may be attached to this board, and the thermal and chemical cycles repeated several additional times, depending upon the complexity of the final product.

Not surprisingly, each board manufacturer uses proprietary manufacturing operations, each with particular solder, solder pastes, fluxes , saponifiers, solvents, cleaners, and process chemicals, from a variety of different suppliers. This has required the development of a variety of thermal ribbons and receiver sheets.

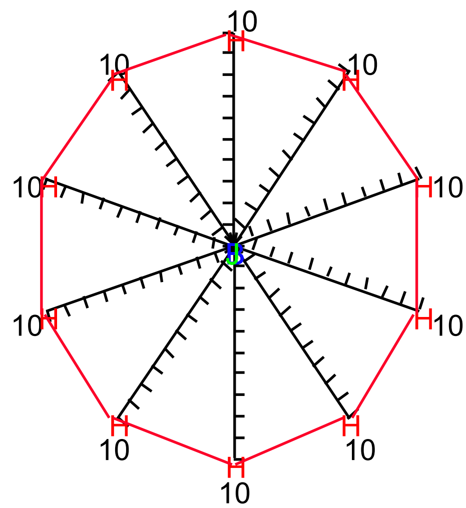

Figure 1. Idealized Perfect Score(each 'spoke' represents a different chemical)

The so-called 'radar chart' in Figure 1 depicts the results of a hypothetical "perfect image", printed on a "perfect receiver." Each 'spoke' of the chart represents a different flux, cleaner, solvent, or other chemical. A score which moves from the origin (score=0) toward the outside (score = 10), indicates the printed image's increased resistance to each particular chemical represented by that spoke. Now we examine actual cases.

Figure 2 depicts the case whereby Thermal Ribbon '1' is printed on receiver substrate 'A'. It has been widely accepted that by changing ribbons one may experience different chemical resistance characteristics, as shown in Figure 3, using Ribbon '2' on Substrate 'A'. Not surprisingly, we now observe different image performance. i.e. the failures observed with Ribbon 1 have been overcome by Ribbon 2. Yet, Ribbon 2 has weaknesses which were not experienced by Ribbon 1. However, once we use a different receiver sheet, 'B', (Figure 4), we see that Ribbon 1 now fails in the solvent it had previously survived with Substrate A, and now performs well in a solvent in which it had previously failed.

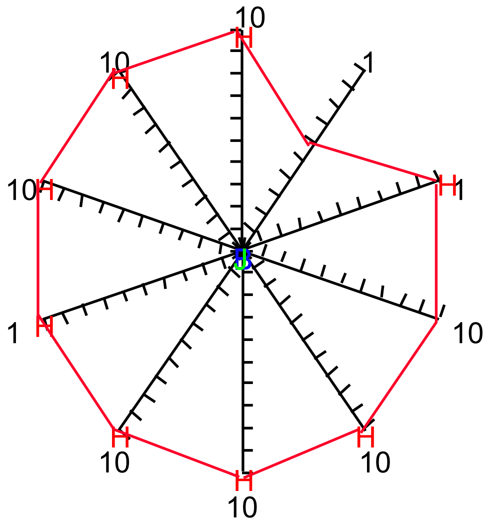

Figure 2. Substrate A, Ribbon 1

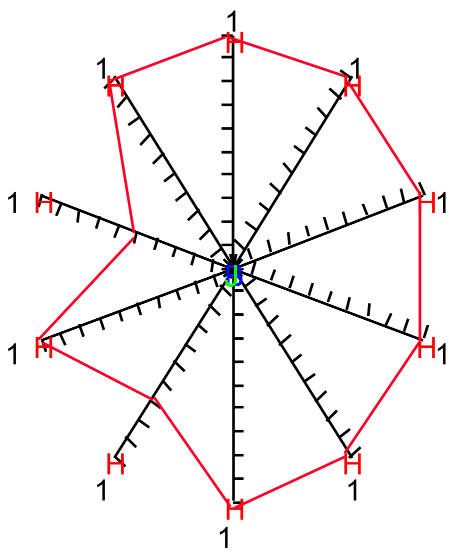

Figure 3.Substrate A, Ribbon 2

How often have we observed that by "changing the ribbon", we can resolve a process change, because the "ribbon works better"? However, the situation is not so simple. Let's consider the case of changing label materials with the same ribbons, 1 and 2, as above. When ribbon 1 is used with Substrate B (Figure 4), the test results in the identical solvents, reveal different results than shown in Figure 2, when Ribbon 1 is printed on Substrate A. The printed image now survives in the solvent in which it had previously failed, forcing reconsideration of the "change the ribbon" concept.

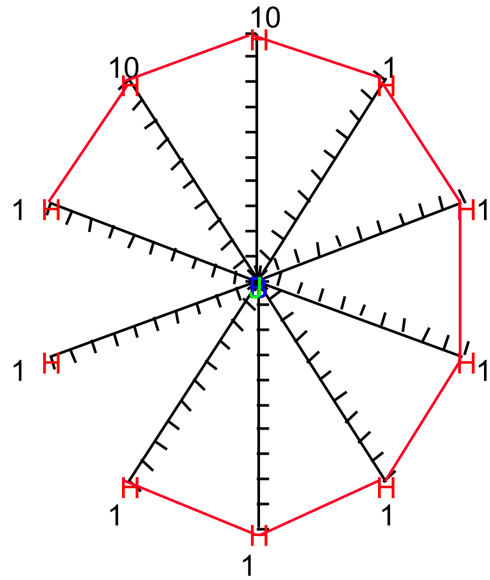

Figure 4. Substrate B, Ribbon 1

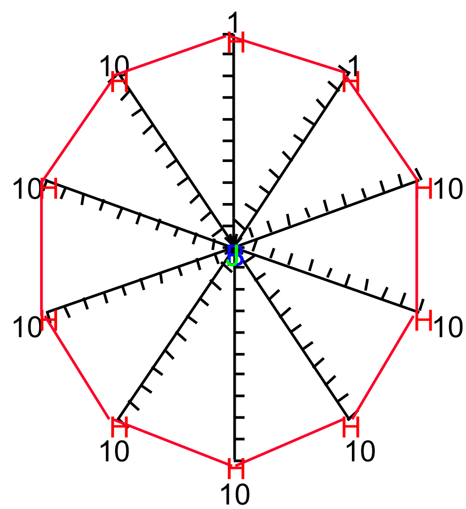

Figure 5.Substrate B, Ribbon 2

Figure 5 shows continued confirmation of the change in result between the same Ribbon 2, but now printed on Substrate B, as compared to Ribbon 2 printed on substrate A.

These idealized examples are based on actual observations in our laboratory, using well-characterized receiver substrates as well as commercially available thermal transfer ribbons. Moreover, we were able to establish unequivocally that the results of a given substrate-ribbon combination could be affected (again using the same solvent resistance testing as shown above) by using thermal transfer printers manufactured by different printer manufacturers.

In summary, the ribbon-substrate combinations chosen for a particular application dictate the outcome, rather than one or the other, independently; the thermal profile of the printer chosen unequivocally influences the result; and, there are several mechanisms at play in the thermal printing process, which influence the outcome for a given application. Our conclusion is that the simultaneous heating of the ink and the substrate is the most critical feature of this printing technology with respect to harsh environment applications.

Metallurgical Applications

An additional aspect of thermal printing technologies is the ease of adaptability of the ribbons and/or receiver sheet surfaces to accomplish specific, demanding tasks. Metallurgical manufacturers want to identify the rolls of hot metals (e.g. steel or aluminum) which are produced in rolling mills, immediately after the process is complete, by attaching a bar code identifier directly to the surface of the hot coils. Each coil may be up to 8' in diameter, 5 or 6' high, and at temperatures up to 750°C. Printing the barcode information on a specialty coated aluminum foil or steel tag was straightforward. However, at these temperatures, once the label is applied, all organic materials burned away within a few minutes, including the carbon black pigment, leaving behind a blank label. However, by using an inorganic black pigment, which was manufactured without too much difficulty by a ribbon company, the image remained at high contrast required for bar code scanning.

Interestingly, a so-called "obsolete" MICR ribbon, used by the banking industry, for printing small quantities of checks, worked very well in this application, except that the image was brown (vs black) due to iron oxides, instead of darker metallic oxides.

Implications - Future of Thermal Printing

Without question, real-time information identifying products has become a routine need. The growth of 'portable transaction terminals, such as car rental receipts, coupon kiosks, etc. will continue. Airport luggage identifiers, and other "cross-docking" applications will abound, perhaps in competition with RFID technologies.

Arguably, many industries will adopt standards for product identification and traceability, beginning on the factory floor, i.e. a so-called 'e-pedigree', an example of which is pending in the State of California, as part of a broadly defined Brand Protection/Anti-Counterfeiting requirement for pharmaceutical products. Many expect that e-pedigrees will become standard across many industries duringthe 21st century.

It is generally recognized that approximately 7-10 % of global production is counterfeit, or affected by, counterfeiting related activities. It touches us all, from fake pharmaceuticals, to tainted pet food; from DVD's and CD's to "fake" aftermarket automotive (and aircraft !) parts. Every industry/SIC code is under attack in today's global economy.

Many technologies have been proposed/used in overt, covert, and forensic ways, to deter, detect, and prosecute counterfeiters; yet, this activity continues on an exponential growth curve. Examples of technologies which are available include: optical and chemical taggants, dyes, phosphors, OVD's (optically variable devices, such as holograms), encrypted and/or secure serial numbers, UV and IR fluorescing agents, so-called IR 'up-converters', quantum dots, nano-particles, surface characterization, and many more, including DNA.

Thermal printing technology can be used as a delivery system for most of these technologies. Not surprisingly, many other printing technologies can also be used. However, it is the uniqueness of the thermal printing process which I believe will enable distinct (and hard to compromise by the criminals) brand protection features to be incorporated onto the product packaging, as well as onto the product itself, **beginning at the point of manufacture**.

As barcode labeling requirements drove the first 'wave' of thermal printing technologies, Brand Protection requirements promise to drive the second 'wave', particularly in industries which already use barcode technologies extensively. The existing AutoID infrastructure can incorporate Brand Protection features with minimal modifications to existing processes. Existing label materials and thermal ribbons can be enhanced by modification with authentication features relatively easily, since the proven ribbon/substrate combinations are well established.