# Flexo printing of fine lines

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**Keywords**

Flexography, line, electronic, plate, distortion

**Abstract**

Flexography is being considered for the volume reel to reel printing of flexible electronics and sensors. It is critical that the process accurately and consistently reproduces small features, particularly gaps and lines. Two plates were made using conventional and digital plate making technology. These were geometrically characterised and compared to the prints produced under identical conditions.

The manufacture of gaps, key to semi-conductors and sensors, highlighted the complex geometric shape on the plate and its potential interaction with the substrate during printing. Each gap had a ridge between it and the solid plateau area. While the width of the gap was similar to the width between the two plateau, the printed line was in most cases approximately double the width. The ridge acts as a bund retaining the ink on the plateau and preventing it from filling in the gap. The main differences between the plate technologies was found in the gaps produced on the plates. The conventional plate produced shallower gaps with more gently sloped sides at the top of the gap. The printed lines were similar from both technologies, but double the width on the plate. The printed acute and right angled corners were affected by the plate geometry leading to rounding of the outside edges and filling in of the angle between the lines.

## Introduction

Flexo is one of the volume printing processes being considered for the reel to reel manufacture of electronics on flexible substrates. A main requirement for the printing of flexible electronics is the ability to print lines with a consistent track and gap. The tracks must be able to turn through sharp angles as are necessary to create interconnections in electrical circuits, while maintaining a

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consistent cross section and not creating any shorts between lines. The distortion of the image carrier during the printing process is key to the achievement of high resolution fault free lines.

The objective of this study was to evaluate the potential of a narrow web packaging press for printing electronics and to compare the performance of conventionally exposed and digitally exposed flexo plates. The two flexo plates were produced with a bespoke image representing a series of features appropriate to printed electronics. This paper examines the changes in feature geometry from the nominal value on the plate to that printed on the film. Accurate measurements of the plate geometry allow the location of the changes in feature size to be indentified.

## Methodology

Electronics test image used for this study is shown in Figure 1. It has fine lines, gaps and nested triangles of varying line thickness and gap representing feature geometries appropriate for printed electronics. The nominal dimensions as specified in the image data file are shown beside the feature. The nominal gaps are located in the middle of the narrow line that runs between the two connection pads but are not visible at this magnification (Fig. 2). The fine lines represent the interconnections (tracks) that would be required to make a circuit. Thus the image has discrete lines 50 – 500 µm across and in the print direction to allow for the measurement of consistency and resistance. These have a high length to width ratio and feature pads to allow for the ease of measuring resistance. The ability to create gaps is critical to functional components such as transistors.

Of critical importance is their ability to maintain a constant cross-section and separation (gap) when running parallel to other lines at any direction with respect to the print direction. The track and gap have to be maintained constant when the line turns through angles of 90˚ or more.  The nested triangles allow the gap consistency to be evaluated both in parallel lines and at acute angles. These have a range of track and gaps from 50 and 100 µm. In addition the electronic test image includes some aerial designs for RFID, negative lines in solid areas and also grids for lighting applications. The image is 50mm wide including bearer bars. It was repeated seven times across the direction of print for use with banded anilox. Two plates were produced using this image, one digital (0.067" Asahi DSF) and one conventional (0.067" Asahi HF)

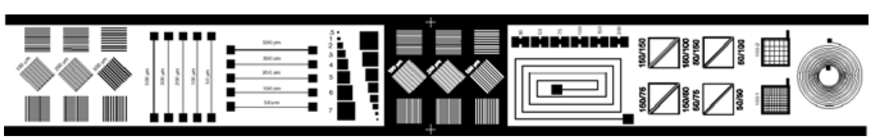


**Figure 1 Test image for printed electronics**

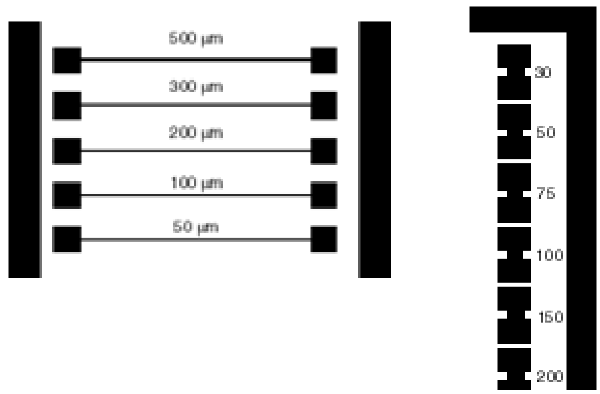



**Figure 2 Image features for track (left) and gap (right) evaluation**

The printing trials were performed on Timson's Tflex600 direct drive development press. The press was run at a constant speed of 30 m/min. the plates were mounted on a 450 mm circumference cylinder using 3M E1015 Cushion-Mount Plus mounting tape. The engagement was set at 75 µm. A constant volume anilox of 4.1 $cm^3m^{-2}$, with 320 cells/cm. Consistency across the width of the contact was evaluated by examining the repeated image across the print direction on the plate.

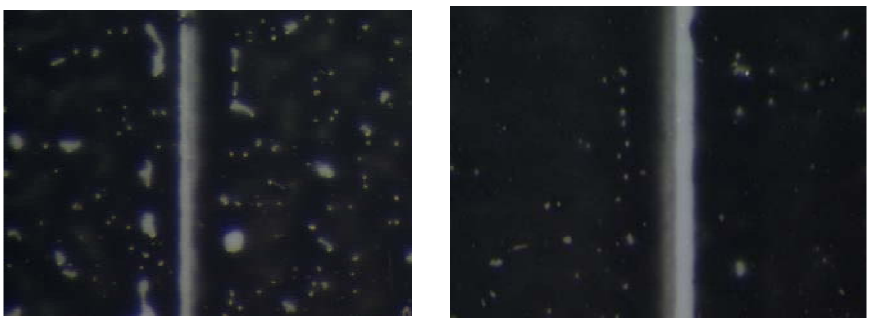
The objective of this investigation was to evaluate the potential of the press and the plate technology to achieve the geometric accuracy of features appropriate for printed electronics and not to achieve specific electrical performance. Therefore, a UV graphics ink (Sun Chemical Solarcat Cationic Process Black, SCT46-FW) was used in preference to an electronic ink which is usually solvent based. The UV ink has the advantage of maintaining the viscosity through the run and the features are as printed without a variable loss of solvent and volume on curing. Thus a direct comparison of plate technology could be made.

The substrate was a white, non-cavitated, uncoated high gloss biaxially oriented polypropylene (BOPP) film for label facestock applications (Rayoface™ W28)

The plate geometry was measured using white light inteferometry while the printed lines were analysed using image capture through a calibrated microscope and analysis.

## Results and discussion

Both the conventional and the digital plate produce clean gaps (Fig 3). In the solid areas adjacent and parallel to the gap, there is significant pinholing, particularly with the conventional plate. This could be a surface tension effect or reticulation around foreign particles. While this is acceptable in a graphics print as the holes are so small as to be invisible, one of the grand challenges for printing electronics and active materials using traditional printing processes is the need to produce level pin hole free solids.



Conventional Digital

**Figure 3. Microscope image of printed 50μm (nominal) gap**

However, the measured printed gaps are more than double the nominal gap specified on the image (Fig 4). The conventional plate produces slightly narrower gaps but at a nominal 35μm the plate fails to print a gap (i.e. the gap width drops to zero). At this nominal dimension the printed gap width does not become any narrower despite the reduction in nominal dimensions.

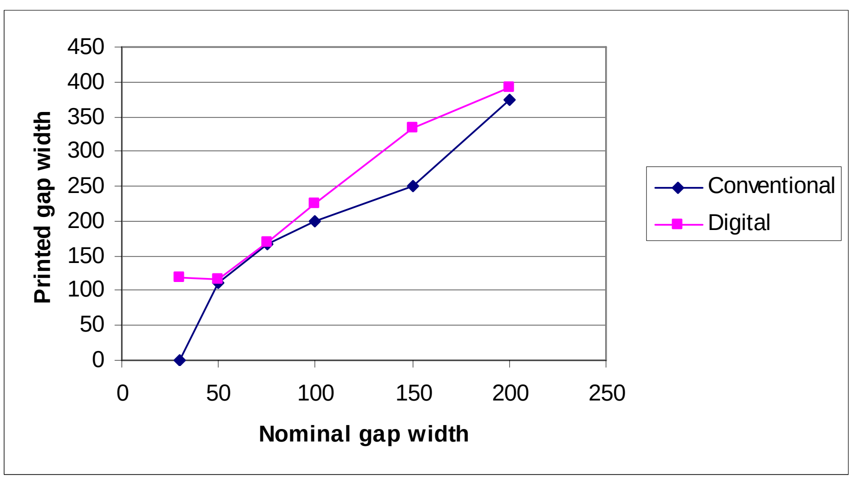



**Figure 4 Printed gap width (μm) versus nominal gap width (μm).**

The white light interferometer gives an accurate three dimensional contour of the surface and two dimensional profile through the gap on the plate (Fig. 5). In all cases the gap exhibited a raised ridge between the flat plateau of the solid area and the gap. It is essential to define the dimensions of the gap width and depth. This could be with respect to the highest point on either side of the gap i.e. the top of the ridge. This would give the dimensions of width $W_2$ with heights on either side of the gap of $H_1$ and $H_2$. Alternately the gap could be defined with respect to the plateau area of the solid, in which case the dimensions would be $W_1$ and $H_3$.

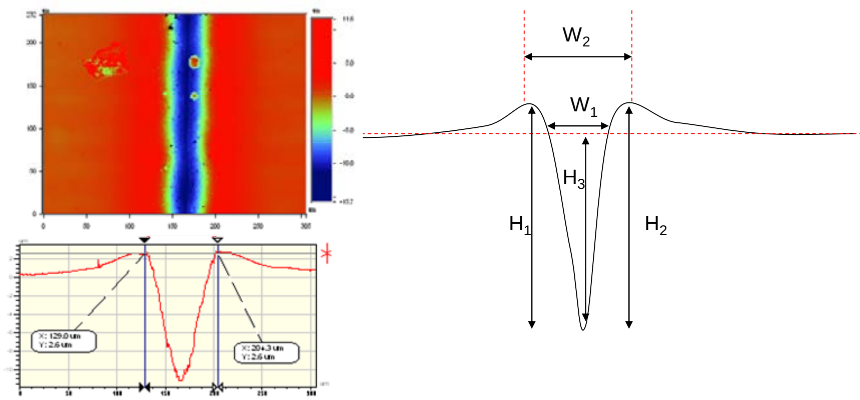



**Figure 5. Contour and section through a gap on the plate.**

The conventional plate produces similar but slightly smaller gaps between the peak on the ridge adjacent to the gap, $W_2$ (Fig. 6). The conventional plate shows an almost linear relationship with the nominal dimension while the digital plate produces a slightly larger gap on the plate at 50 and 75µm. The gap at the height of the plateau, $W_1$, is on average 14µm smaller for the digital plate compared with 27µm for the conventional plate.

If the percentage gap gain on the plate is defined as the increase in gap width compared to the nominal, then the conventional plate is producing a gap within 5% of the nominal value at $W_2$ at above 75µm while the digital plate only achieves better than 10% above 150µm (Fig. 7). At below this value the gap produced by the conventional plate is larger than the nominal dimensions, rising to 40% larger at 30µm. The digital plate exhibits a large gain at below 100µm. The width measured at the solid plateau height, $W_1$, for the digital plate has a negative gap gain of less than 10% at 100µm and above. However, the $W_1$ dimension is 27µm less for the conventional plate and this produces a large negative gap gain, i.e. the gap is significantly narrower on the plate than on the image. From these results it is apparent the care that has to be taken in plate making to ensure the gap is as requested on the original image. The differences between the plate and the nominal values are likely to be a function of the image setter and highlights the need for calibration during the plate production process.

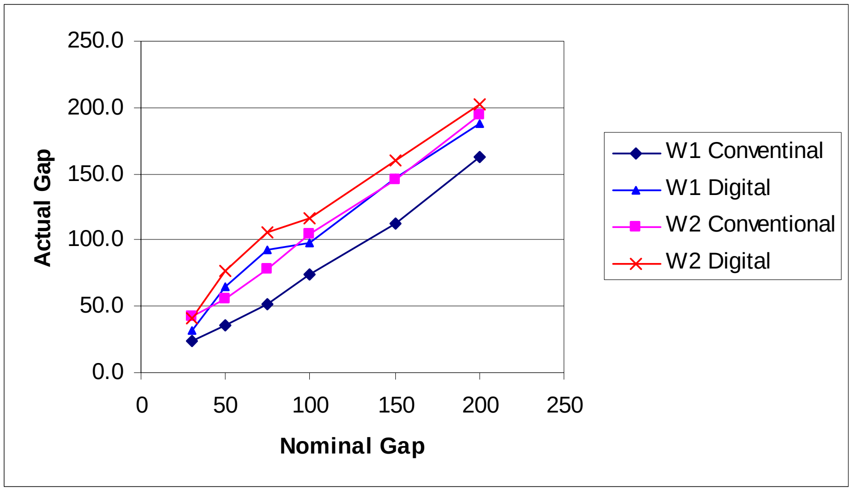



**Figure 6 Actual gap (µm) compared with nominal gap (µm) on the plate**

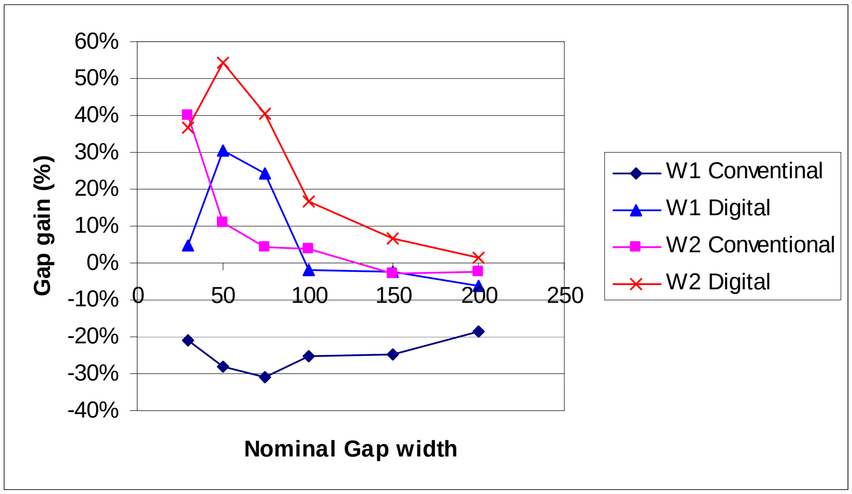



**Figure 7 Gap gain vs nominal gap width (µm)**

$W_2$ is nearer to the nominal dimensions and represents the edge of the gap, i.e. point at which the surface slopes into the gap with no further positive slopes, this is similar to the edge of a half tone dot and has been used to represent the measured gap on the plate in the remainder of this paper.

The gap depth, taken as the average of the height to the ridge on either side (average of $H_1$ and $H_2$) is compared with the gap width ($W_2$) is shown in figure 8. The conventional plate produces a much shallower gap, over half that of the digital plate for most of the gaps. The depth of the gap on the conventional plate is on average 30% of the width, while that on the digital plate is 70% of the width.

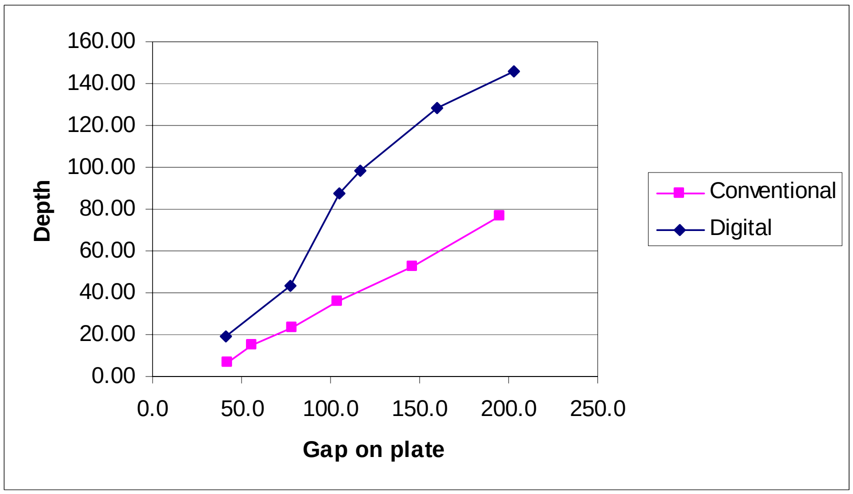



**Figure 8. Gap depth compared to gap width on plate**

Even though the gap depth is shallower, the height of the ridge (the difference between the depth below the plateau area, $H_3$ and the average of $H_1$ and $H_2$), is of a similar value of from 1 µm rising to 3-4 µm for both the conventional and digital plates (Fig. 9). As there is a larger difference between the height at the plateau area and that measured at the top of the ridge on the conventional plate, then this implies the slope at the top of the gap is shallower than the digital plate.

The printed gaps are much wider than the measured gaps on the plate, approximately double in most cases (Fig. 10). The smallest gap on the conventional plate (30 µm) did not print. The width at the ridge level was slightly larger than the digital plate. However, at the level of the plateau, the width of the gap on the conventional plate was only 24µm (compared with 31 for the digital plate) and would have strong similarities to a textured solid area, so has printed accordingly. Also, the shallow slope from the gap to the ridge would mean any distortion of the plate in this region due to engagement would produce pronounced barreling causing the slope to meet the substrate, increasing the solid area and eliminating the gap. There is also an anomaly with the digital plate at the narrowest gap in that although the gap is smaller on the plate the printed gap remains the same.

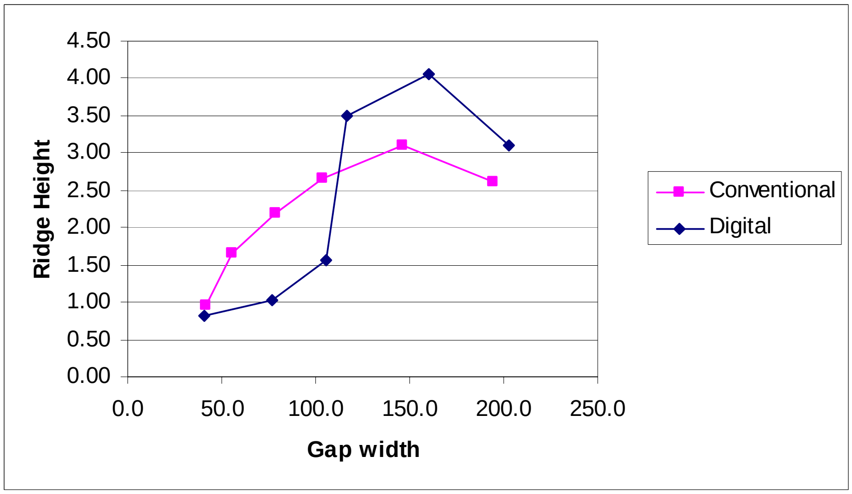



**Figure 9. Ridge Height (µm) versus actual gap width (µm) on the plate**

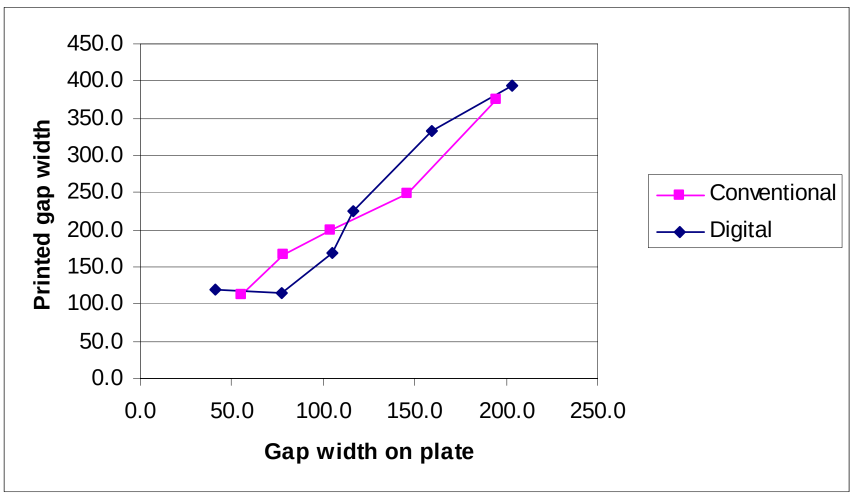



**Figure 10 Printed gap width (µm) compared with gap width on plate (µm)**

The amount of increase in the gap compared to the plate by considering the gap gain plate to print as percentage difference between the printed gap and that measured on the plate compared to the plate (Fig 11). The percentage gain is in all most cases near to 100% (a doubling in gap compare to the width). This suggests the measured width does not relate to the area from which the ink is transferred. If the plateau area was considered to be the region which only carried the ink and the ridge was in effect a bund to the area, then a the plate made engagement with the substrate, the ridge would make contact first and create a seal. Ink would only be transferred from the plateau area on the other side of the ridge which would mean the gap would be larger. This might also create negative pressure leading to cavitation and possible reticulation leading to the formation of pinholes. This would be particularly prevalent near to the ridge, creating the line of pinholes seen on the printed images (Fig. 3).

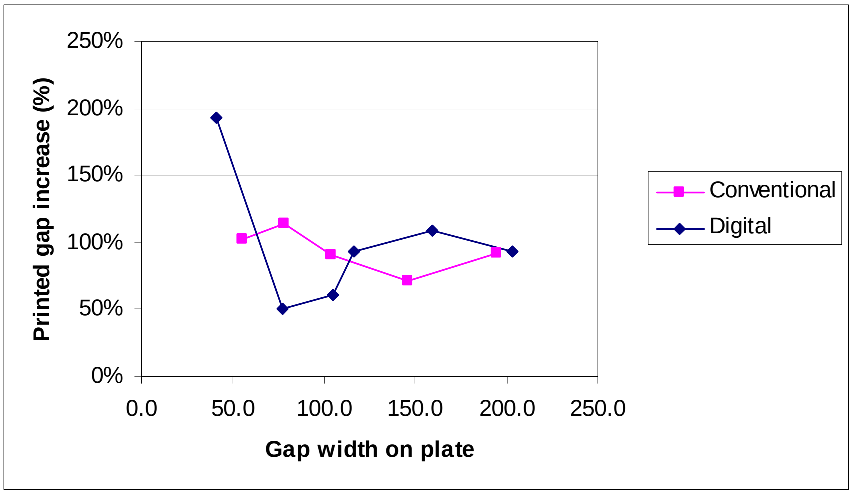



**Figure 10 Printed gap gain (%) compared with width on the plate (µm)**

Both plate technologies produce good quality lines, although the digital plate appears to produce a thinner line for the same nominal width (Fig 11). The measured line width is nearly double the nominal line width in both cases (Fig. 12).

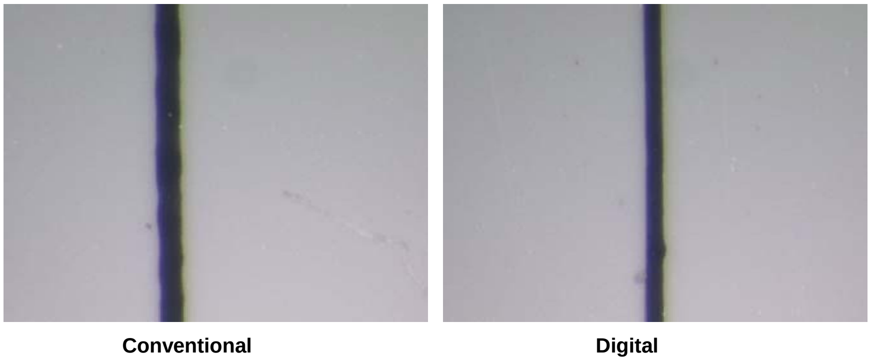



**Figure 11 Microscope image of 50µm printed lines**

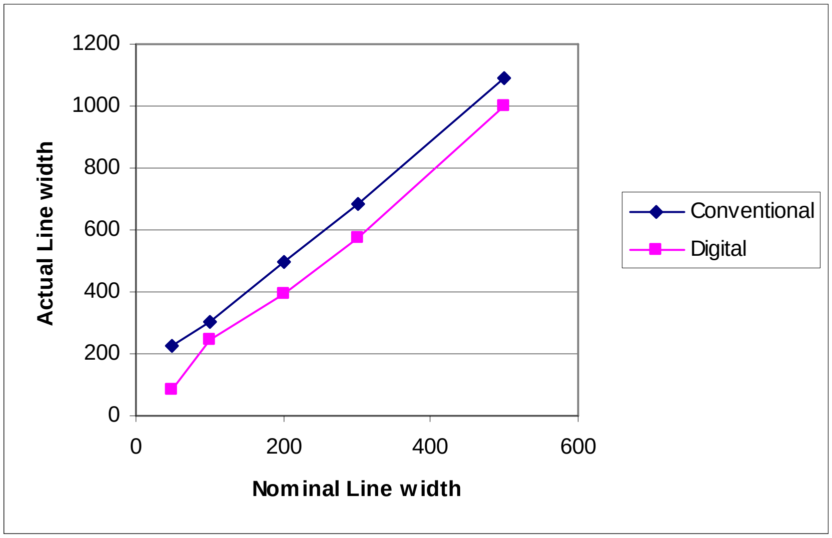



**Figure 12 Across line width (µm) compared to nominal line width (µm)**

However, the measured line widths on the digital plate are smaller than the nominal widths whilst the line widths on the conventional plate are larger than nominal. When the printed line widths are compared against the line widths on the plate, then the printed line widths are found to be approximately 2 to 2.25 the size on the plate (Fig. 13). There is little different in the performance of the two plate technologies. There is substantial gain which suggests that both the plate and the ink film are spreading whilst in the printing nip.

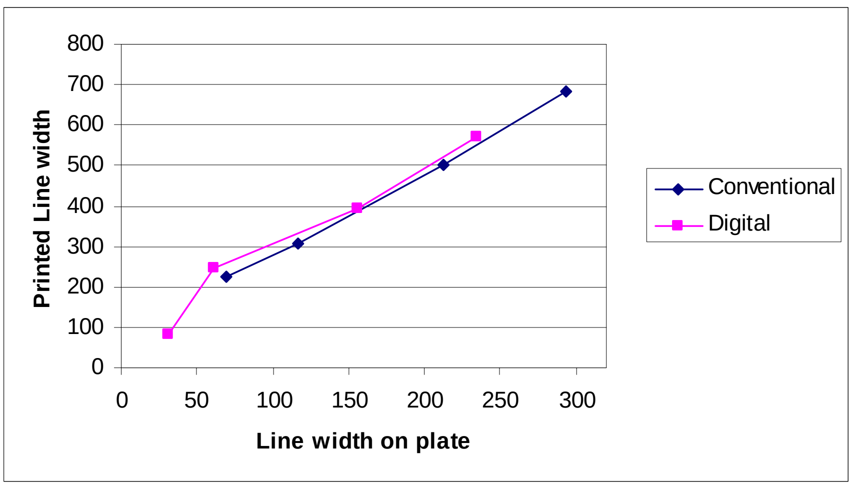



**Figure 13. Printed line width compared with line width on the plate (µm)**

A typical example of parallel lines turning through an acute angle are shown in Figure 14. The inside edge of the corner has tended to fill in while the outside edge has been rounded. The contour of the corner obtained with white light inteferometry highlights that the inside of the corner has gentle slope to the gap and the outer edge of the corner has been rounded (Fig. 15). This was examined by taking successive profiles across the width of the track (Fig. 16). The straight portions leading up to the corner are narrower than at the midpoint of the bend. This is as one would expect from the geometry, as the two straight lines are cut at an angle of 22˚ where they meet at the corner. The surface of the line also appears to be higher in the corner. It is not possible to ascertain whether this is a inherent function of the plate making process or a slight tilt of the image (the difference in height along the surface is of the order of 3 to 4 µm). However, the critical aspect is the slope on the inside of the corner. This is far less than the slope shoulder and slope of the straight line. The straight line would suffer some spreading and barrelling of the sides to meet the substrate, which resulting in the high gains observed for the lines in isolation. The inside edge of the acute corner would be prone to carry more ink and because of the slope be much more affected by distortion due to engagement.

As well as the rounding of the corner during manufacture, it is interesting to note the top surface of the line in the corner slopes from the outside towards the inside edge. This slope would lead to the outside edge engaging the substrate before the bulk of the line. Thus, this would tend to displace ink towards the inside edge of the corner, exacerbating the effects of barrelling and additional ink carriage on the slope. This leads to a thinner ink deposit on the outside edge of the corner of the line.

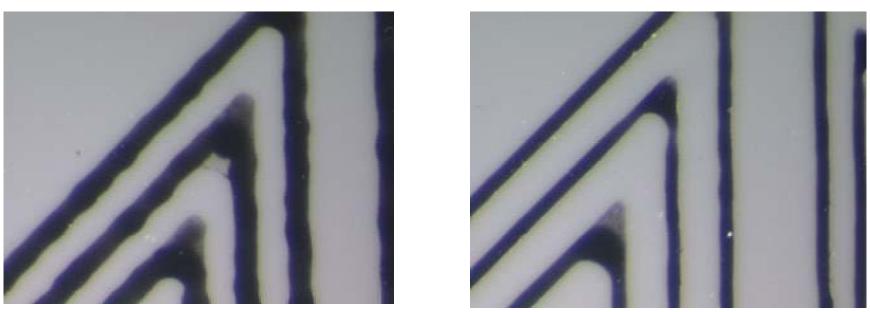



**Figure 14 Printed parallel line turning through an acute (45˚) corner**

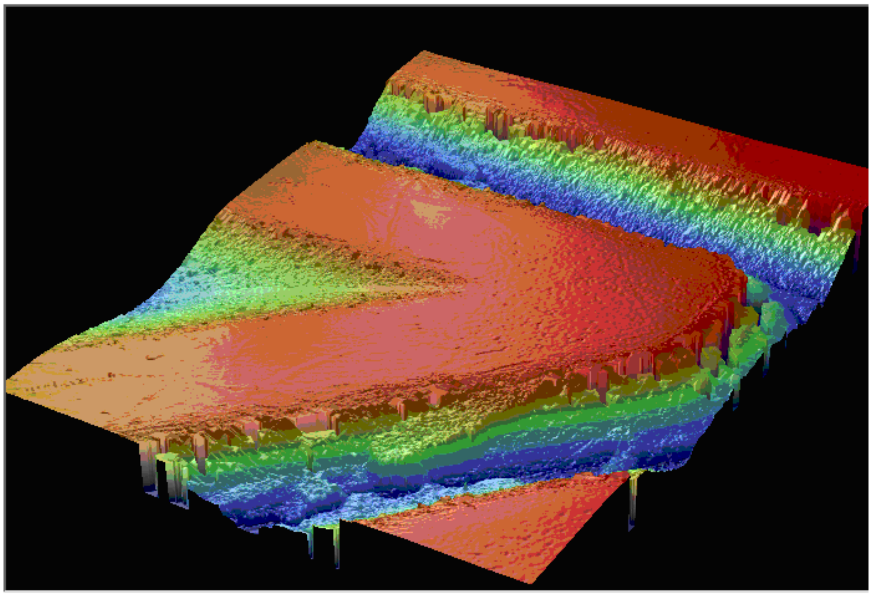


**Figure 15 Plate contour on an acute (45˚) corner**

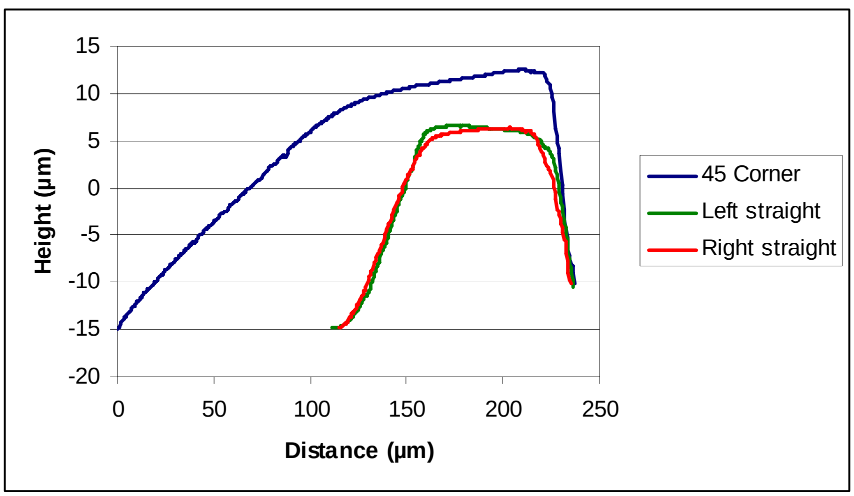
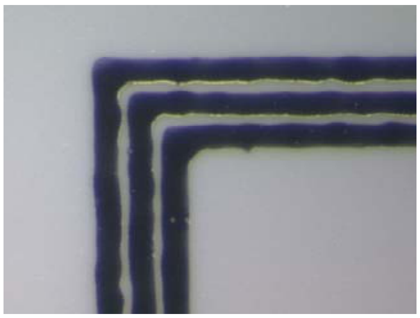
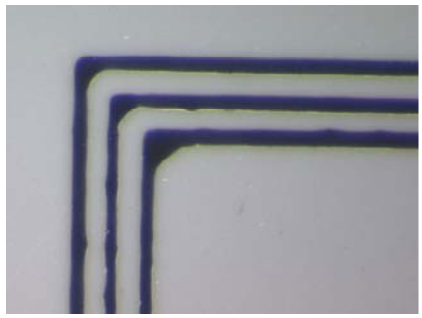



**Figure 16 Profile of a line on the plate through an acute (45˚) corner**

Typical examples of printed parallel lines turning through a right angle are shown in Figure 17. The lines tend to fill in on the inside of the corner, though not to the same extent as on the acute angle. Also, also there is slight rounding of the outside edge of the corner. The contour of the corner of the plate shows that there is rounding of the outside edge and a slight slope on the inside edged of the corner (Fig. 18). These are not as large as for the acute angle. The profiles of the line through the corner confirm this (Fig. 19). One would therefore anticipate that the level of ink fill on the inside is less, as has been observed. There are differences in the manufacture of the plate. In this corner the plate would appear to have a slight slope to the outside edge. However, as this is of the order of 1 µm one would anticipate less impact on the ink transfer, compared with the 2-4 µm in the opposite direction on the acute angle. The line also appears to slope down into the corner. This suggests the level of the top surface is either a function of the measurement or a random affect of the plate making process.



Conventional



Digital

**Figure 17 Printed parallel line turning through a right angled corner**

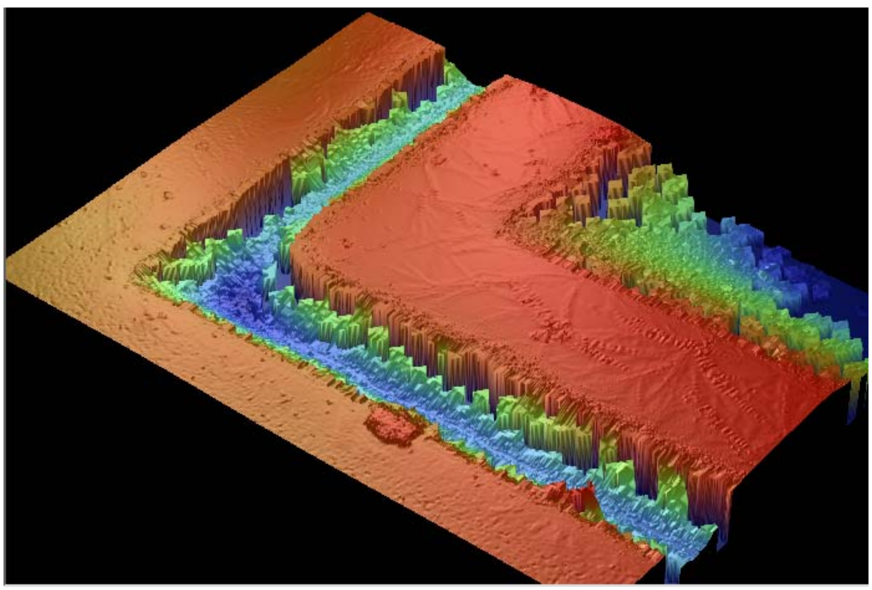


**Figure 18 Plate contour on a right angled corner**

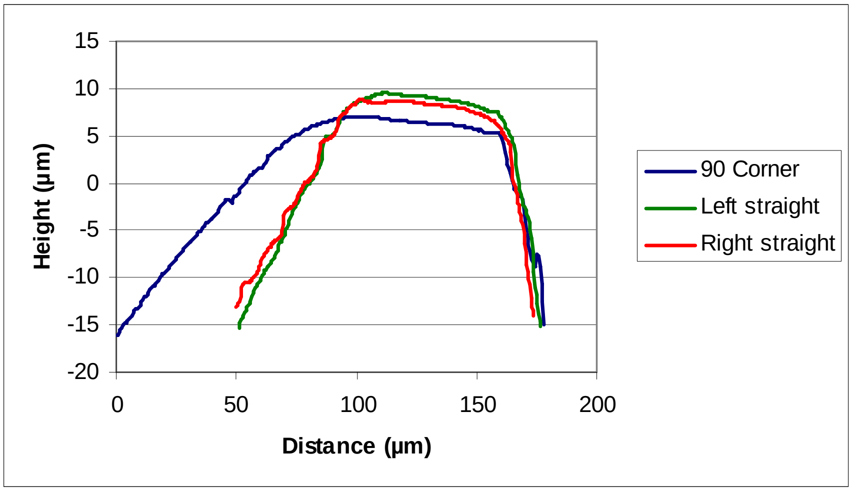



**Figure 19 Profile of a line on the plate through a right angled corner**

## Conclusions

The variation between the prints produced by the digital and conventional plate technologies can mostly be attributed to differences between the nominal feature size and the actual size on the plate. This highlights the need to fully calibrate the plate making process if the plates are to be used for accurate fine line work for electronic applications.

Both plate technologies exhibited a ridge which was higher than the plateau area on either side of the gap. The width of the gap between the peak of these two ridges approximately corresponded to the nominal dimensions in most cases. However, the plates printed to produce gaps approximately double this gap. This suggests the ridge acts as a bund, retaining the ink on the plateau area during printing. Thus gap should probably be measured from the point at which the ridge meets the plateau. It also probably contributes to negative pressures during the ink film splitting process and subsequent cavitation that leads to pinholing of the solid. When a minimum ridge height and narrowest gap occurred at the level of the plate plateau, then no gap was printed and the plate behaved as if it were printing a solid.

The main difference between the plate technologies was in the gap geometries. The conventional plate produced a shallower gap than the digital plate. It also had a gentler slope between the ridge and the gap.

The lines printed to approximately twice the dimensions measured on the plate. This is probably a combination of ink film spreading and barrelling of the line on the plate.

The printed parallel lines showed evidence of filing in on the inside corner and rounding on the outside corner. These both can be attributed to the plate profile. The inside slope of the corner tends to be less than the near vertical walls of the straight portions of the lines, particularly on the acute angles. This would create a reservoir for ink on the inside edge and make the plate easier to distort to meet the surface, effectively widening the line through the corner. On the outside corner, the plate was rounded by the plate making process, but had similar steep slope to the straight section of lines. As the cross section of the line would naturally widen through the corner from geometric considerations, there is a need to develop effective design strategies to ensure that any conducting tracks would both maintain their integrity and separation through corners in the circuit.

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