# Revolutionary Technique for Preparing Microvia Microsections of Printed Circuit Boards

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**Abstract**
We describe the design of a novel test structure, to which we have given the name "HD", that will facilitate the evaluation of blind and buried microvias in printed circuit boards, in comparison with existing, standard test coupons. HD will consume less board space than and be, at least in the case of blind vias, more representative of realistic board structures than standard coupons.

## 1 Introduction

Industry and military specifications for printed circuit boards typically require microsectioning of 3 vias within a maximum distance from the via center at 10% of the via's diameter. Figure A demonstrates this concept. Preparing a suitable microsection (hereinafter 'section') within that distance of a 100-micron via when using standard sectioning equipment on a structure like the B coupon described in IPC-2221 is little more than a matter of luck. Drilling of tooling holes takes separately from microvia drilling, so the probability of their being located correctly with respect to the microvias is remote. Even if the tooling holes themselves could be located correctly, uncertainties in section location resulting from undercut of grinding paper and location of tooling stops would allow little chance of sectioning success with microvias 100 microns in diameter.

Hence, labs commonly prepare microvia sections via tedious grinding and polishing by hand, and even then may only get one suitably prepared microvia at any point in time.

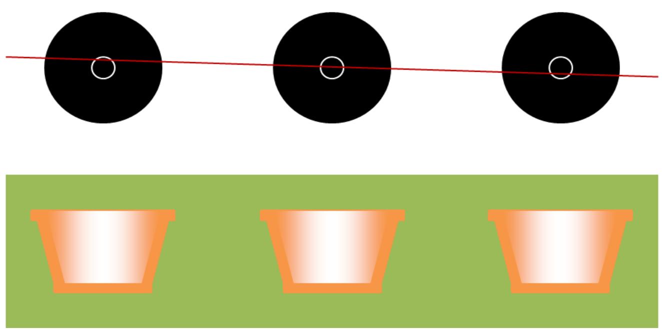

**Figure A**

For the benefit of readers who may not have prepared or seen a microvia section, Figure A shows a section of a buried (internal to the printed circuit board) microvia. Thickness of plating is an important parameter and may be estimated from scales incorporated into a microscopic image. Also critical for observation are the registration of the drilled hole to the capture (top) pad and to the target (bottom) pad, and the integrity of the junction between the target pad the copper plating.

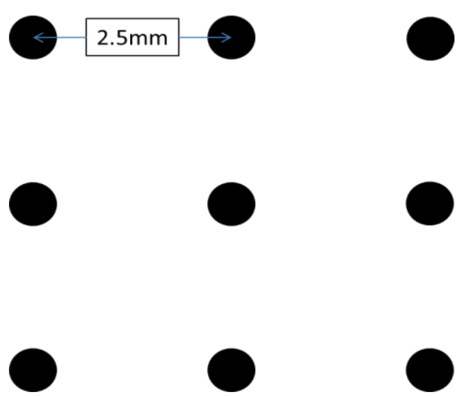


**Figure B**

Some years ago, Neves[(1)] described a test coupon that would facilitate microvia sectioning. We have designed another test structure, which we refer to as "HD" and which consists of an array of microvias. HD allows preparation of a section with at least 3 suitable microvias rapidly and with no special equipment beyond a simple grinding and polishing wheel. As an ancillary benefit, this test structure is more representative of a genuine board microvia than one fabricated as part of a standard B coupon, of which Figure B depicts a typical version. Further, it is likely (depending on the microvia parameters) to consume less area and to be located more conveniently on a fabrication panel than a standard coupon would be.

Fig C shows a view of a version of HD as seen when looking down onto the surface of a printed circuit board. (The same image would appear to someone looking at an internal plane of the board, in the case of buried microvias.)  HD arranges microvias in a hexagonal array, analogous to a single plane of a hexagonal close-packed crystal. We characterize HD with 2 parameters:

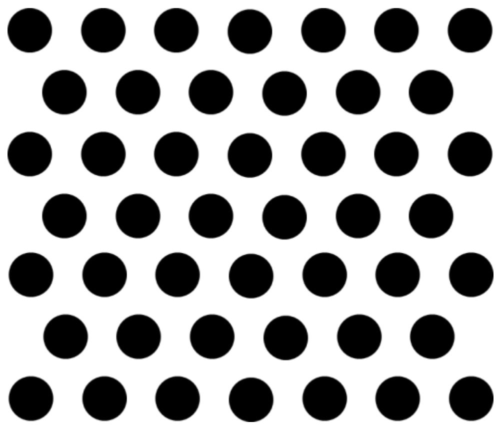

**Figure C**

k = distance between the centers of adjacent microvias

d = diameter of microvia (as drilled, before any plating).

The minimum value of k will be dictated by the design-determined annular ring of the microvia.

In section 2, we describe the design and properties of HD through a 5-step analysis. Section 3 shows the proposed complete HD. Section 4 demonstrates how HD allows incorporation of all blind and buries microvias in only two coupons.

**2 Design of HD: Maximum grinding-angle construction and calculation**

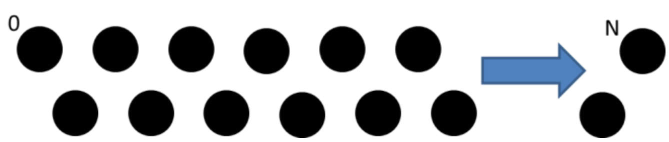


**Figure D**

Consider an array of microvias consisting of two rows, viewed above the surface of the new coupon, as in figure D. This array is the basic element of HD. How many microvias are in those two rows? That number is to be determined, and is principal result of this work. Think of the two rows as the top two rows of those comprising a hexagonal array like that we saw in Figure C.

**2.1** - As the first step in the analysis, assume the microsection line in Figure E passes through the center of the microvia on the upper left of the array in Figure D. (The plausibility of this assumption we will address later.) This microvia we denote as 0. If the section is prepared in a perfectly horizontal manner, it will pass through the center of all microvias in the first row. What is the maximum angle deviation, denoted by α, from 'perfection' that will allow 3 microvias to be sectioned within 10% of their diameters? Consider Figure E. It shows a section passing through the center of microvia 0 and passing through microvia 2 at a distance of 10% of the diameter from its center. (Clearly, the section will pass through microvia 1 at a distance less than 10% of the diameter from its center.) The exploded portion of Figure E shows the relation between the 10%d in hole 3 and the sectioning angle α.

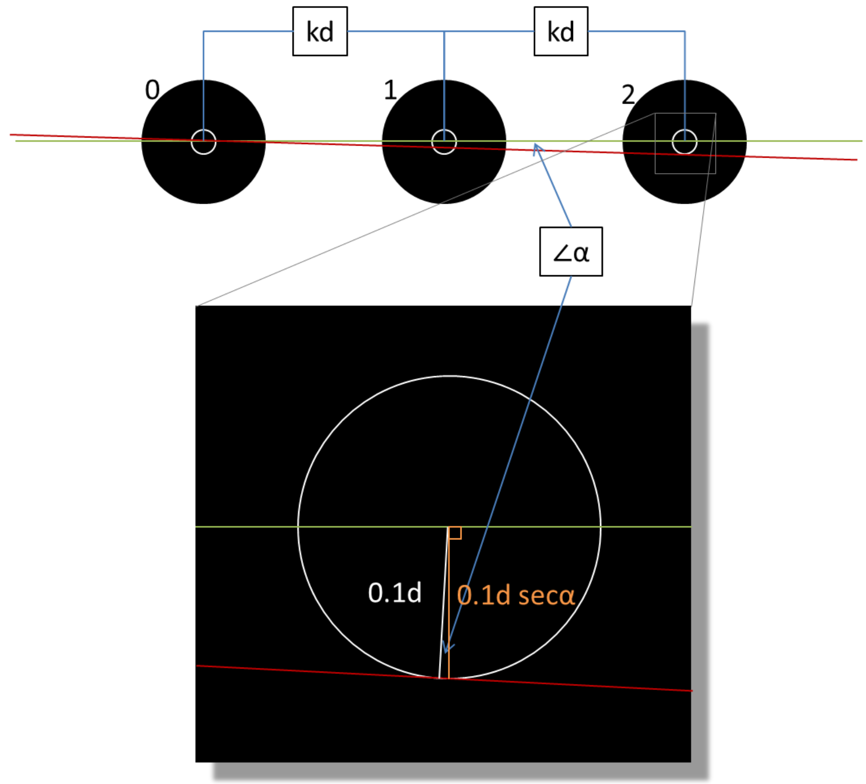


**Figure E**

Equation (1) shows how α is a function of k.

Since $\tan\alpha = \dfrac{0.1d\sec\alpha}{2kd}$

We get an exact solution as

$$\alpha = \sin^{-1}\left(\frac{0.1}{2k}\right) \qquad (1)$$

For k = 2, α = 1.45˚; k = 3, α = 0.995˚.

**2.2** – When the section is prepared such that it passes through microvia 2 at a distance equal to 10% of the microvia's diameter from its center, it must 'capture' microvia C, at the end of row 2, in the sense that it passes through that microvia at a distance of 10% of the diameter from its center. See Figure F. The angle between the axis of microvia centers in row 1 and the section remains α, as in step 1. That angle dictates what the distance D, in Figure G, of microvia C from the left edge of the HD structure, the line passing through the center of microvia 0 and perpendicular to the axis of row 1. Refer to Figure G, which relates D to the number of microvias N in row 2: D = Nkd – ½ kd

Note that the number of microvias in row 1 is thereby N+1.

Notice that the distance between the center lines of rows 1 and 2 = kd sin 60˚ =0.866 kd. Thus equation (2) shows the relation between α and N.

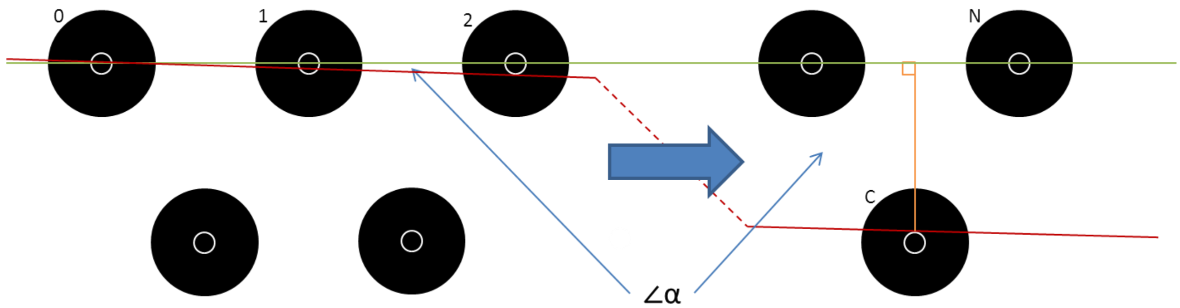


**Figure F**

From Figure G we see

$$\tan\alpha = \frac{0.866kd - 0.1d\ \sec\alpha}{Nkd - \frac{1}{2}kd}$$

From which

$$N = \frac{0.866k - 0.1\sec\alpha + \frac{1}{2}k}{k\ \tan\alpha} \qquad (2)$$

For k = 2 (implying α = 1.45˚ found in step 1), N ≈ 52; k = 3 (α = 0.995˚), N ≈ 118.

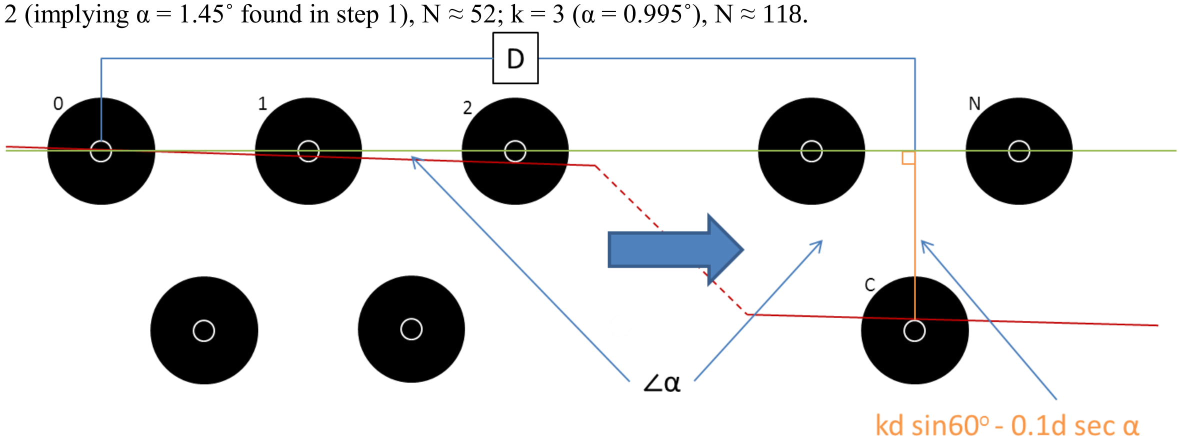


**Figure G**

**2.3** – When the section 'leaves' microvia 1, i. e., is more than 10% of its diameter from the microvia's center, our design intends for it to capture microvia A, at the middle of row 2. Refer to Figure H. The angle between the axis of row 1 and the section we call β. Equation (3) shows the relation between k and β.

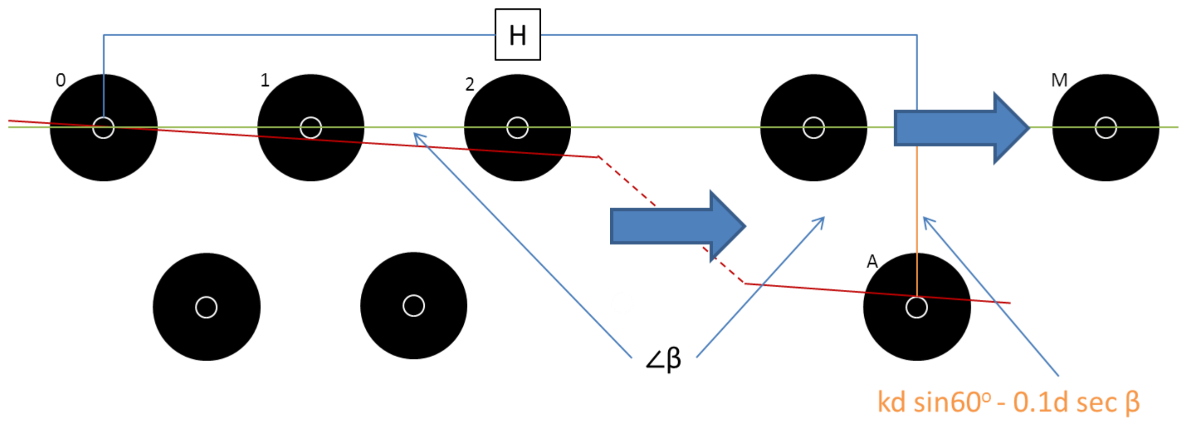


**Figure H**

Since $\tan \beta = \dfrac{0.1d \sec \beta}{kd}$,

$$\beta = \sin^{-1} \frac{0.1}{k} \qquad (3)$$

For k = 2, β = 2.90˚; k = 3, β = 1.91˚.

In figure H, we show the number of microvias in row 2 as being M. At this time in the discussion, we want to evaluate the number M and compare it to N calculated in 2.2. HD design will have to use the greater of the two numbers to assure the minimum of 3 microvias are properly sectioned at angles between 0˚ and β. The distance H from the vertical line through the center of microvia 0 to the vertical line through the center of microvia A is, in terms of M,

$$H = \frac{Mkd}{2} - \frac{kd}{2}$$

(Notice that the section through microvia B in row 2, as seen in Figure I, will pass within 10% or less of the microvia diameter from the center of microvia 2 as long as the value of k, the distance between the centers of adjacent microvias in units of the microvia diameter d, is less than some maximum. We will calculate that maximum k below in Step 5.)

Equation (4), obtained in a manner analogous to that used to derive equation (1), shows the relation between β, M, and k.

From Figure H,

$$\tan \beta = \frac{0.866\,kd - 0.1 \sec \beta}{\frac{1}{2} Mkd - \frac{1}{2} kd}$$

Leading to equation (4)

$$M = \frac{0.866\,k - 0.1 \sec \beta + \frac{1}{2} k \tan \beta}{\frac{1}{2} k \tan \beta} \qquad (4)$$

For k = 2 and the attendant β = 2.90˚, M = 33.19; for k = 3 and its attendant β = 1.91˚, M = 52.73. Each value of M is less than the relevant N (52, 118) from 2.2, so HD will use the larger N to define the number of microvias in its rows.

The reader may be asking - For angles between α and β, does the section achieve the maximum 10% diameter goal for at least 3 microvias? We can point out that, as β decreases toward α, the value of ½ M in the equation preceding (4) effectively increases, assuring the minimum 3 microvias are properly sectioned. Alternatively, one can visualize β decreasing slightly from its value in Figure H, with the section losing microvia A, but recapturing securely microvia 1 while continuing to maintain a distance less that 10% of the microvia diameter from the center of microvia B. Such an argument can be extended to every microvia in row 2 to the right of microvia B.

**2.4** – Following on 2.3, we want to determine what the maximum angle, γ in Figure J, is that permits the section to pass within 10% of the microvia diameter of the center of microvia B. That angle is the maximum angle for which we have calculated the section will encompass the required minimum of '3 microvias within 10%'. All of the HD structure parameters are available at this point, so calculation of γ is straightforward.

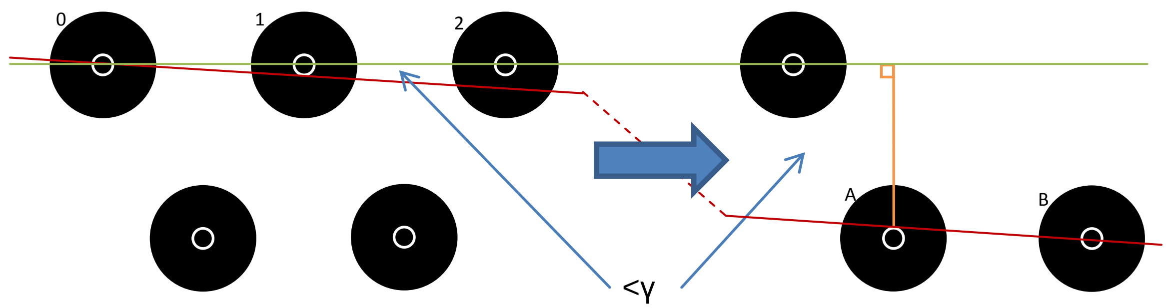


**Figure I**

Equation (5), following on the pattern used to obtain equations (2) and (3) shows the relation between M, k, and γ. Notice that we use M in equation (4), as that number characterizes the location of microvia A, as seen in 2.3, even though we have N holes in row 2.

$$\tan\gamma = \frac{0.866k + 0.1\sec\gamma}{\frac{Mk}{2} + k} \qquad (5)$$

Equation (5) does not have a closed-form solution, but we will assume γ is small such that sec γ is close enough to unity and we can use equation (6) to evaluate γ and not be concerned with any practical impact of the error. This assumption seems justified in that, for example, sec 2.90˚ = 1.0013.

$$\gamma \cong \tan^{-1}\left[\frac{0.866k + 0.1}{\frac{Mk}{2} + k}\right] \qquad (6)$$

Taking M = 34 when k =2 above, we find γ ≈ 2.913˚, which does not seem to be a notable increase over the value of β = 2.90˚ found earlier. When we use the value of M calculated for k = 3, the difference between β and γ seems to be less than the error in the approximate calculation.

**2.5** – Figure J is a detailed view of the section through microvias A and B, when microvia A initially, at the angle β, is included in the required minimum of '3 microvias within 10%'. As microvia B becomes increasingly distant (horizontally) from microvia A by moving to the right, as Figure J shows, the section will pass the maximum 10% of the microvia diameter below the center of microvia B when k = some maximum value, denoted by K. As seen from Figure K, the relation between K and β is according to equation (7).

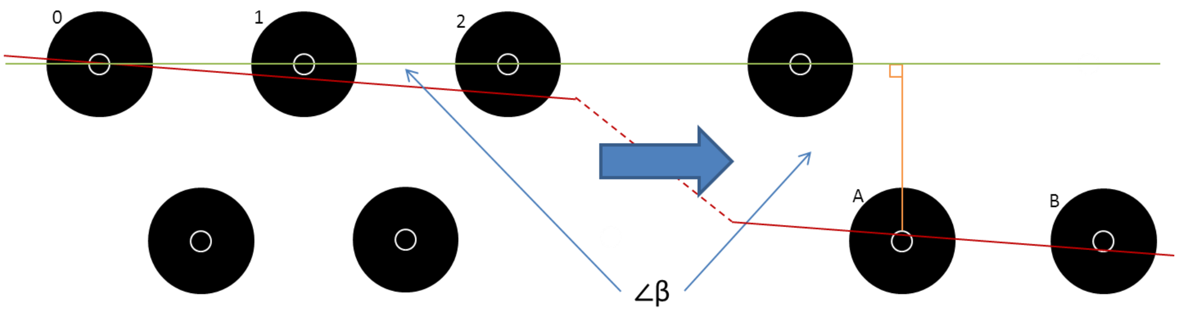


**Figure J**

Since $\frac{Kd}{2}\tan\beta = 0.1d\ \sec\beta$

K = 0.2 csc β (7)

For β = 2.90˚, K ≈ 4; for β = 1.91˚, K≈ 6. Hence, microvia B will meet the 10% criterion whenever microvia A does.

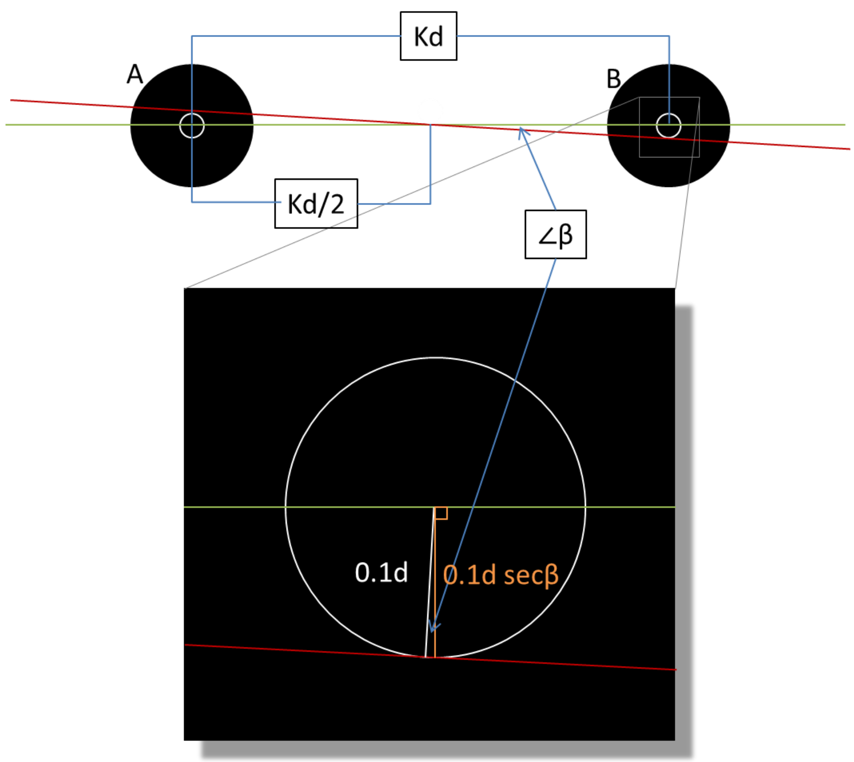


**Figure K**

**3 Complete HD structure**

To assure we can easily get a section to pass through the center of microvia 0, we propose to replicate microvia 0 in our figures to its left and above and above row 1 – multiple times, along with the other microvias in rows 1 and 2. Figure L shows this concept. The goal in preparation of the section is thus reduced to having the section pass through the center of one of the microvias in the rectangle on the upper left of Figure L.

By symmetry, we could interchange the roles of microvia 0 and of the last microvia in row 1 (denoted previously as microvia 3), at the same time reflecting the angles α and β about a vertical axis through the center of HD. The analysis and results would be no different from the ones we performed based on the section's passing through microvia 0. There is no reason to favor our approach and analysis above, which starts with the microvia 0 on the upper left, over one locating microvia 0 on the upper right. Hence, the range of angles for which the section is properly prepared, with the required 3 microvias, is from $-\gamma$ to $+\gamma$, i.e., $2\gamma$.

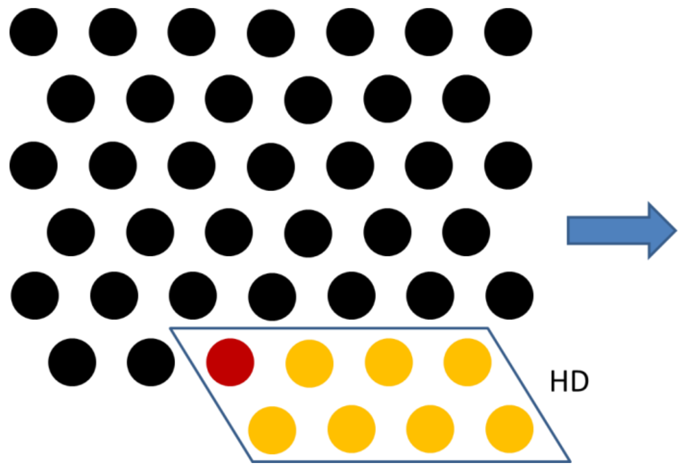


**Figure L**

**4 Use of HD on multiple layers of the same coupon**

Multiple HDs can be incorporated into the space formerly occupied by one coupon, such as the B coupon seen earlier. HDs could be made for alternating dielectric layers so only two coupons would be needed for any number of layers. See Figure M, which indicates how, for a six-layer panel, coupon И can encompass microvias connecting layers 1-2, 3-4, 5-6 while coupon Б encompasses microvias connecting layers 2-3, 4-5. HDs in the two coupons would allow sectioning of all required microvias through quick grinding and polishing of two coupons.

**Example of HD size**

As a practical example, consider the case of a 100-micron microvia, with k = 3. The distance between centers of adjacent microvias is thus 300 microns. We saw, from step 3 above, the number of microvias N+ 1 in row 1 is 119. Hence the length of row 1 is 35 700 microns = 35.7 millimeters.

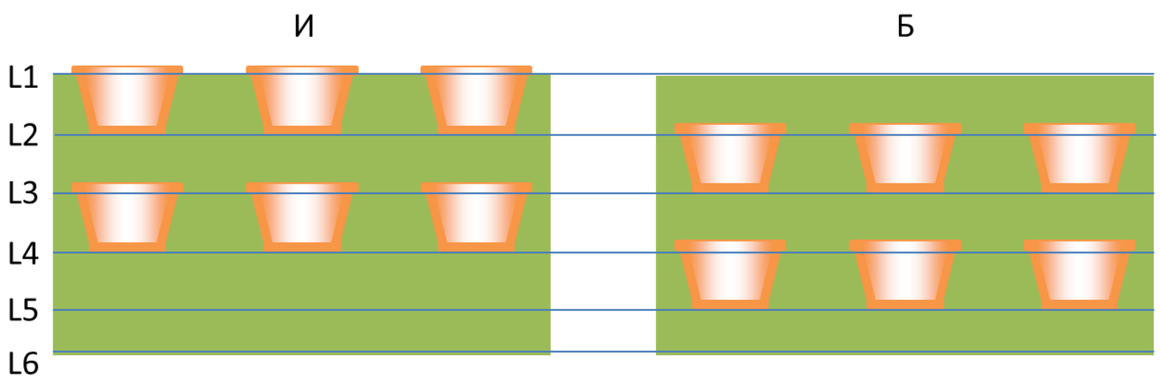


**Figure L**

The distance between row 1 and row 2 is, using the analysis in step 3, 259.8 microns or about 0.26 mm.

Hence, rows 1 and 2 consume an area 35.7 mm x 0.26 mm.

Suppose we choose to complete HD by replicating microvia 0, as described in section 3, 20 times to its left and 10 times above row 1. These replications would produce a complete HD area roughly 41.7 mm x 2.9 mm.

**Reference**

1. Bob Neves, 'Testing Tiny Holes and Thin Dielectrics', *Circuitree*, August 1997.

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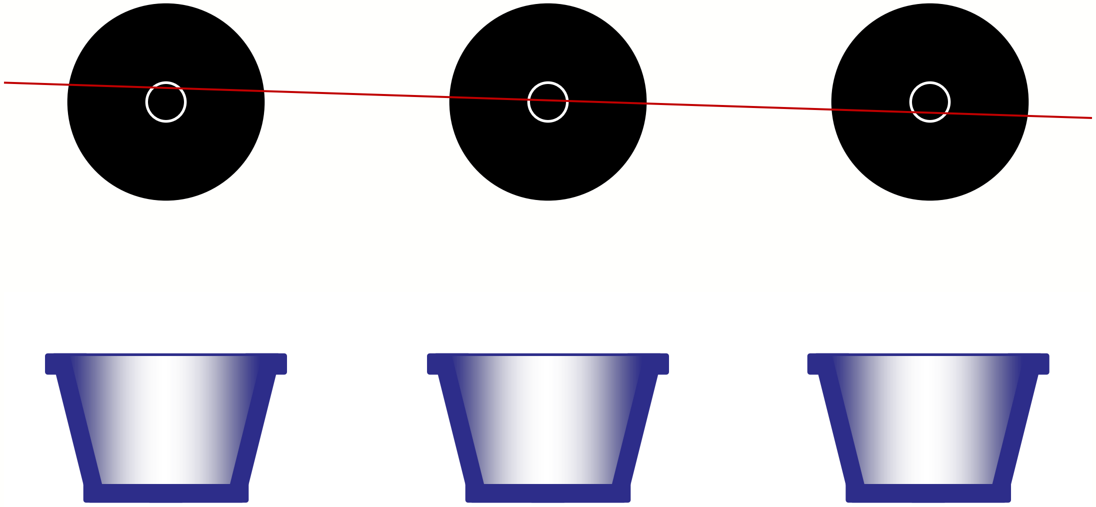
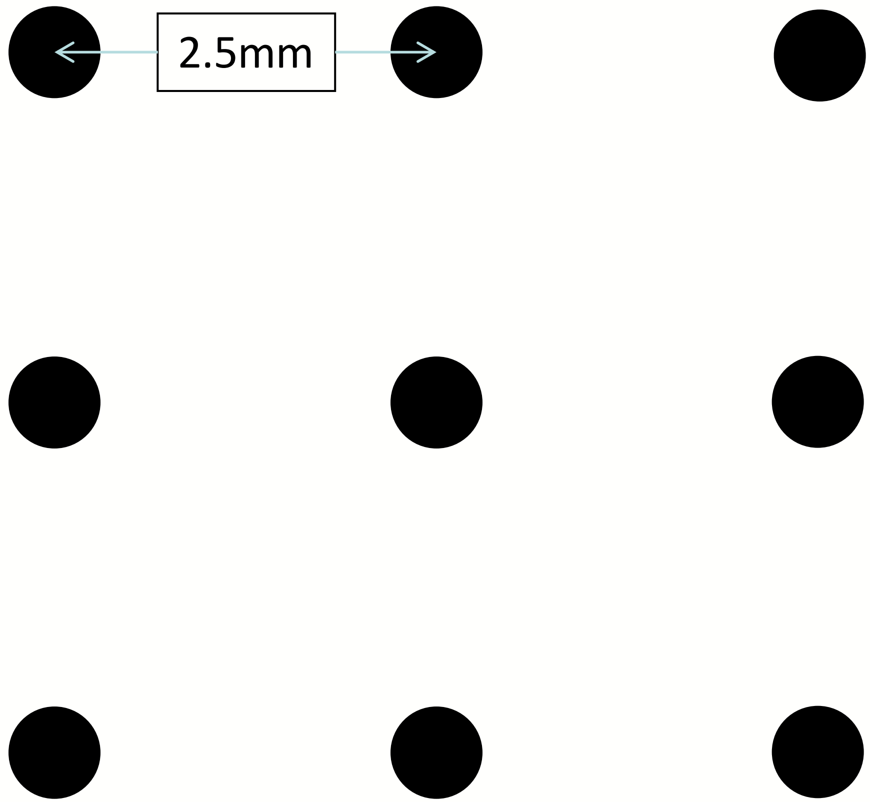
# OUTLINE

- Problems with current microvia approach
- Overview of revolutionary technique
  - Allows range of angles
  - Consumes little space
- High-level Analysis of HD, in 4 stages
- Example

A



B



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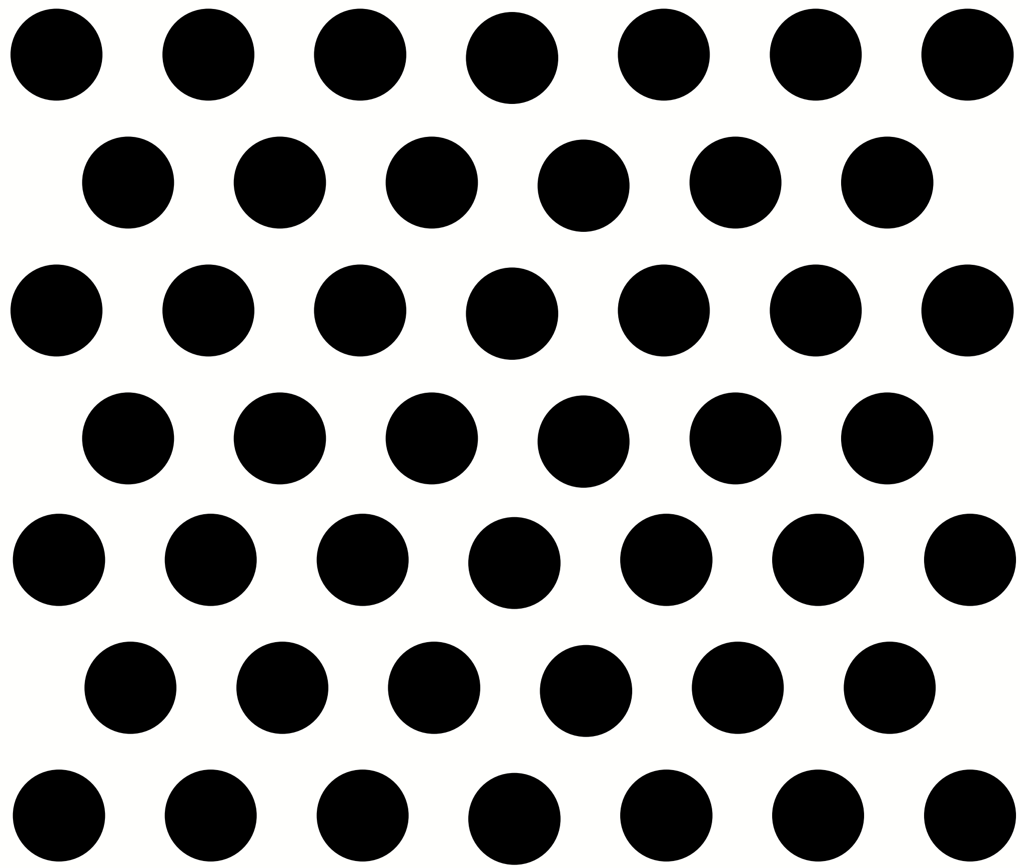

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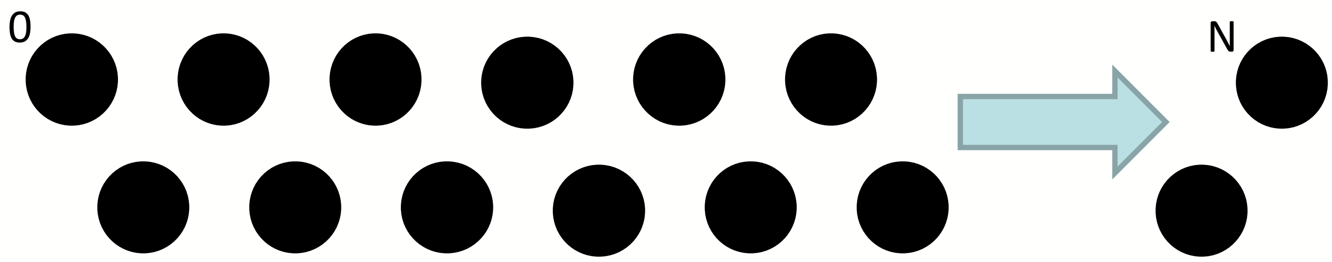

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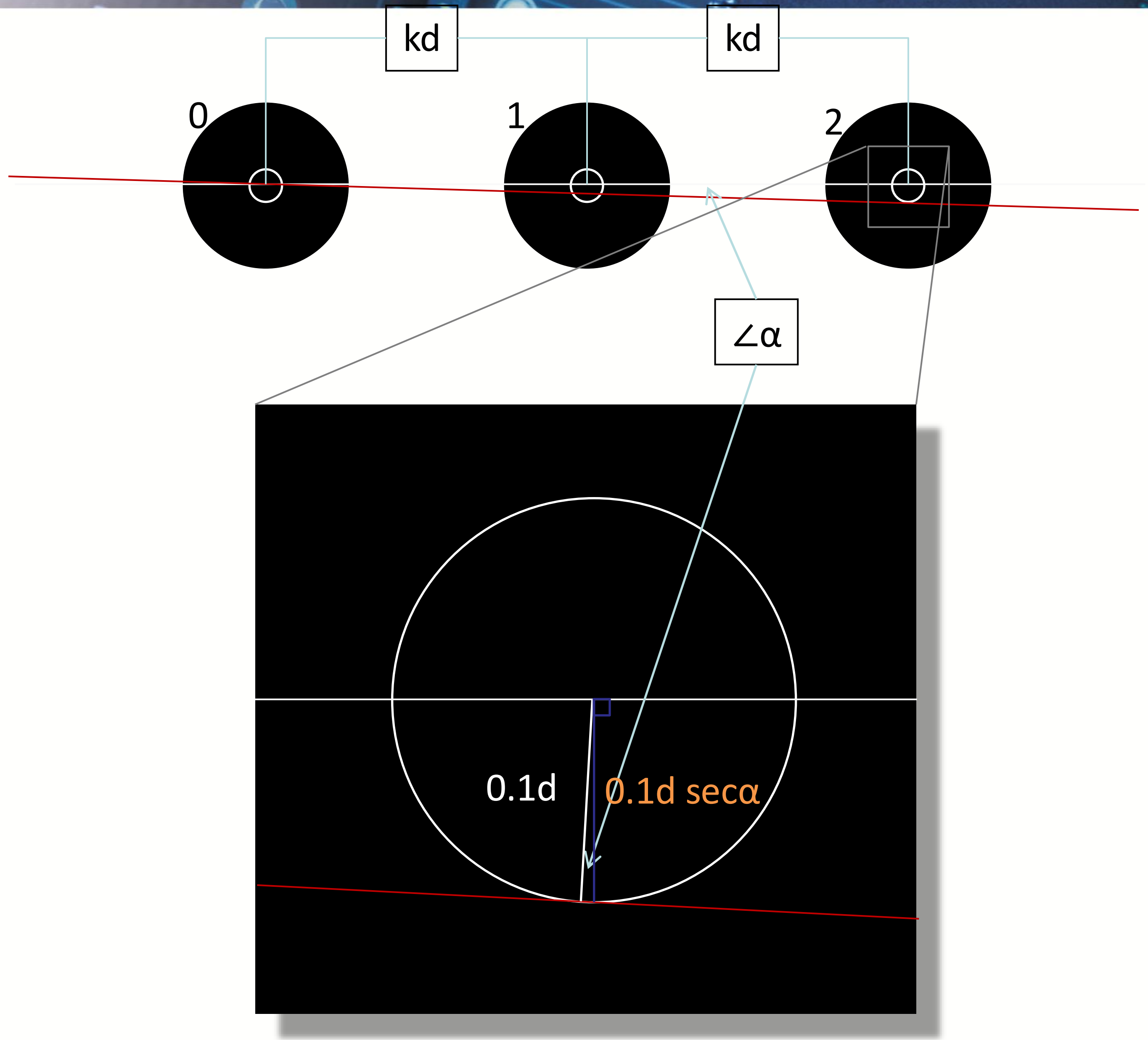

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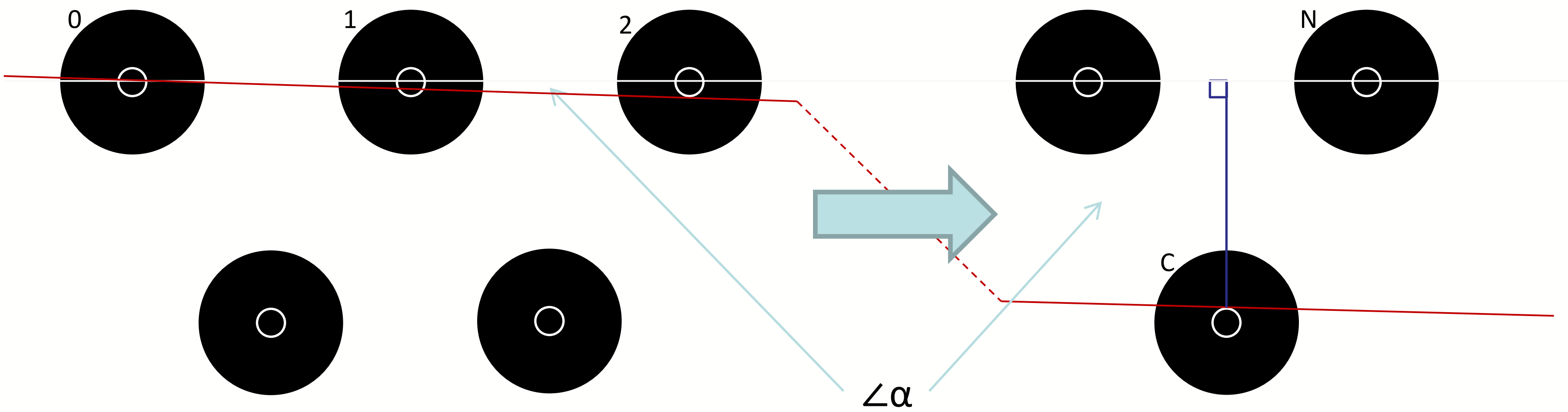
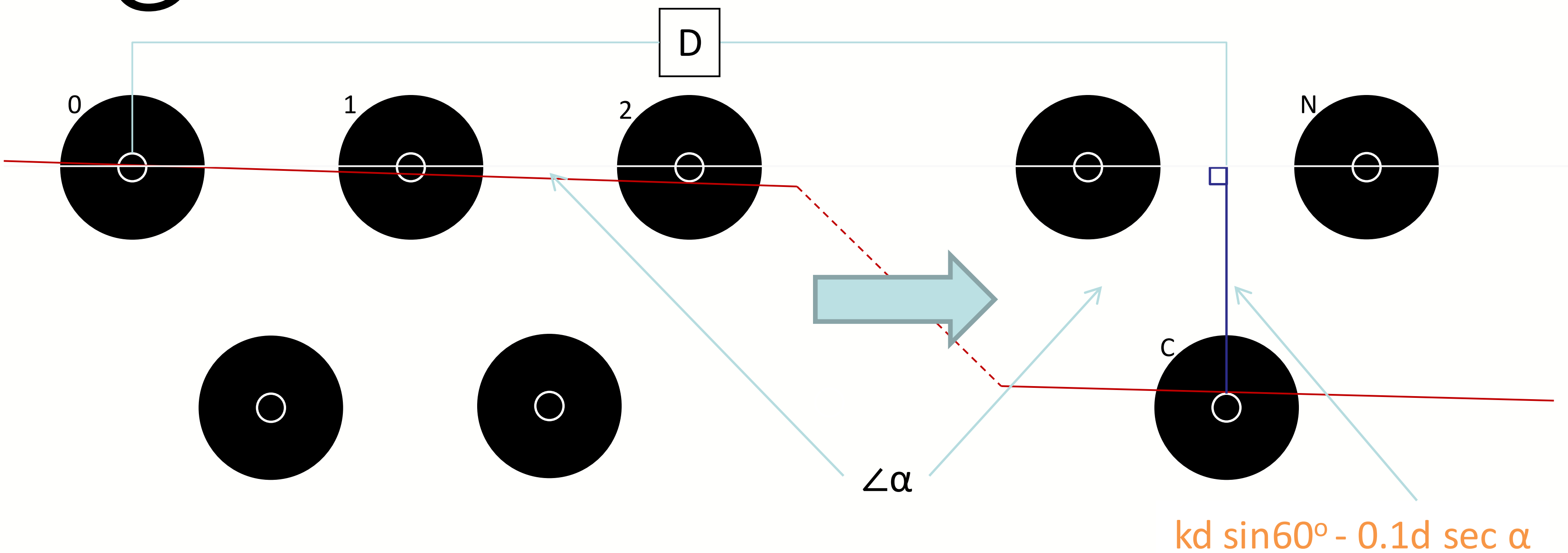
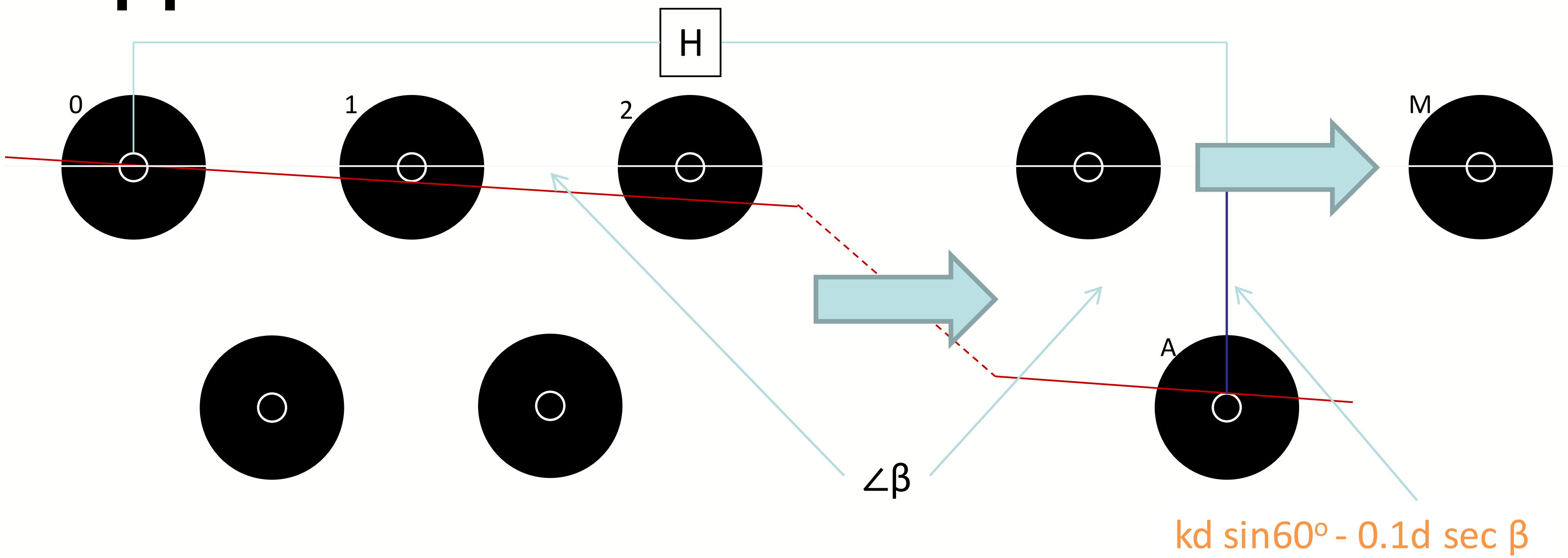


# G



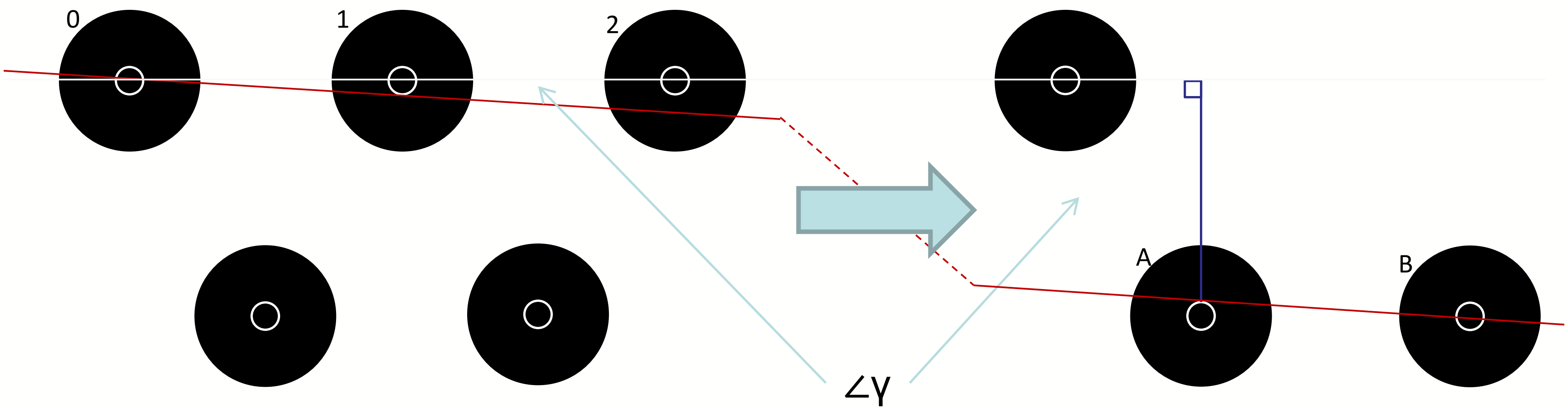

$$D = Nkd - \frac{1}{2}kd$$

# H

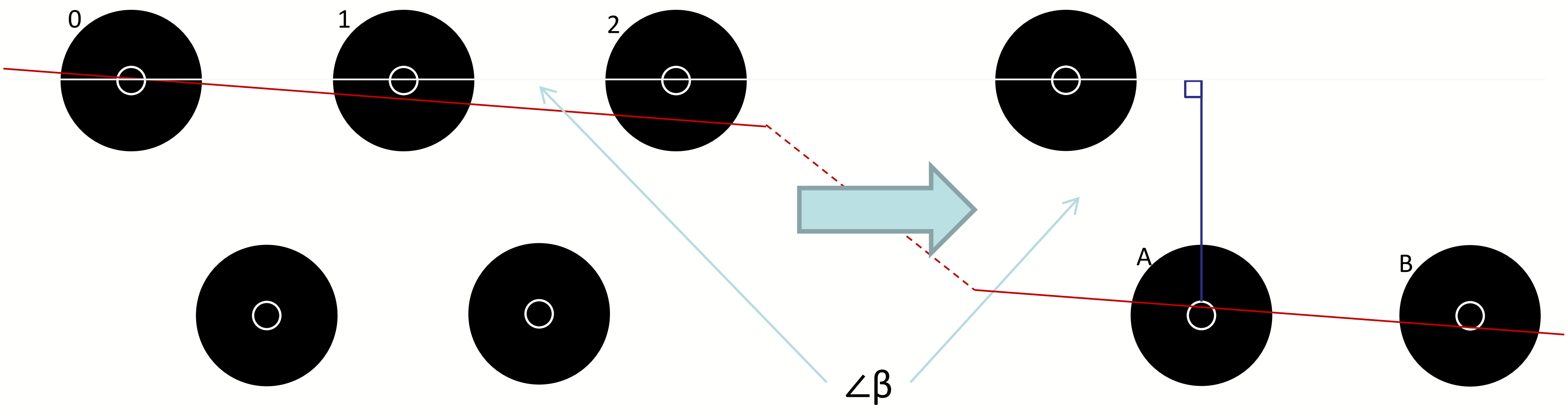



$$H = \frac{Mkd}{2} - \frac{kd}{2}$$

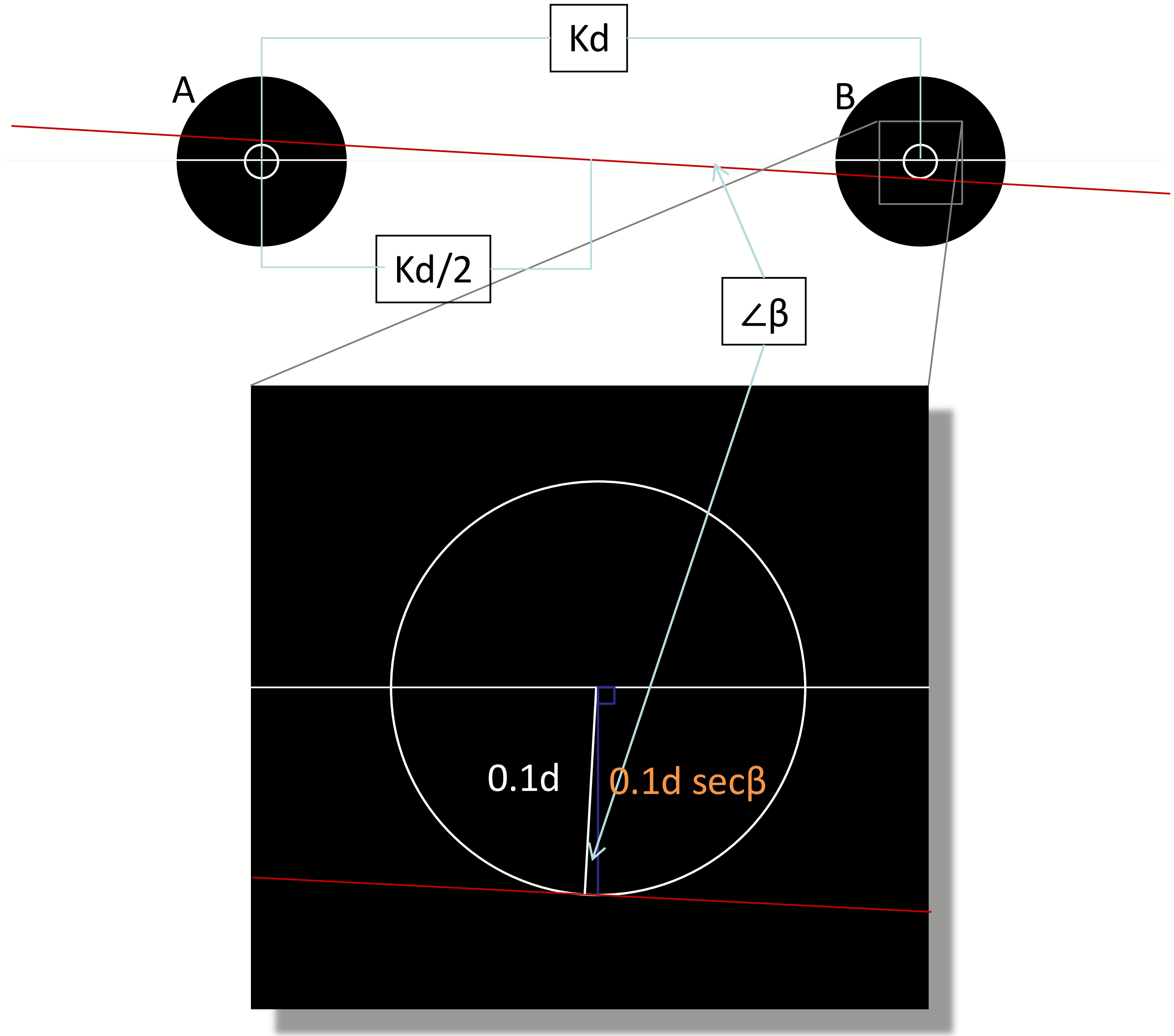
l



# J



# K



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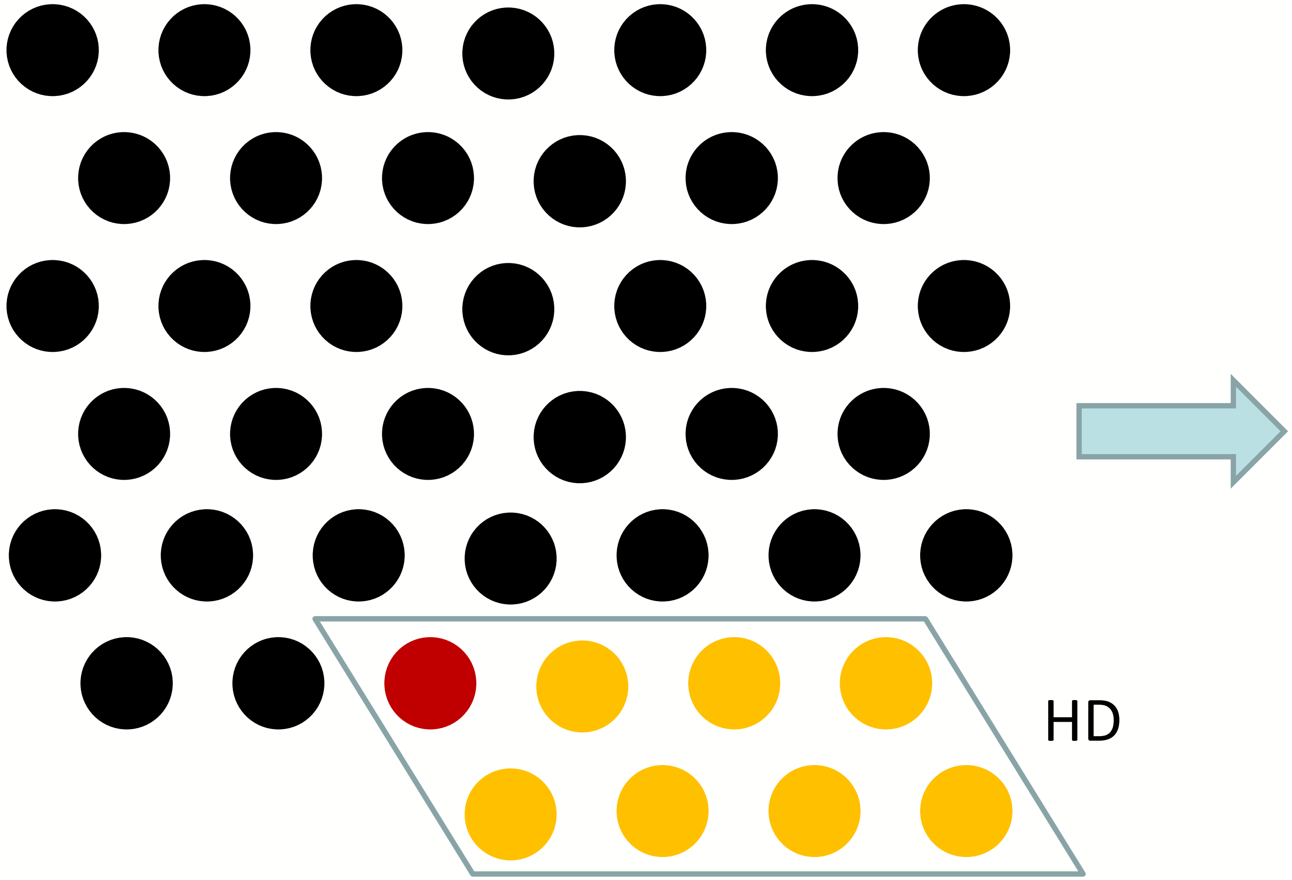

# M