The Enigmatic Breakout Angle

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Abstract
We describe a coupon design that makes available, in an elegant and efficient way, information unattainable even from multiple-coupon vertical cross-sections. The new design allows quantitative determination of annular ring and of breakout angle on internal layers of printed circuit boards. The new design provides evidence for compliance (or lack of it) with user requirements regarding internal annular ring and breakout angle. It permits assessment of the adequacy of design rules and allows collection of data for statistical process control or process optimization via designed experiments.

Introduction – Registration, Breakout Problem, Background
Registration of plated through holes (PTH) in multilayer printed circuit boards (PCB) is of interest to users and fabricators of those components. If these holes are not suitably registered, board reliability is threatened. Specifically, the annular ring on boards may be insufficient to assure a good layer-to-layer bond and concomitant PTH integrity.
Some useful data on PTH registration may be obtained using the test systems described by Paur in his two patents [1, 2]. These systems provide more than a simple go-nogo measurement, but do not provide continuously variable data. The mis registration data are 'binned', as the system indicates the mis registration is within some interval, rather than being continuous. The systems also consume some space on a circuit board panel and entail a slight increase in drilling time and tool use.
Acceptance standards IPC-6012 and -6013 define 3 classes of PCB reliability, in order of increasing reliability requirements, denoted as class 1, 2, and 3. Classes 1 and 2 allow some annular ring to be missing on internal layers, expressed as 'breakout angle'. Figure 2 demonstrates the concept of breakout angle. (As of this writing, class 1 boards may have internal annular ring with 180˚ breakout and class 2 boards may have internal annular ring with 90˚.)
Unfortunately, the acceptance standards call for vertical microsections of coupons on PCBs, which do not allow measurement of breakout in internal annular ring. As Clifford [3] demonstrated, even when vertical microsections meet class 3 acceptability requirements, the PTHs themselves may not meet breakout requirements, in reality. Horizontal microsections could reveal the actual breakout, but preparing such microsections is time-consuming in comparison to vertical ones. Another, serious disadvantage of horizontal microsections is loss of a retainable record, as each section is destroyed as one proceeds into layers deeper and deeper in a PCB. Fabricators and users typically want microsection records and samples retained for some time after boards are made and shipped.
This unappealing situation led us to search for an exact way to measure internal annular ring breakout.

Methodology – Geometry Review and Basis
Before going into the details of the new design, it may be worthwhile to remind you of a tool from trigonometry – the Law of Cosines. We will use the Law later in this paper.
Many engineers and scientists are comfortable with use of the Law of Sines, which permits calculation of the length of all sides and magnitude of all angles in a triangle if the length of one side and magnitude of two angles are known.

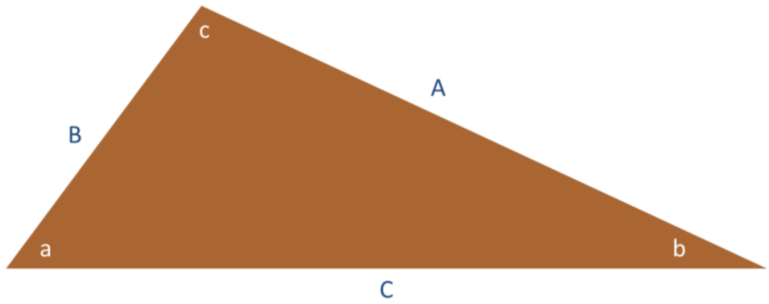

Figure 1

Referring to Figure 1, if you know the length of side A and angles b and c, the Law of Sines allows you to calculate the length of sides B and C:

$$\frac{\sin a}{A} = \frac{\sin b}{B} = \frac{\sin c}{C} \quad (1)$$

Less frequently seen is the Law of Cosines, which permits calculation of the length of all sides and magnitude of all angles in a triangle if the length of two sides and magnitude of the angle between them are known.

Referring again to Figure 1, if you know the length of sides A and B, and the angle c between them, the Law of Cosines allows you to calculate the length of side C:

$$C^2 = A^2 + B^2 - 2AB\cos c \quad (2)$$

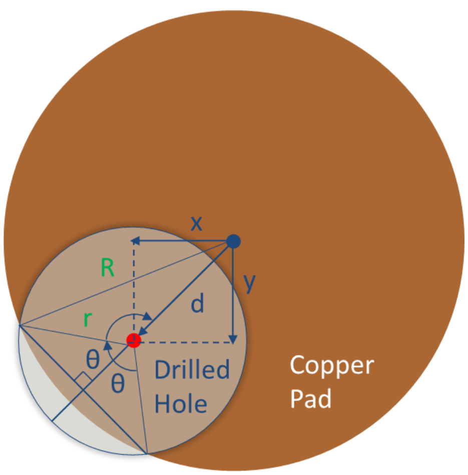

Figure 2

Refer now to Figure 2, representative of a hole drilled in a circular copper pad of a printed circuit board. Using Figure 2, we show below that, knowing the displacement d of the center of the drilled hole of diameter r from the center of the circular pad of radius R, one can calculate the breakout angle 2θ by using the Law of Cosines.

The displacement d of the center of the drilled hole (red dot) and the center of the copper pad (blue dot) is, in terms of x and y,

$$d = \sqrt{x^2 + y^2} \quad (3)$$

Using the Law of Cosines,

$$R^2 = r^2 + d^2 - 2rd\cos(r, d) \quad (4)$$

Hence,

$$\cos(r, d) = \frac{-[R^2 - (r^2 + d^2)]}{2rd} \quad (5)$$

and, with d calculated from eq. (3),

$$(r, d) = \cos^{-1}\left\{\frac{-[R^2 - (r^2 + d^2)]}{2rd}\right\} \quad (6)$$

From Figure 2, notice that

$(r, d) = 180 - \theta \quad (7)$

So

2θ = **Breakout Angle (8)**

However, how does one determine x and y when the pad is on an internal layer? The next section has the answer. It also includes some comments on *measurement* of R and r. The latter two parameters are known, at least approximately from the design, but users of this new system can measure true values with relative ease.

Results – Registration System and Measurements

Consider Figure 3, which shows the circular pad and drilled hole from Figure 2 and adds a chevron and a square pad to the right and left, respectively. The chevron and square pad are the two elements of the novel registration measurement structure. The chevron and square pad are formed at the same time, from the same material, and by the same process as the circular pad. Typically, the chevron and pads would be copper foil remaining after printing and developing of copper-clad laminate.

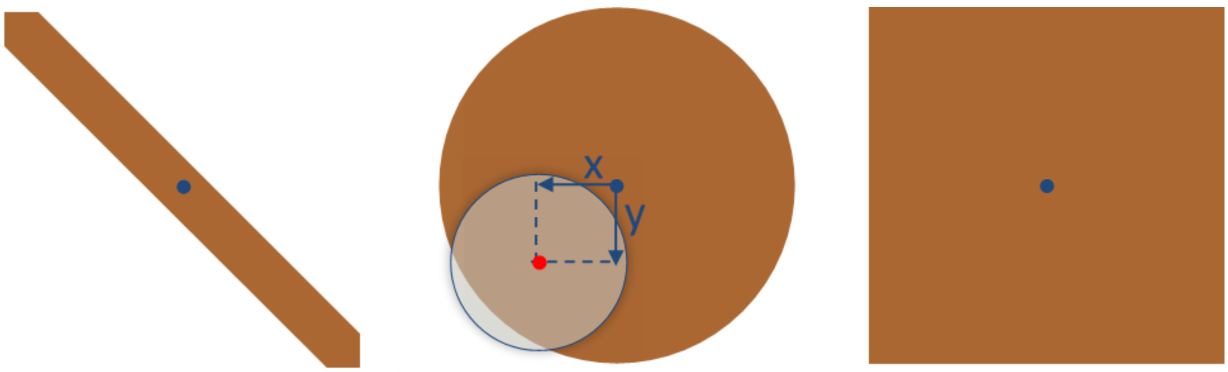

Figure 3

Notice that the length of the sides of the square pad is designed to be the same as the diameter of the circular pad, R. However, any layer-to-layer variations in printing, developing, and etching the internal circular pads will affect also the square pad, so the *true* circular pad diameter can be determined from by measuring the length of a side of the square pad.

The length of the chevron is equal to the diagonal of the square, $\sqrt{2} * R$.

The diameter of the drilled hole, r, can be measured directly from the microsection, as the technique and equipment is designed to take the section through the center of the drilled hole.

Figure 4 contains the same elements as Figure 3, and adds the line S representing the plane of a vertical cross section through the center of a hole drilled in a circuit board.

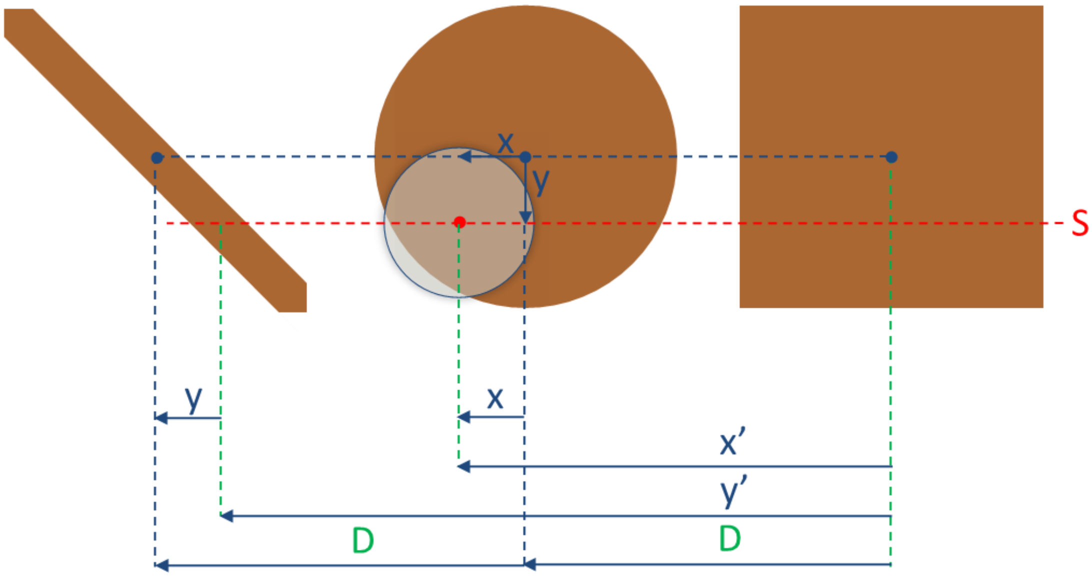

Figure 4

The user finds the value of x to be used in equation (3) by measuring the distance x' between the observed center of the drilled hole and the observed center of the square then subtracting from x' the distance (already known as D from the design of the pads and their locations) between the center of the circular pad and the center of the square pad. Notice that the user makes one measurement, x', to find the value of x from equation (10).

$$x = x' - D \quad (10)$$

The user finds the value of y to be used in equation (3) by measuring the distance y' between the center of that portion of the chevron visible in the cross section and the observed center of the square, then subtracting 2D from the measured distance y'. Notice, once again, that the user makes one measurement, y', to find the value of y from equation (11).

$$y = y' - 2D \quad (11)$$

The results from equations (10) and (11) allow calculation of breakout angle by utilizing the Law of Cosines. Note that, by the definition of internal annular ring in IPC-T-50, you must use the radius of the *drilled* hole r, not the radius of the plated hole.

Conclusion – Advantages and Applications

This new method has some attractive features:

- Minimal space consumption on panel, may often be incorporated into an A/B coupon
- Precision of measurement of break out angle and misregistration is limited by uncertainty in measurements of linear dimensions in coupons
- Sample preparation takes place concurrent with standard microsection of multilayer panels
- Allows for preservation, as part of quality records, of breakout and misregistration information of all layers.

If space consumption on a panel is extremely critical, the chevron could be incorporated as a 'negative', ie, by removal of copper, in the square pad.

There are number of applications of the new method that come to mind:

- Permits measurement of breakout angle for conformance to IPC class 1 or 2 requirements, from vertical microsection
- Variables data are available for use in Statistical Process Control of PCB lamination, for displacements of inner layers
- Variables data can be used in designed experiments for process optimization
- Design rules can be formulated which incorporate statistics of drilling and lamination misregistrations to determine pad size on internal layers required to assure a desired yield in fabrication.

References

1. Tom R. Paur, United States Patent 4,894,606, System for Measuring Misregistration of Printed Circuit Board Layers (January 1990).
2. Tom R. Paur, United States Patent 4,918,380, System for Measuring Misregistration (April 1990).
3. Tom Clifford, Round the Clock, Printed Circuit Design & Manufacture, (June 2004, pp. 36-39).

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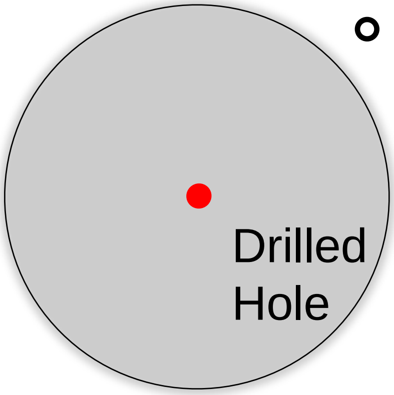
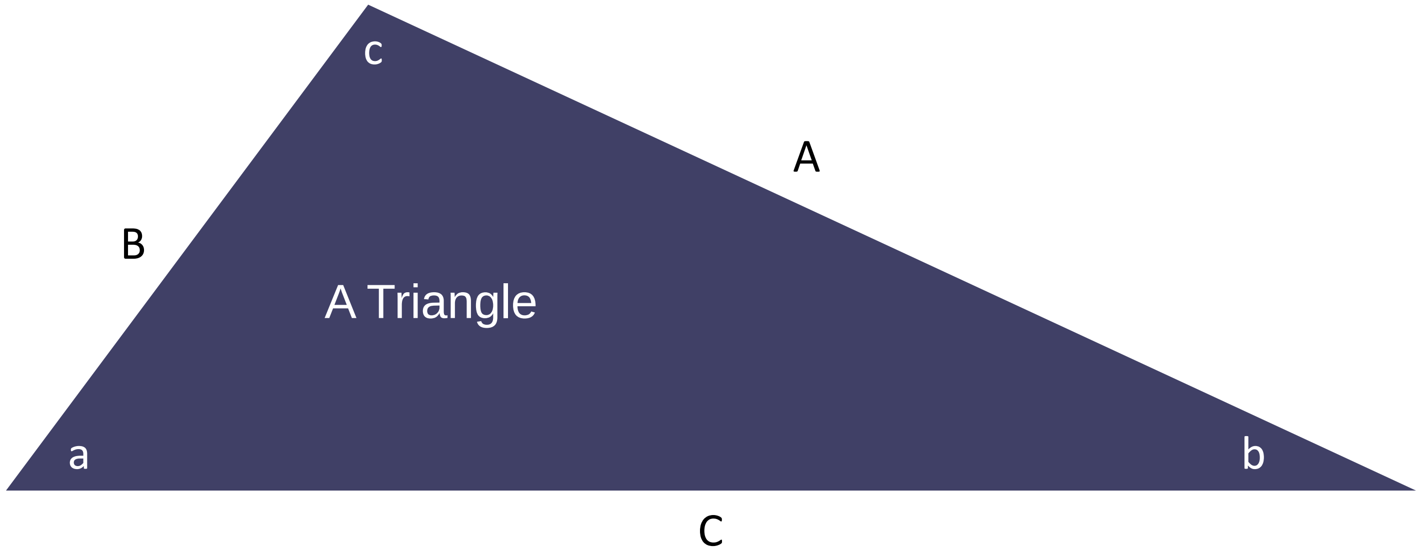
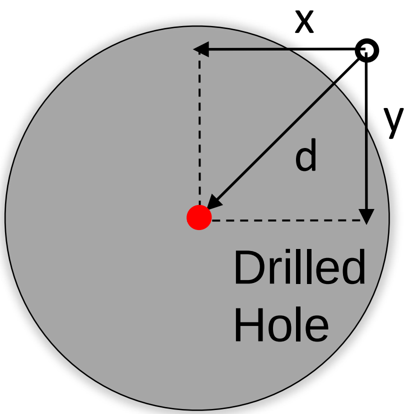
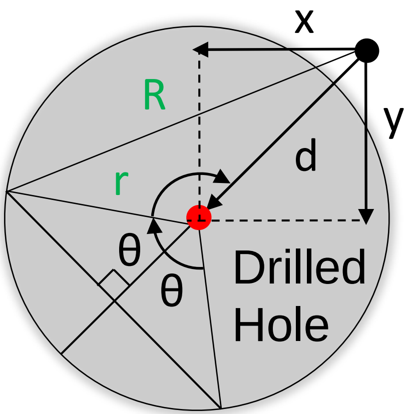

Drilled
Hole

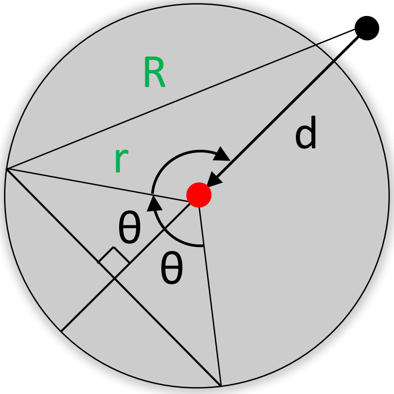

c
A
B
A Triangle
a
b
C


x
y
d
Drilled
Hole



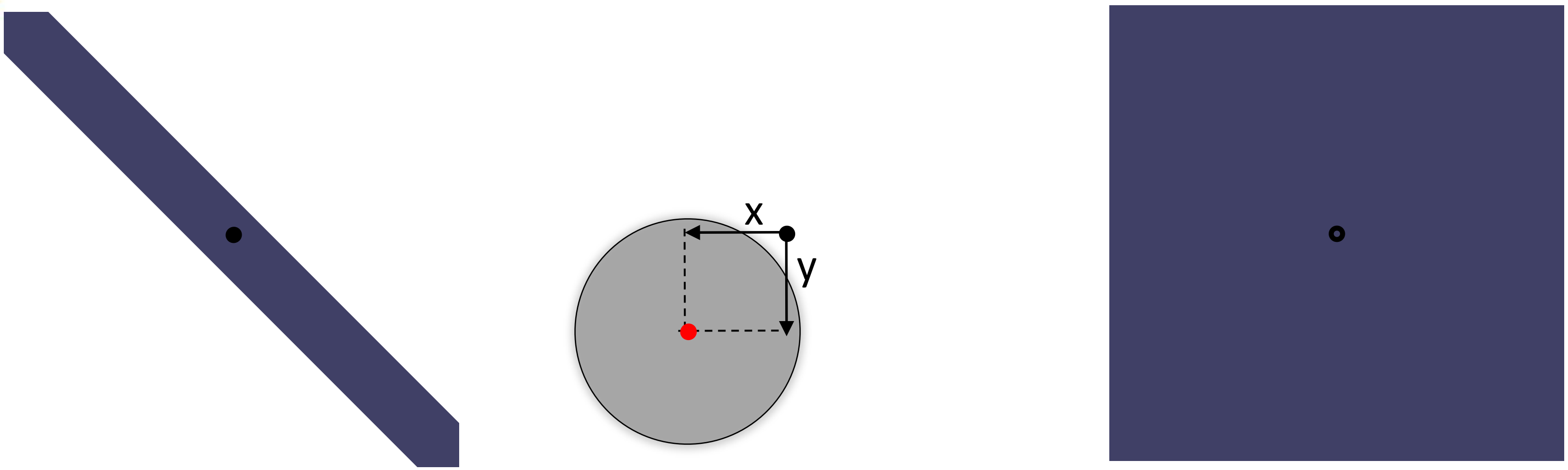
x
R
y
d
r
θ
θ
Drilled Hole

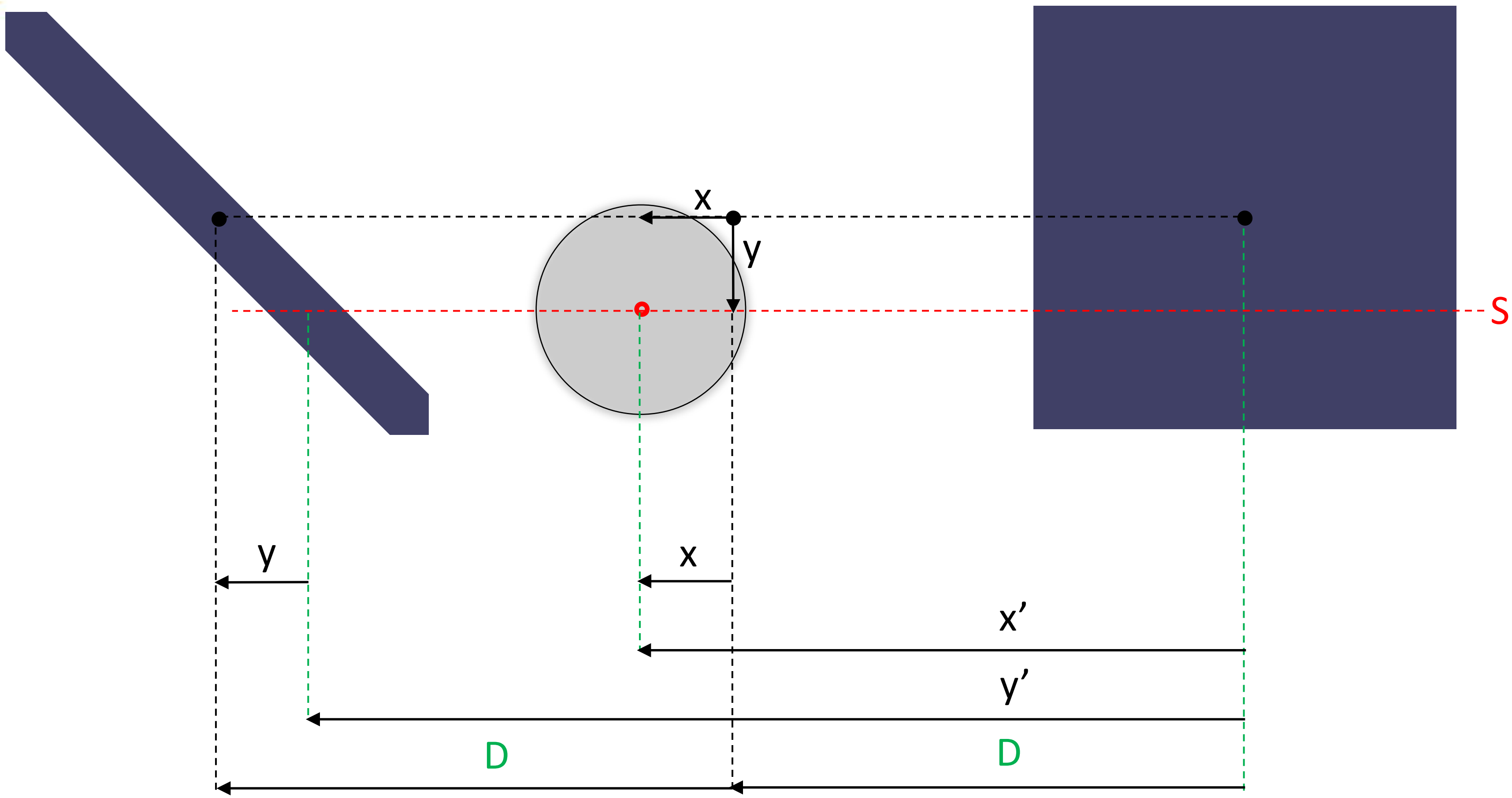
Law of Cosines: $R^2 = r^2 + d^2 - 2rd \cos(r, d)$



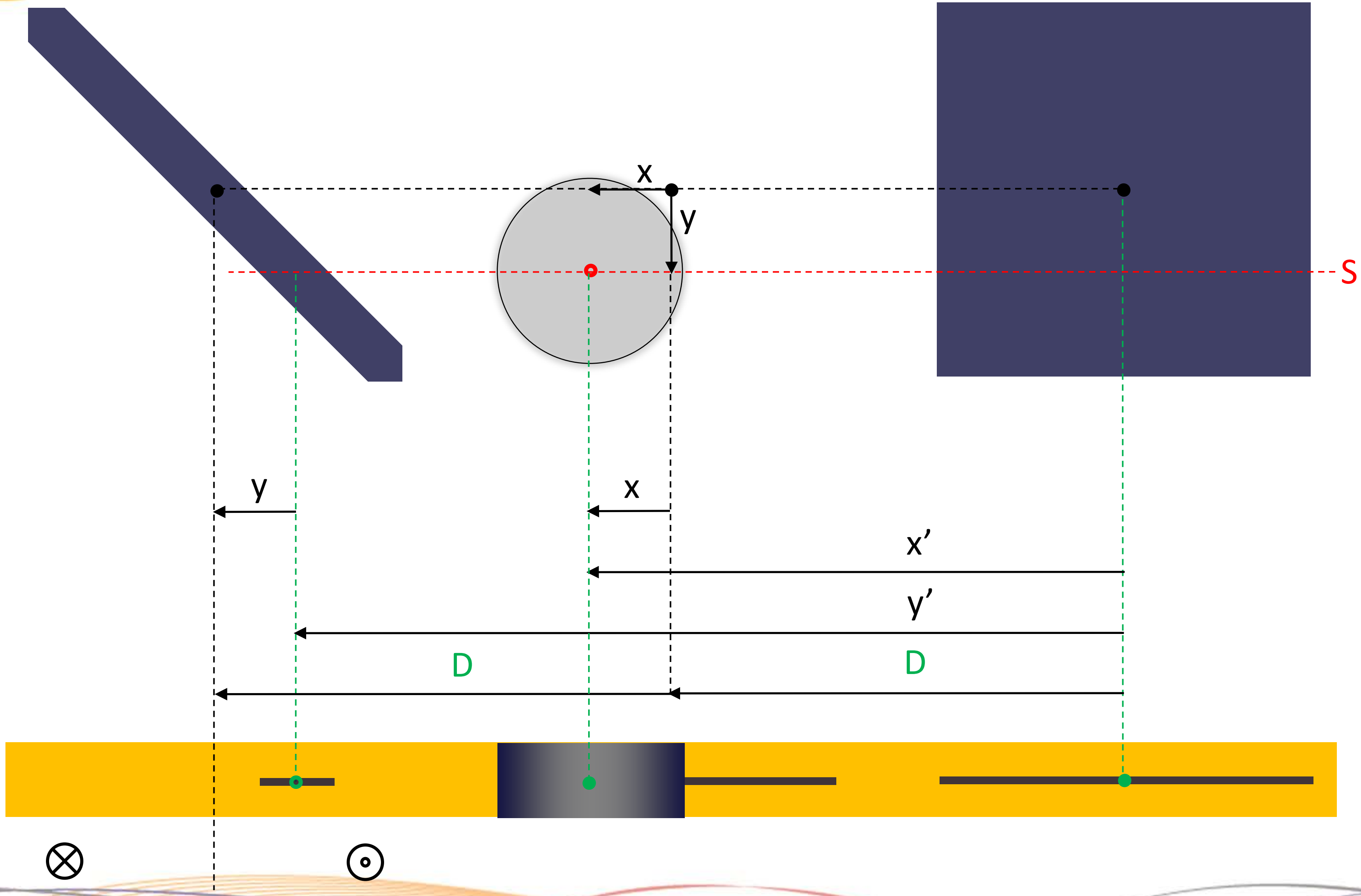
$\cos(r, d) = \cos(180 - \theta)$

Break out angle = 2θ


x
y



$$x = x' - D$$
$$y = 2D - y'$$


x
y
S
y
x
x’
y’
D
D

Thank you!

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