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Schmoll Maschinen GmbH

Coupon Mapping - Training manual

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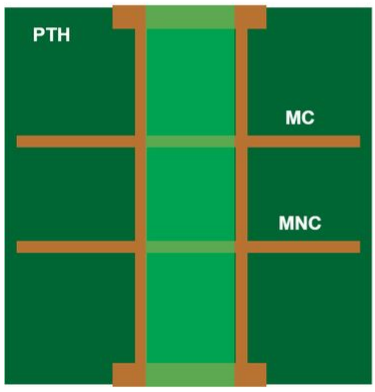
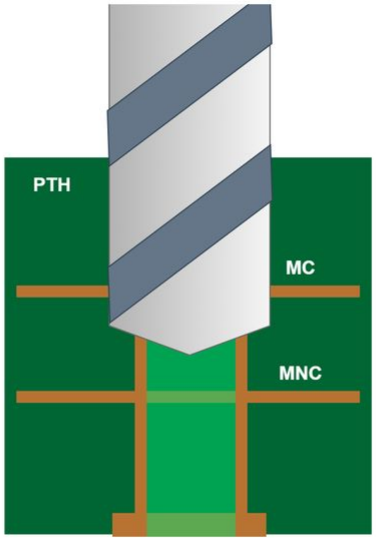
1 Background back drilling

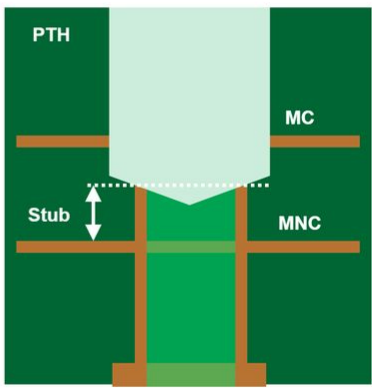
- Back drilling describes the process of removing parts of a plated thru hole (PTH) in a multi-layer PCB to break unwanted connections between layers.
- With regards to inner-layers, must cut layers (MC) and must-not cut layers (MNC) are distinguished.
- Goal of back drilling processes is to remove the connection between the PTH and the MC layer, and to have a tightly defined segment of the PTH - the so called stub - remain on top of the MNC layer.
- One defining characteristic of back drilling processes is therefore the achievable stub-length tolerance.
- Panel manufacturers strive to achieve a constant stub-length for all target depths and back drill locations, since it influences boards' signal integrity and therefore performance.



Plated thru hole with must cut and must-not cut layers



Back drilling process



Back drilled hole with stub

2 Basic machine working principles

2.1 Absolute and relative drilling depth

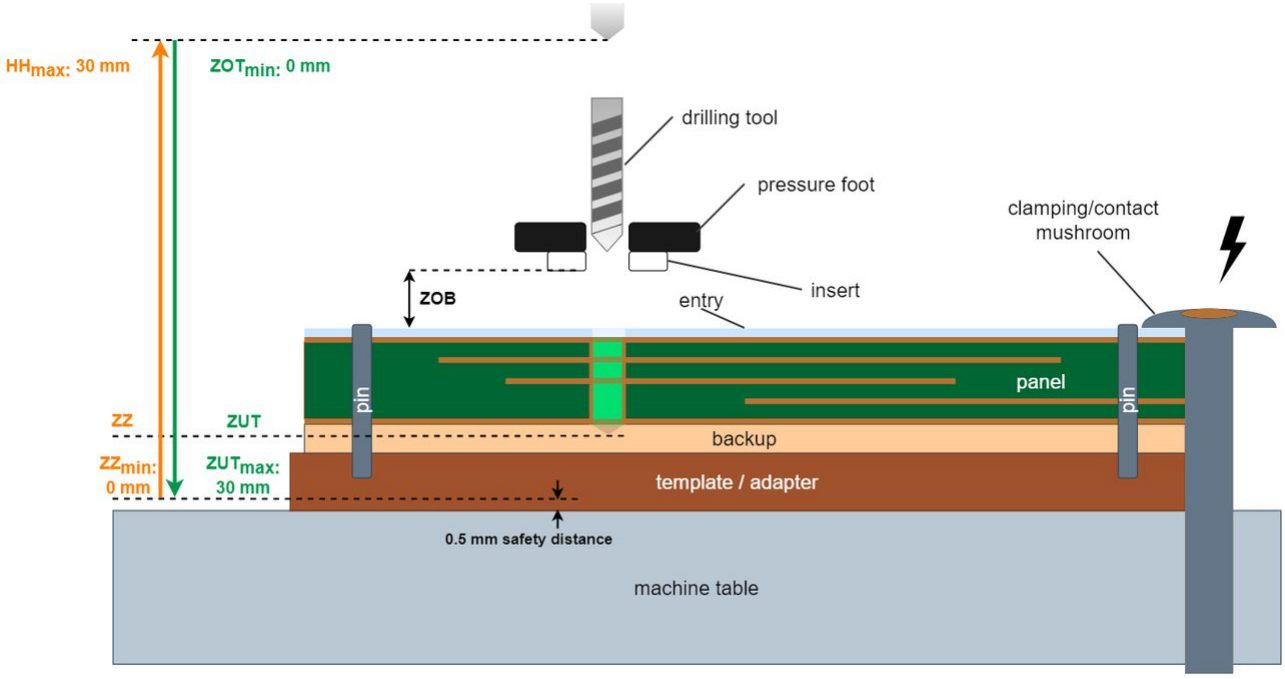
For the purpose of this training it is necessary to explain the difference between absolute and relative depth commands:

2.1.1 Absolute depth commands

- Depending on its settings, a machine either uses the HH/ZZ or the ZUT/ZOT nomenclature to describe its absolute z-axis position.
- HH/ZOT describe a machine's highest z-axis position (HHmax: 30 mm / ZOTmin: 0 mm)
- ZZ/ZUT describe a machine's lowest z-axis position (ZZmin: 0 mm / ZUTmax: 30 mm)
- Thru-hole drilling programs are usually carried out using absolute depth commands, making sure that drill strokes reach a target depth (ZZ or ZUT) that sees a tool's tip reach about 0.2 mm into the backup board.

2.1.2 Relative depth commands

- Relative depth commands require a reference level, usually determined via contact bit drilling (alternatively using the 2nd measuring system that's connected to the pressure foot).
- From this reference, a user-defined the z-axis moves down the defined depth (G08/M18).



2.2 Contact bit drilling (CBD)

- When drill bit gets into contact with conductive surface on the stack (entry sheet, full copper panel surface, copper pad, etc.) that's connected to the machine (via contact mushroom and/or copper tape), the machine detects the closed loop and marks the z-axis position at which the contact was detected.
- Contact bit drilling is used for multiple purposes

2.2.1 Tool break detection

- While drilling, the machine gets permanent contact information when the drill bit touches a conductive surface.
- This information is used by the machine to "learn" where the panel surface is.
- If a contact with the learned panel surface is "late" (the z-axis position is deeper than expected), then this can be an indicator that the tool is broken and a laser measurement is triggered.

2.2.2 Quick drill application

- While drilling, the machine gets permanent contact information when the drill bit touches a conductive surface.
- This information is used by the machine to "learn" where the panel surface is.
- Based on this information, the z-axis is retracted only by the designated ZOB value → this reduces the distance the z-axis travels and therefore increases processing speed.

2.2.3 Layer sensing

- The machine uses contact bit drilling to detect the z-axis position of inner-layers (used during coupon sensing/mapping).

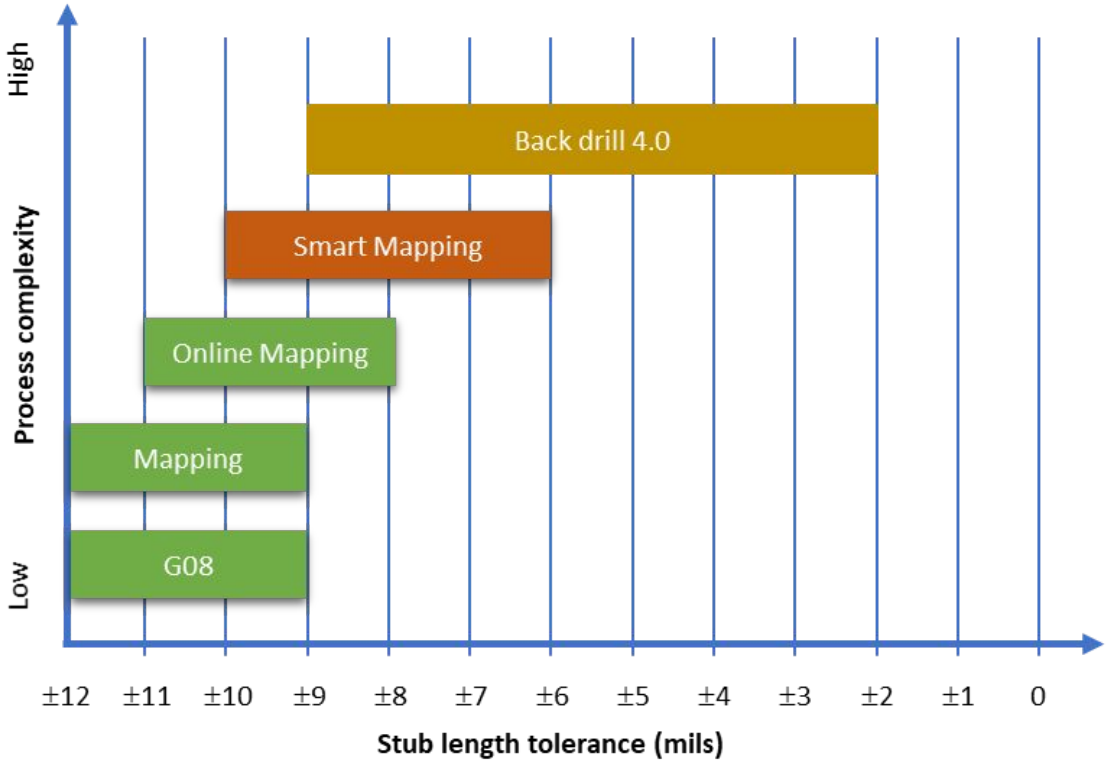
2.2.4 (Relative) depth drilling

- The machine uses a detected contact as reference to drill to a depth relative to the detected surface.

3 Back drilling applications at Schmoll

There are various back drilling methods available with Schmoll machines, with varying degree of complexity but also depth accuracy.

The following section describes G08/M18 depth drilling, since it is the most basic functionality. Furthermore, the working principles of smart mapping and coupon sensing are described, since the combination of both applications is the foundation for the Back Drill 4.0 application.



3.1 G08/M18 command - depth drilling

3.1.1 Description

- The simplest approach to conduct back drilling operations
- Machine uses contact bit drilling (or the 2nd measuring system) to detect a (surface) layer and applies the designated drilling depth.
- No consideration of panel thickness.
- No consideration of inner layer information.

3.1.2 Requirements

- Stack with conductive surface (e.g. panel or entry sheet) connected to machine ground (contact mushroom/ copper tape)
- Conductive drill bit

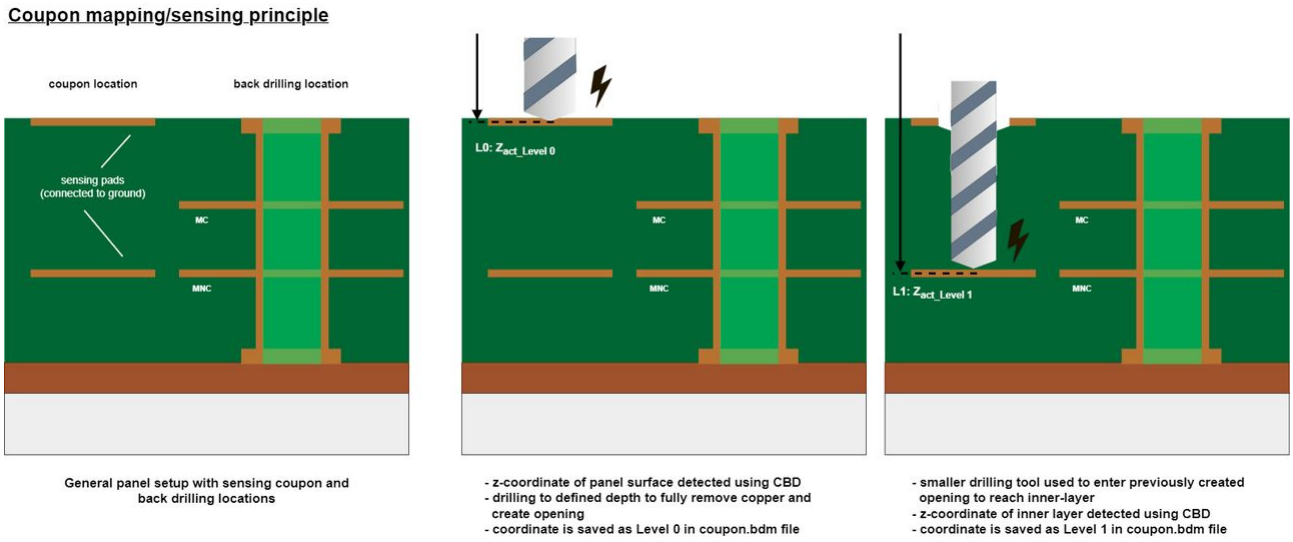
3.1.3 Alternative procedure

- Usage of 2nd measurement system to detect even non-conductive surface (mechanical measuring system integrated to pressure foot)
- Downside: decreased depth accuracy

3.2 Coupon Sensing/Mapping working principle

3.2.1 Description

- The basic idea of Coupon Sensing is that the true depth of a target layer can be determined using contact bit drilling to detect a conductive surface (e.g. copper pad) that's on the same layer as the target layer.
- This conductive surface is called a depth sensing coupon and is placed in close proximity to the back drilling locations.
- Depth sensing coupons have the sole purpose of allowing the machine to collect information on the panel structure. They have no function with regard to the board's ultimate use-case and therefore need to be added to a panel design.



- The Coupon formula takes the difference of z-axis coordinates for inner and surface level contact, as well as the targeted stub length into account, to calculate nominal drilling depth ($\mathbf{D_{nom}}$) for any given target layer.
- To get more reliable data, numerous coupon locations for the same target layer should be used in order to enable calculation of a mean nominal drilling depth result.

Coupon Formula

$$L1_{mid} - L0_{mid} - Stub = D_{nom}$$

Variables of coupon formula

Name	Meaning	Info
$L1_{mid}$	Mean value of all inner layer z-coordinates for a specific target depth	• Individual L1 values for specific x and y coordinates are stored in coupon.bdm as level 1 entries • Instead of "mid", the "min" or "max" value that's been detected can be used in the formula instead
$L0_{mid}$	Mean value of all surface layer z-coordinates for a specific target depth	• Individual L0 values for specific x and y coordinates are stored in coupon.bdm as level 0 entries • Instead of "mid", the "min" or "max" value that's been detected can be used in the formula instead
Stub	Value of targeted stub length	Defined by user
D_{nom}	Nominal drilling depth	Relative drilling depth for a specific target layer

3.2.2 Requirements

- Panel design featuring dedicated sensing coupons
  - Surface and inner layer sensing pads connected to ground to enable CBD based sensing
  - Numerous sensing coupons per target layer, ideally evenly spread over the panel and in close proximity to back drilling locations
- Conductive drill bit
  - Depending on sensing coupon design, multiple drill diameters may be required
- Part program with special Coupon Sensing commands
- Function needs to be activated on machine.

3.3 Sensing Coupons

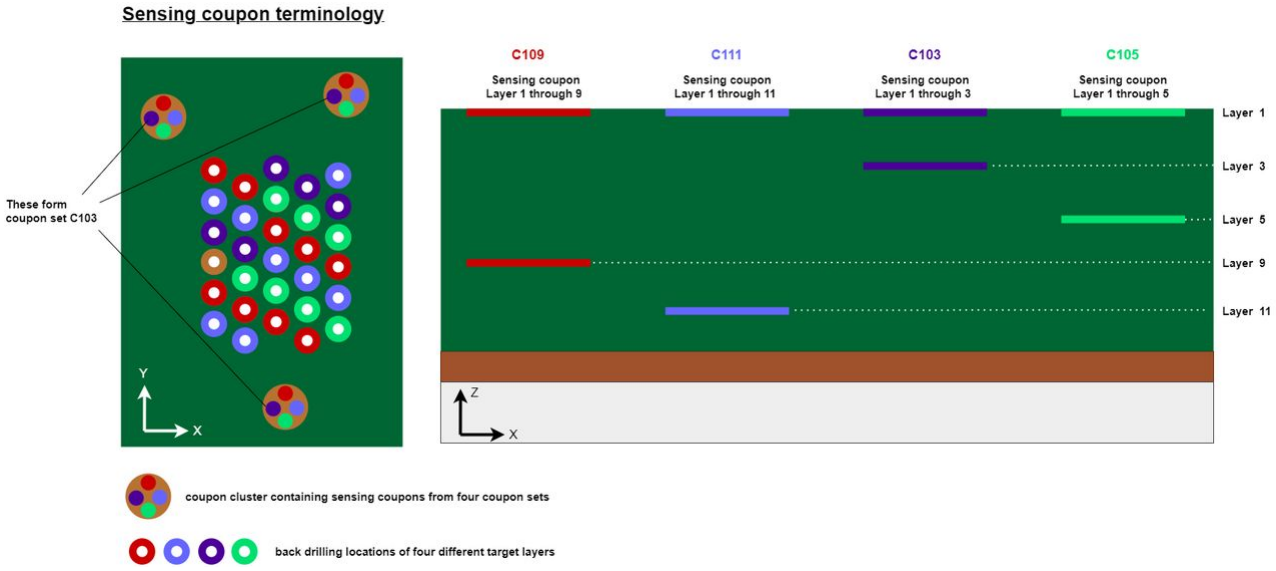
3.3.1 Sensing coupon terminology

For easier communication, the following terms are introduced.

- **Sensing coupon**
  - For every target depth, there is at least one sensing coupon
  - This sensing coupon
    - features a surface level pad (L0)
    - features a Must Not Cut (MNC) layer pad (L1)
    - can feature a MC layer pad - but this is optional.
- **Coupon set**
  - An individual coupon or multiple sensing coupons for the same target depth are part of a coupon set.
  - Coupon sets are named by a capital letter "C", followed by up to four digits (e.g.: C12, C112, C1224)

> One approach for coupon set naming is to incorporate drilling depth information into the name. For example, a coupon set named C112 can indicate that the target depth describes a back drilling operation from layer 1 to layer 12.

- Coupon cluster
  - A local collection of sensing coupons is called a coupon cluster.
  - A cluster can feature sensing coupons that belong to a single or multiple coupon sets



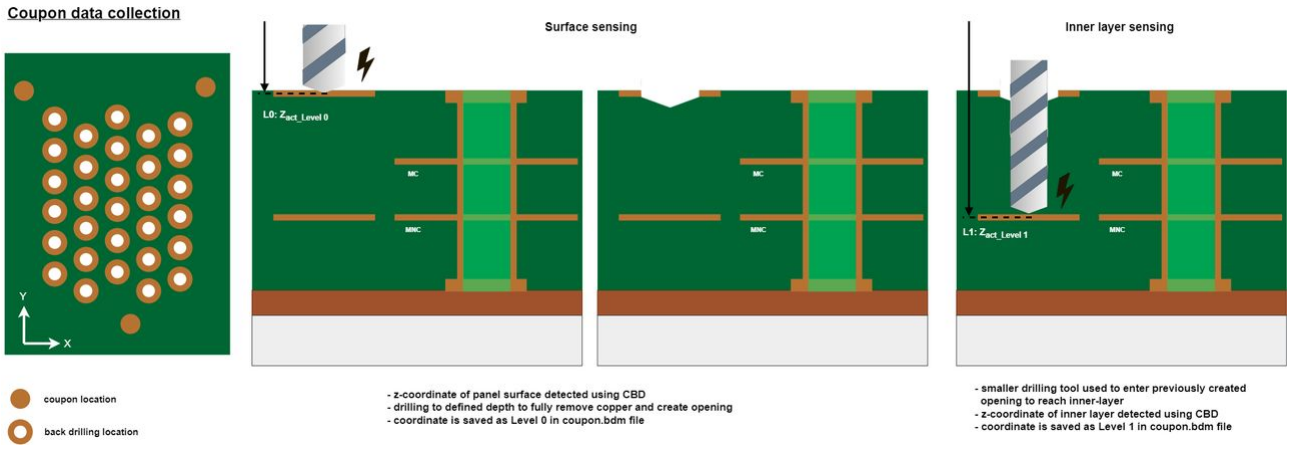
The machine carries out three sequential tasks:

- Coupon data collection
- Depth calculation
- Application of calculated depths at back drilling locations

3.3.2 Coupon data collection

- The first step during part program processing in Coupon mode is the collection of contact level information for sensing coupons at their surface and inner layer level.

- For every sensing coupon within a coupon set, the z-coordinates at which contact is detected on the panel surface (L0) and the inner layer (L1) is recorded and stored in the *coupon.bdm* file
- L0 and L1 values are stored for every sensing coupon (X and Y coordinates) and every active machine station.



3.3.3 Depth calculation

After data collection is complete it is processed in mathematical calculations to determine drilling depth per coupon set.

Coupon formula calculation

- z-coordinate information stored in *coupon.bdm* are fed into the user-defined coupon formula
- The formula calculates the nominal drilling depth (D_{nom}) for every coupon set for each active machine station
- The results are stored in *c_result.bdm* file

Coupon Formula

$$L1_{mid} - L0_{mid} - stub = D_{nom}$$

- This formula represents a standard coupon calculation formula.
- Instead of using levels' mean results, max or min values can be used instead.
- In this example, stub length is not considered in the coupon formula. It therefore needs to be featured in the smart mapping formula.
- Depending on machine configuration, more than one formula can be used to calculate drilling depths, e.g. if variation in stub-length is required.

3.3.4 Depth application

After depth calculation is complete, users have the chance to review the results and make changes.

Afterwards the drilling process continues and the machine applies the relative depths at every programmed back drilling location.

4 Coupon mapping program design

Part programs need to follow certain syntax rules in order to be applied within coupon mapping applications. Depending on the currently active machine mode, a machine's processing and data collection behavior varies.

4.1 Coupon mapping part program commands

The following table summarizes all commands that are part of a coupon mapping program.

Command	Examples	Comment
M47,\P:CBDN	M47,\P:CBDN	• Deleting of current data set
M47,\P:CBDSCccccD0L5	M47,\P:CBDSC109D0L5 M47,\P:CBDSC111D0L5	• Triggering data collection for specified coupon set (e.g. 109 or 111) at panel surface (D0) • Following x and y coordinates are marked as part of the specified coupon set
M47,\P:CBDSCccccD1L5	M47,\P:CBDSC109D1L5 M47,\P:CBDSC111D1L5	• Triggering data collection for specified coupon set (e.g. 109 or 111) at inner layer sensing depth (D1)
M47,\P:CBDC	M47,\P:CBDC	• Finish writing into .bdm files
M47,\P:CBDV0	M47,\P:CBDV0	• Triggers calculation of coupon formula results • Writes *c_result.bdm* file • Does not display calculation results to operator
M47,\P:CBDV1	M47,\P:CBDV1	• Triggers calculation of coupon formula results • Writes *c_result.bdm* file • Displays calculation results to operator
M47,\P:CBDQCccccD1	M47,\P:CBDQC109D1 M47,\P:CBDQC111D1	• Calculation results of the specified coupon sets are called from *c_result.bdm* file
M47,\P:CBDQ0	M47,\P:CBDQ0	• End of data calling

4.2 Coupon mapping part program structure

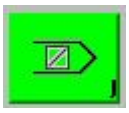
The following image depicts the structure of a coupon mapping part program.

description	program
Header and other commands (e.g. CCD registration)	M48 T01 C0.5 ... T02 C0.3 T03 C0.4 % ....
clear coupon.bdm file	**M47,\P:CBDN**
Tool call and sensing depth command	T01 G08 Z0.400
Data collection coupon set 109 surface level	**M47,\P:CBDSC109D0L5**
x/y coordinates sensing coupon	Xx.xxx Yy.yyy Xx.xxx Yy.yyy Xx.xxx Yy.yyy
Data collection coupon set 111 surface level	**M47,\P:CBDSC111D0L5**
x/y coordinates sensing coupon	Xx.xxx Yy.yyy Xx.xxx Yy.yyy Xx.xxx Yy.yyy
Clear current quick drill level	M47,\P:Z9999
Tool call and depth command	T02 G08 Z0.050
Data collection coupon set 109 inner layer	**M47,\P:CBDSC109D1L5**
x/y coordinates sensing coupon	Xx.xxx Yy.yyy Xx.xxx Yy.yyy Xx.xxx Yy.yyy
Clear current quick drill level	M47,\P:Z9999
Data collection coupon set 111 inner layer	**M47,\P:CBDSC111D1L5**
x/y coordinates sensing coupon	Xx.xxx Yy.yyy Xx.xxx Yy.yyy Xx.xxx Yy.yyy
Clear current quick drill level	M47,\P:Z9999
End of data collection Show calculation results Inspection stopp	**M47,\P:CBDC** **M47,\P:CBDV1** M09

Tool call	T03
Call results for coupon set 109	**M47,\P:CBDQC109D1**
Depth drill place holder	**G08Z0.0**
x/y coordinates back drill locations for coupon set 109	Xx.xxx Yy.yyy Xx.xxx Yy.yyy Xx.xxx Yy.yyy
Call results for coupon set 111	**M47,\P:CBDQC111D1**
Depth drill place holder	**G08Z0.0**
x/y coordinates back drill locations for coupon set 109	Xx.xxx Yy.yyy Xx.xxx Yy.yyy Xx.xxx Yy.yyy
stop calling coupon data	**M47,\P:CBDQ0**
program end	M30

4.3 Optional delete functionality for CCD commands

- For processes that rely on CCD camera registration, implementation of Schmoll machines' optional delete functionality is recommended.
- By putting a program's registration commands behind the optional delete marker ("/") and activating the function from the main page, the CCD registration process will be skipped.
- This is useful when running the machine in Table Top mode (no panel with registration marks present) and when running the machine in Top mode (registration markes covered by entry sheet).



5 Panel and coupon design

5.1 Coupon variants

Coupon sensing uses contact bit drilling to detect a panel's outer surface and inner layer(s) at specified sensing coupon locations. Aside from the surface layer, at least one more layer representing the Must Not Cut layer on the panel inside is required in order for coupon sensing to work. Inclusion of the Must Cut (MC) layer is optional.

The physical coupon design can vary, either featuring concentric or staggered placement of sensing pads.

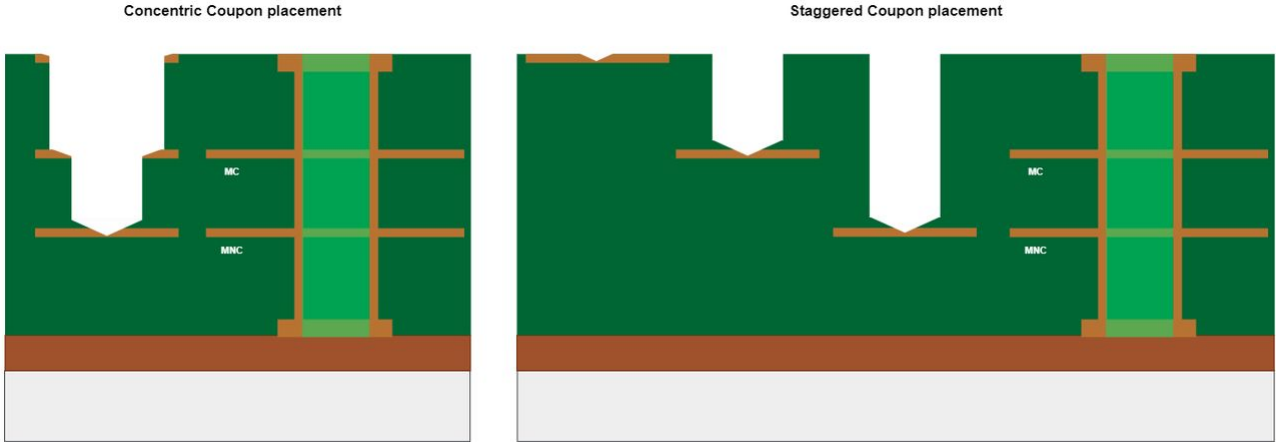
5.1.1 Concentric Coupon placement

To reduce space requirement on the panel, all sensing drilling operations for a specific coupon bore can take place at a single drilling position. This requires usage of drill bits with decreasing diameters, to ensure that no faulty contacts are detected when drilling down to (the MC or)MNC layers.

> Drill bit diameter reduction should be at least 0.2 mm with each sensing operation. For example:
> - 1st sense: 0.8 mm
> - MC sense: 0.6 mm
> - MNC sense: 0.4 mm

5.1.2 Staggered Coupon placement

The alternative is to conduct sensing on panel surface, (MC) and MNC layers at different locations. This variant takes up more space within the panel, however there is no need to use varying drill bit diameters.

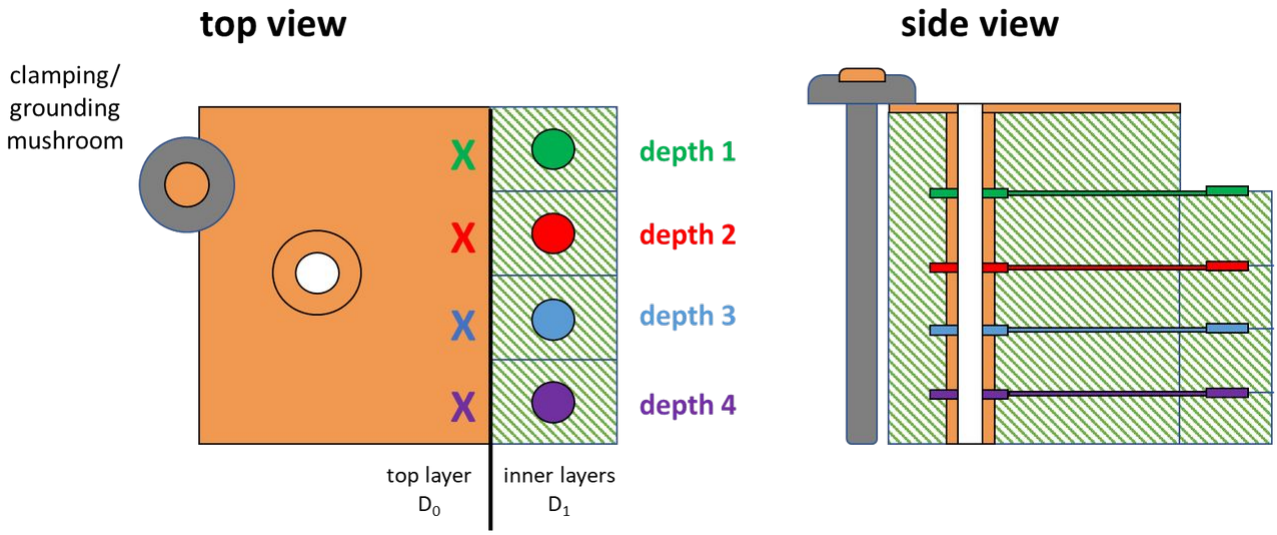


5.2 Sensing coupon design suggestions

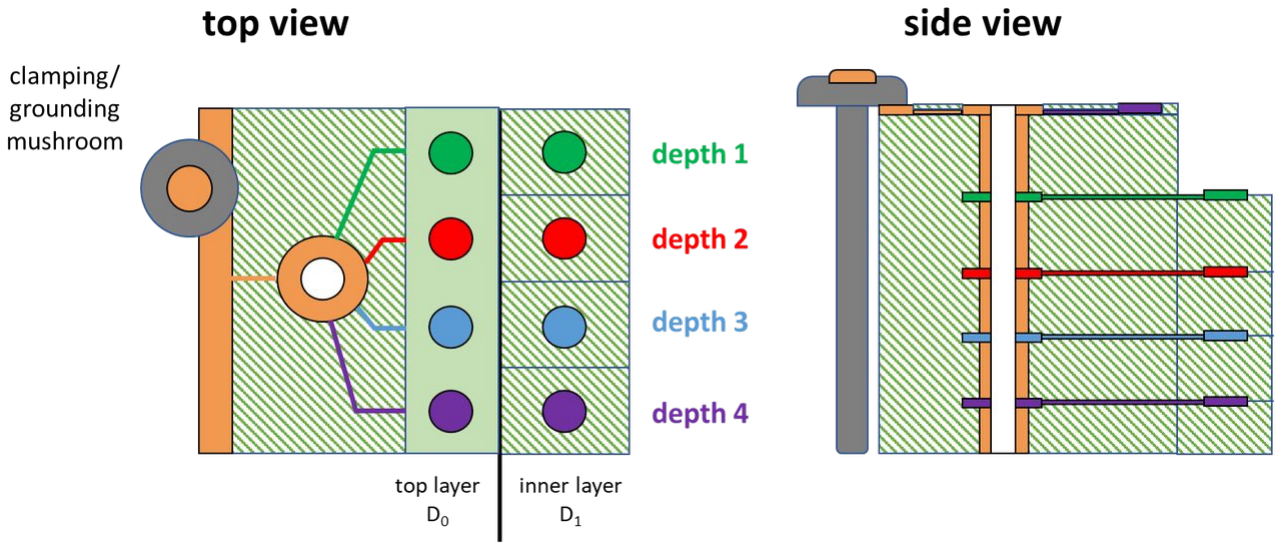
The working principle behind coupon sensing is Schmoll's contact bit drilling technology. For this technology to work, sensing surfaces and inner layer pads need to be connected to machine ground.

The following images provide suggestions on how sensing coupons can be designed to comply with coupon mapping requirements.

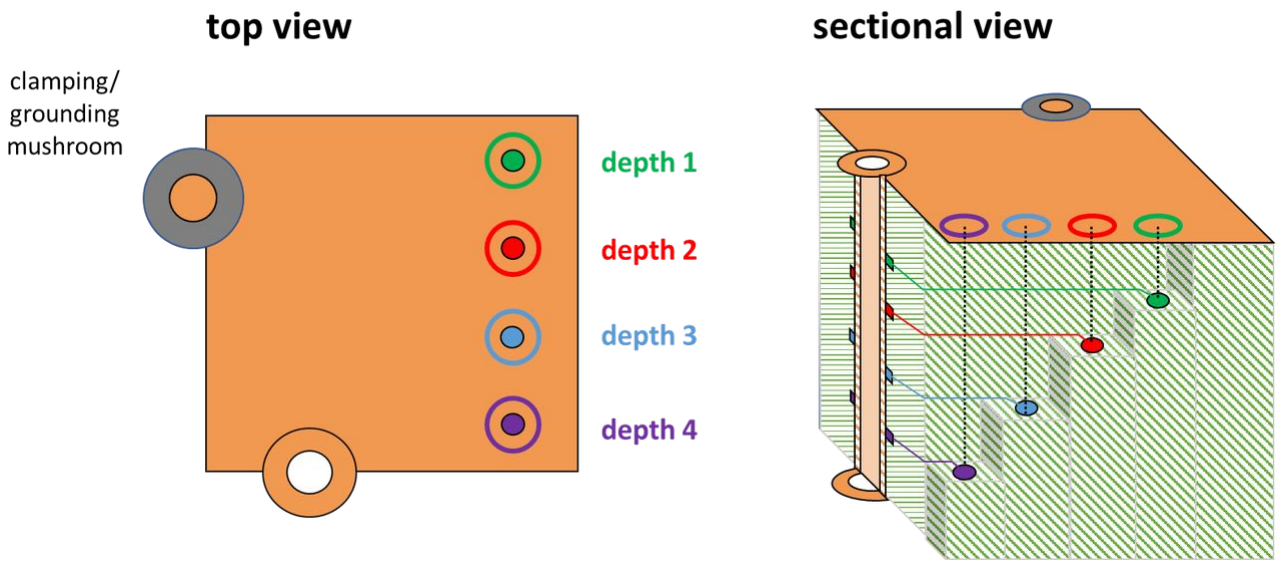
5.2.1 Staggered placement of coupons – full copper surface



5.2.2 Staggered placement of coupons – copper edge

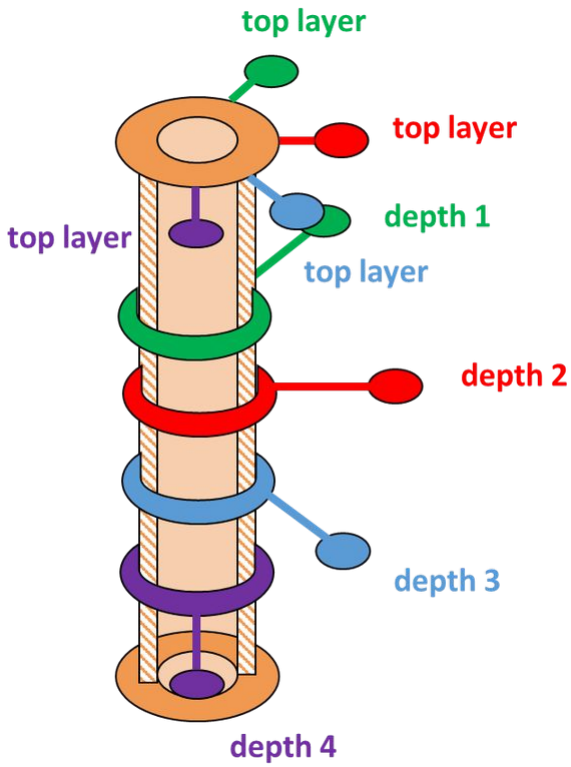


Concentric placement of coupons – full copper surface



Drill bit diameter for surface layer sensing needs to be larger than inner-layer sensing tool diameter

Circular coupon arrangement



5.3 Sensing coupon placement and panel integration

Ideally, multiple sensing coupons for a given target layer are placed in close proximity to their related back drilling locations. This will contribute to sensing coupons better representing panel structure at the actual back drilling locations and therefore improving sensing and ultimately drilling results.

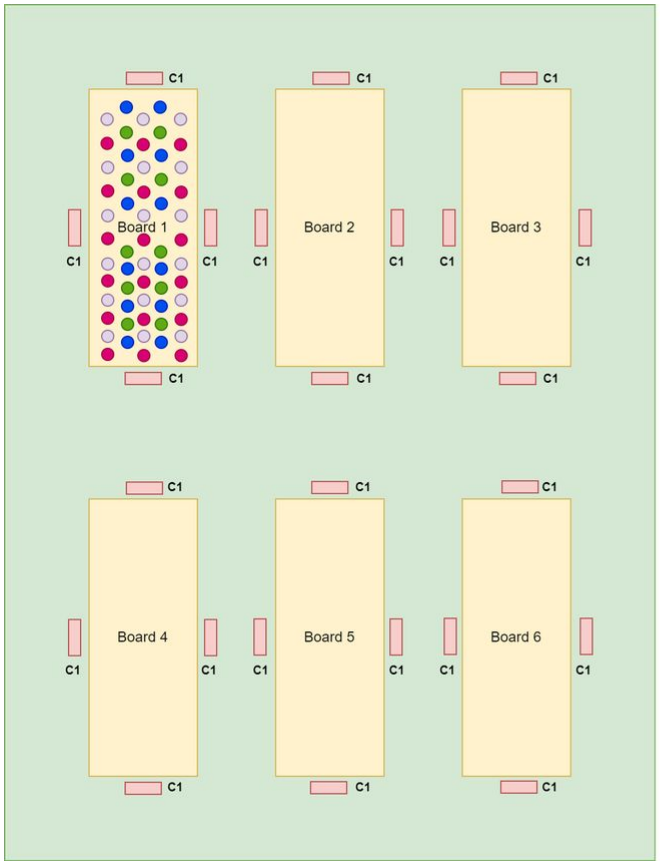
Furthermore, mimicking a panel's structure with regard to copper density in the coupon cluster areas, can also contribute to sensing coupons being more representative of the situation in the back drilling areas.

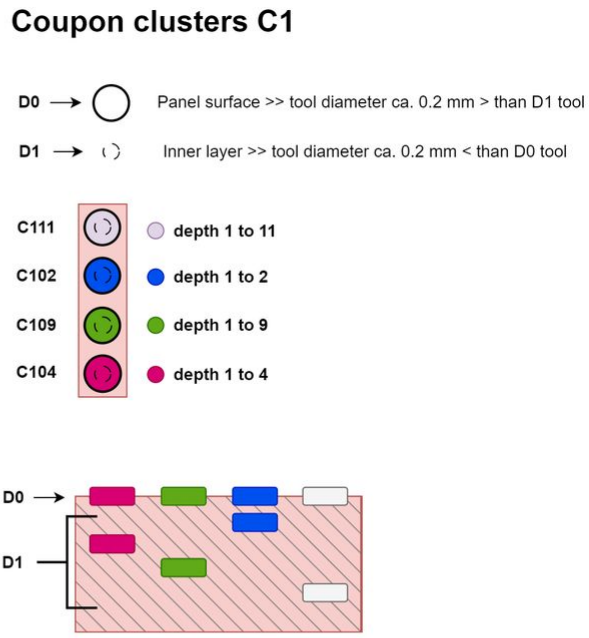
> Having a single sensing coupon in the panel's border area, with the back drilling loaction being far away on the panel center is unlikely to provide sensible depth sensing results.

The following images depict an exemplary positioning of coupon clusters on a panel. Note that the examples distinguish between unified coupon sets and board-specific coupon sets.

5.3.1 Unified coupon sets throughout panel

For panels with homogeneous structure for all boards, using a unified set of coupons, with results being evened out and then applied throughout the entire panel, can make a lot of sense.

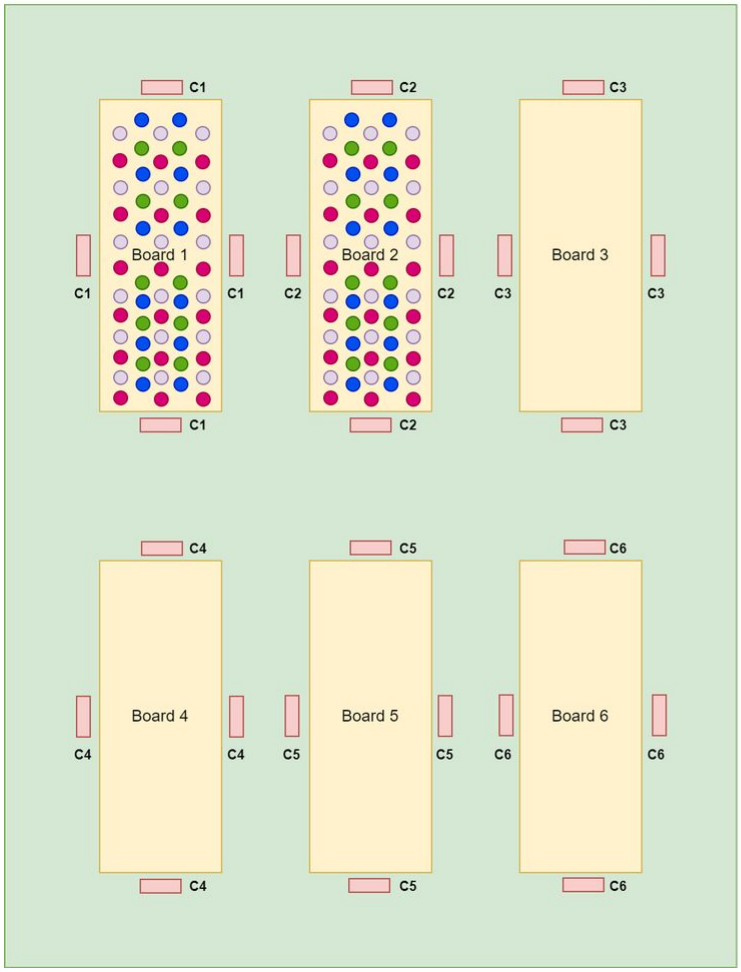




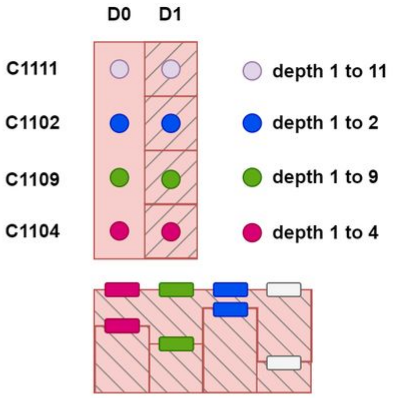
5.3.2 Board specific coupon sets

For panels with varying structures for all boards, using board specific coupon sets can make a lot of sense.

This can require the coupon set naming scheme to feature additional digits to enable conclusive data handling.



Coupon clusters C1 for board 1



Coupon clusters C2 for board 2