FUNDAMENTALS & APPLICATIONS FOR NON-DESTRUCTIVE TESTING

Eddy Current Array (ECA) Testing is a great extension for conventional eddy current testing theory and techniques. The Eddy Current Array Technology book is designed to meet and exceed ISO9712 training requirements. This book is used as a course textbook for ECA Level 1 & 2 certification. Many ECA unique concepts are discussed, including:

- ✓ **Theoretical Concepts:** background theory, signal multiplexing, encoders, C-Scans & array modes are discussed with many examples. Principles of ECA scanning and analysis are discussed.
- ✓ **Probes:** eddy current probes, array elements, and types of array probes are discussed in detail. How an array probe is built from conventional sensors is shown from the first array probes to modern multi-mode probes. Topologies and array transmit-receive modes are discussed.
- ✓ **Acquisition:** a complete walkthrough from calibrating the signal to recording a scan are shown including example scans. Scan plan methods and techniques are outlined.
- ✓ **Analysis:** methodologies including signal pattern recognition, sizing, flaw positioning are explained in detail with examples.
- ✓ **Advanced Topics:** advantages & limitations are outlined for many ECA inspection modes and probes. Exclusion maps and signal processing is illustrated. Technical information including ECA probe mode coverage and detection limitations is outlined.
- ✓ **Tips & Guidelines:** industrial applications and weld inspection guidelines are discussed to enable the reader to apply ECA theories in real NDT applications.

I hope this book serves as a good reference in ECA technology and is enjoyable to read.

Michael Wright

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EDDY CURRENT ARRAY TECHNOLOGY

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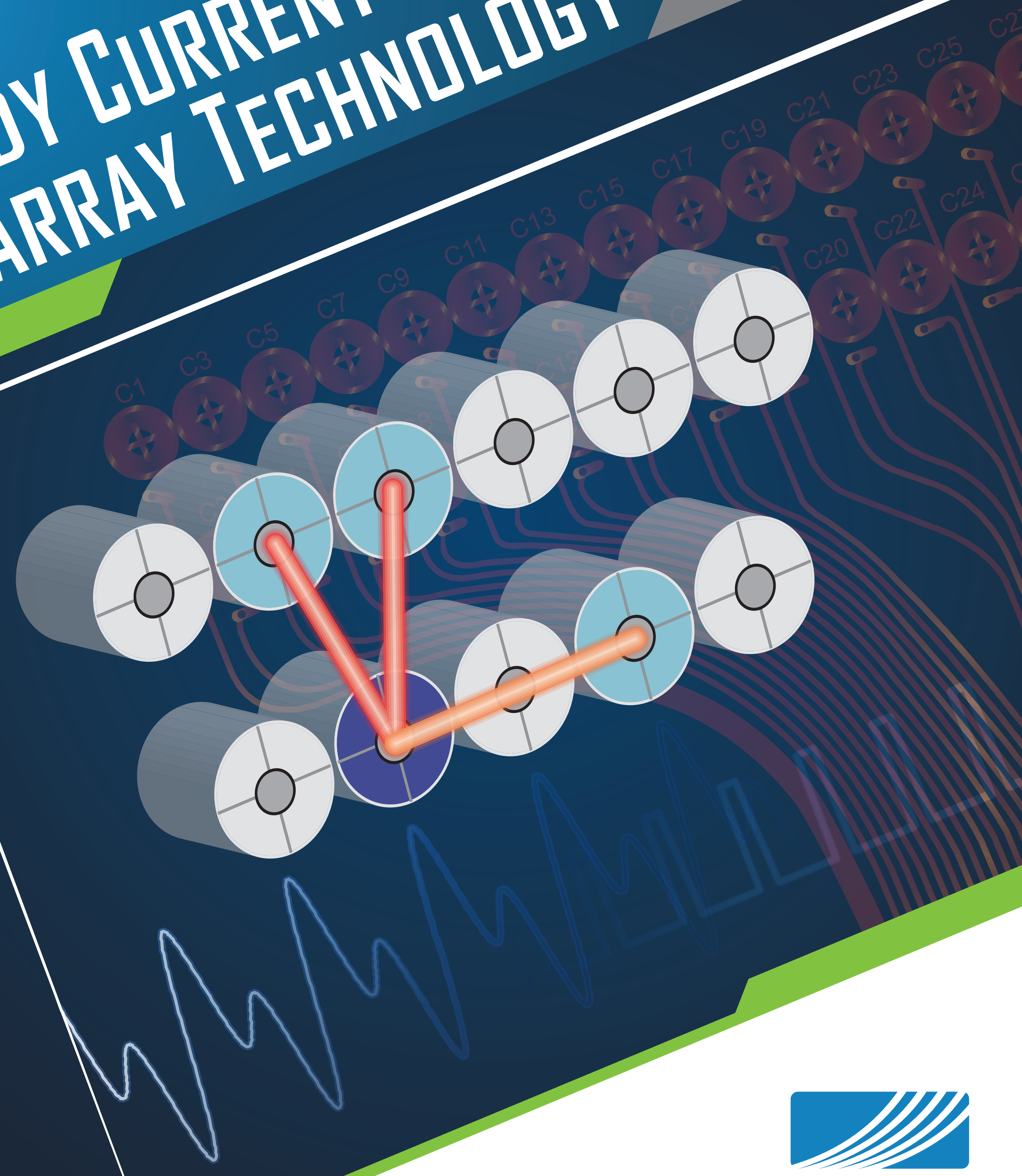

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CHAPTER (8): ARRAY SIGNAL CALIBRATION

8.1 ARRAY SIGNAL CALIBRATION EXAMPLE

This section will show a step by step calibration for our example probe. This is the same probe that was discussed in previous sections.

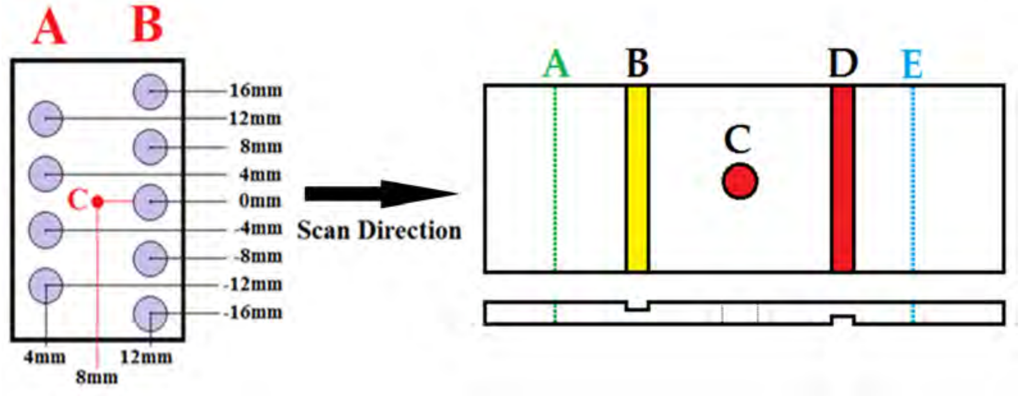


Figure 8-1 Example probe with an example calibration plate

This calibration plate has 3 calibrated defects. Location A is the location where the probe will be nulled, or where the eddy current instrument is hardware nulled. Defect B is a near-surface groove, C is a typical defect that the inspection is looking for, D is a far-surface groove, and E is the location on the calibration plate where the probe is lifted off of the surface or where a lift-off will be performed.

The near-surface groove will be used to set the rotations to 5° and the volts will be set to 5 volts using the volts peak-to-peak measurement. The lift-off event will be used to set up the lift-off, and exclusion map C-Scans. The lift-off will be rotated to 0° and the voltage will be set to 10 volts peak-to-peak.

Since this probe has 3 axial locations for the C-Scan, this calibration from the channels will be technically more involved than most setups.

It is traditional for eddy current calibration groups (collections of related data) to have 3 calibration scans in a row. Also, a calibration file is usually labeled with a 999. This tradition was inherited from tube testing. Tube testing is the most common type of eddy current testing. Vessels have their tubes labeled by row and column or by X and Y. Since there are never 1000000 tubes in a vessel, it is always safe to reserve tube Row999 and Column999 for files that do not contain tube data. So traditionally, calibration files are labeled as R999C999, and surface scanning has kept the same traditions. The first 999 (calibration file) is saved, and then the probe will be set up using this file.

All software will have specific widgets to perform this action. The following are images from EddyView 1.5.

Once the calibration widget is open, it will display the methods that data can be calibrated by. This example will be done using the channels. After selecting the channels method, the list of references will display the required indications to complete a calibration. This example uses the near-surface groove (NSG), the near-surface groove odd (NSG-O), the near-surface groove even (NSG-E), and the lift-off event.

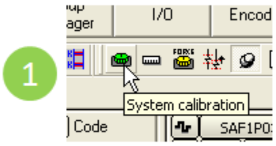
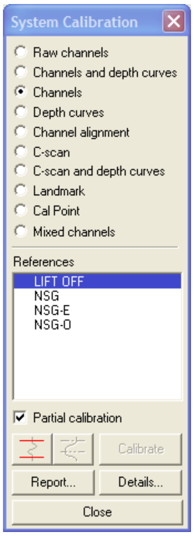


Figure 8-2 Button to open the calibration widget


System Calibration

○ Raw channels
○ Channels and depth curves
● Channels
○ Depth curves
○ Channel alignment
○ C-scan
○ C-scan and depth curves
○ Landmark
○ Cal Point
○ Mixed channels

References

LIFT OFF
NSG
NSG-E
NSG-O

☑ Partial calibration

Figure 8-3 Calibration widget

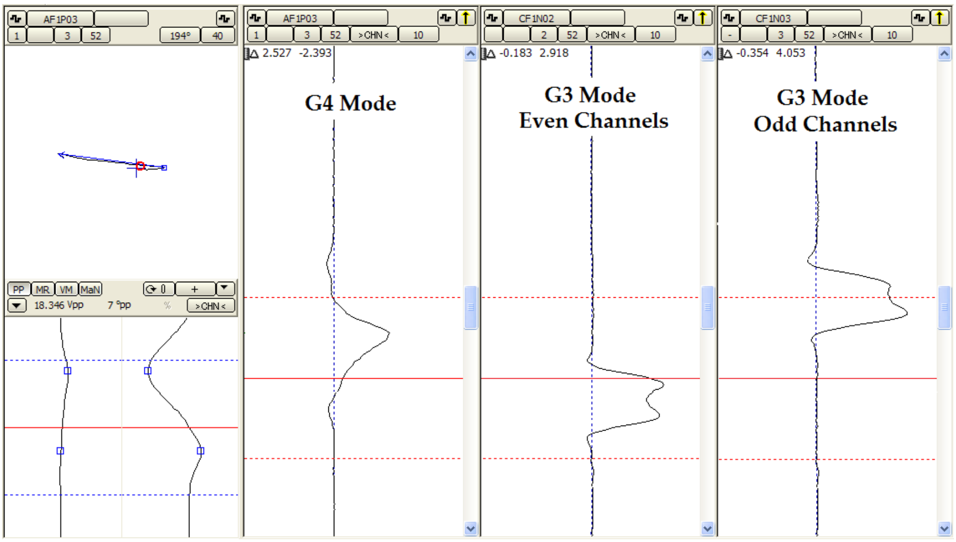


Figure 8-4 Channel data showing the near-surface groove response at the 3 axial locations

Since the G3 mode even, G3 mode odd, and G4 mode channels are located at separate axial locations, they will encounter the indications on the calibration plate at different times. Figure 8-4 illustrates that the G3 odd channels will encounter the NSG first. The G4 or P channels will encounter the NSG next, while the G3 even channels will encounter the NSG last, causing the indication to be at different slices in the channel data. This is the reason there are separate indications for these events in the calibration widget. The probe null location and the lift-off events will occur at the same moment in time, and will all have the same slice number. This creates an alignment for these events in the channels, and an offset for these events in the G3 mode C-Scans.

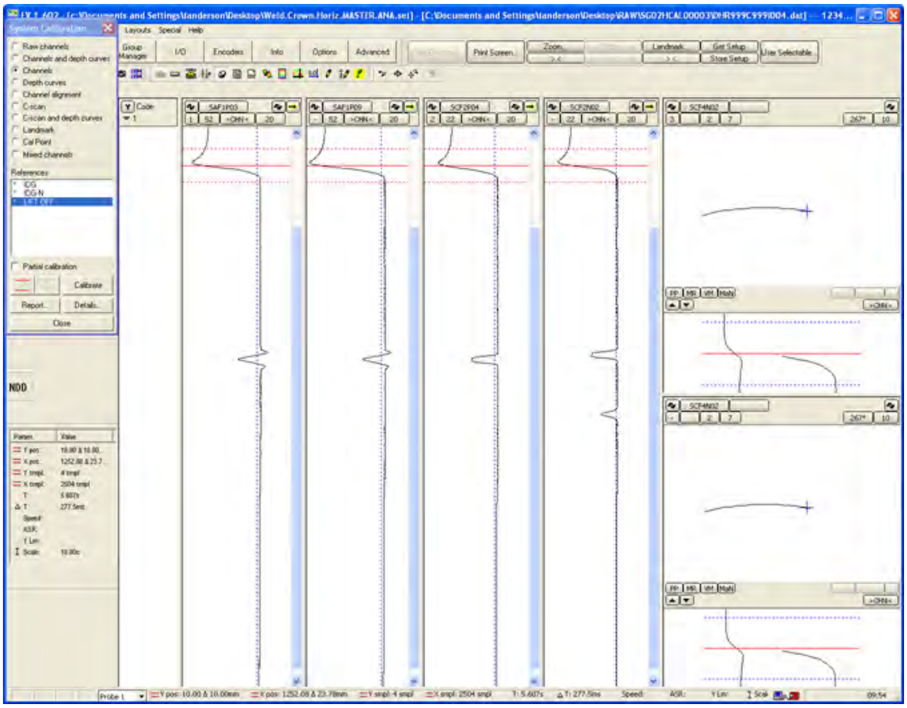


Figure 8-5 Lift-off event occurs simultaneously at all 3 axial locations

Once the locations have been entered, the calibration can be performed. After the calibration is completed the calibration is always verified. The verification of the calibration requires checking the rotations and voltage settings for every channel. This is done using the C-Scans. The C-Scans make it quick and easy to verify these settings for every channel. Remember, the C-Scans are organised in groups.

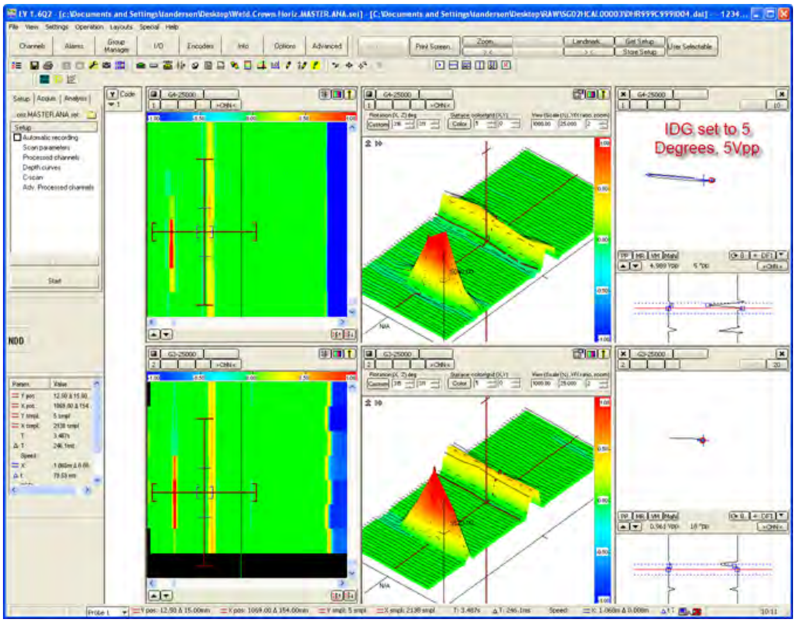


Figure 8-6 Quality verification of calibration as applied to the NSG (IDG)

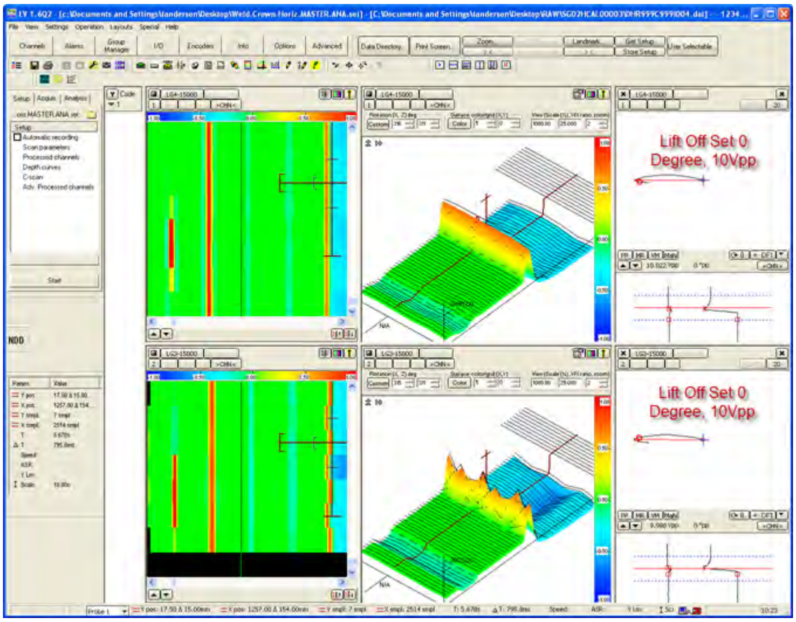
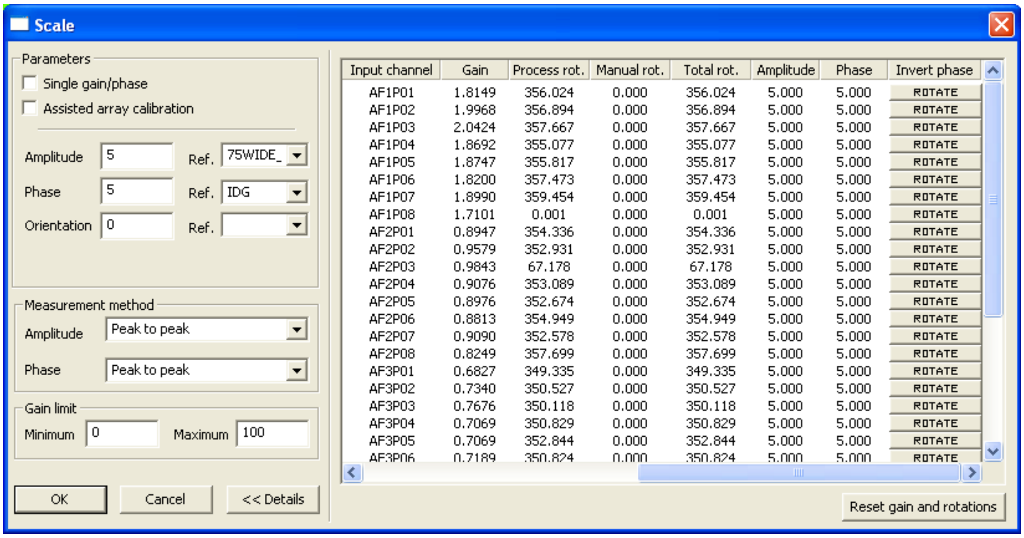


Figure 8-7 Quality verification of calibration as applied to the lift-off event

The auto calibration widget will store the rotations and the gain settings for every channel. These are stored in the scale widget details.



Scale

Parameters

☐ Single gain/phase
☐ Assisted array calibration

Amplitude 5 Ref. 75WIDE_

Phase 5 Ref. IDG

Orientation 0 Ref.

Measurement method

Amplitude Peak to peak

Phase Peak to peak

Gain limit

Minimum 0 Maximum 100

Input channel	Gain	Process rot.	Manual rot.	Total rot.	Amplitude	Phase	Invert phase
AF1P01	1.8149	356.024	0.000	356.024	5.000	5.000	ROTATE
AF1P02	1.9968	356.894	0.000	356.894	5.000	5.000	ROTATE
AF1P03	2.0424	357.667	0.000	357.667	5.000	5.000	ROTATE
AF1P04	1.8692	355.077	0.000	355.077	5.000	5.000	ROTATE
AF1P05	1.8747	355.817	0.000	355.817	5.000	5.000	ROTATE
AF1P06	1.8200	357.473	0.000	357.473	5.000	5.000	ROTATE
AF1P07	1.8990	359.454	0.000	359.454	5.000	5.000	ROTATE
AF1P08	1.7101	0.001	0.000	0.001	5.000	5.000	ROTATE
AF2P01	0.8947	354.336	0.000	354.336	5.000	5.000	ROTATE
AF2P02	0.9579	352.931	0.000	352.931	5.000	5.000	ROTATE
AF2P03	0.9843	67.178	0.000	67.178	5.000	5.000	ROTATE
AF2P04	0.9076	353.089	0.000	353.089	5.000	5.000	ROTATE
AF2P05	0.8976	352.674	0.000	352.674	5.000	5.000	ROTATE
AF2P06	0.8813	354.949	0.000	354.949	5.000	5.000	ROTATE
AF2P07	0.9090	352.578	0.000	352.578	5.000	5.000	ROTATE
AF2P08	0.8249	357.699	0.000	357.699	5.000	5.000	ROTATE
AF3P01	0.6827	349.335	0.000	349.335	5.000	5.000	ROTATE
AF3P02	0.7340	350.527	0.000	350.527	5.000	5.000	ROTATE
AF3P03	0.7676	350.118	0.000	350.118	5.000	5.000	ROTATE
AF3P04	0.7069	350.829	0.000	350.829	5.000	5.000	ROTATE
AF3P05	0.7069	352.844	0.000	352.844	5.000	5.000	ROTATE
AF3P06	0.7189	350.824	0.000	350.824	5.000	5.000	ROTATE

Figure 8-8 Details tab in the scale widget

8.2 CALIBRATION REQUIREMENTS

Array probes have very few calibration requirements. Calibrating array data is basically the same as calibrating conventional eddy current data. Since there are many ways that an array probe can be set up, there are also a number of ways that an array probe can be calibrated. The key to understanding calibration requirements is to understand the probe and its mode or modes. The setup can have a calibration that is intended to be performed on the channels, on the C-Scan data, or in some situations on both.

Channel calibration is a superior method since the raw channels are resaved as scaled channels. The C-Scans are then built from the calibrated channels; resulting in C-Scans that are built calibrated. Hence, no C-Scan calibration is required. When calibrating on channels the key to a successful calibration is to select the proper channels that show the point you are trying to calibrate. You have to remember that some coils are positioned at a different axial location. This will result in data where the channels are data slewed. So, when locking in a data point, you have to ensure that the point is going to be the proper point to use.

The only array-specific requirement is that an event such as a lift-off or the scanning of a defect must happen to all of the channels or coils in the array probe. A 10 mm long EDM notch cannot be used to calibrate a probe with a coverage that is larger than 10 mm. If an indication is smaller than the array foot print, then the voltage response from each channel will not be the same. The setting of the horizontal and vertical gains cannot be done for each channel or position of the array. EDM type defects can be used as calibration artifacts as long as they are long enough to trigger a similar voltage response across the entire array. The simplest method of calibration is to use a plate with no defects. A lift-off event can be used to set up the rotations and the gain settings based on the knee location of the lift-off curve.

8.3 LO BASED CALIBRATIONS AND EXCLUSION MAPS

Lift-off calibrations and exclusion maps are not needed for tubular inspections since the lift-off (fill factor) is self-limiting. Lift-off based calibrations are possible for surface inspection probes. Lift-off calibration curves relate voltages into the distances the coils are from the test sample. To create a lift-off to voltage calibration curve, the voltage at several steps, or predetermined distances, must be measured. Figure 8-9 shows an example setup to measure the voltage at several steps. Each step is the same thickness. The voltage on the test sample will measure very close to 0 volts peak-to-peak.

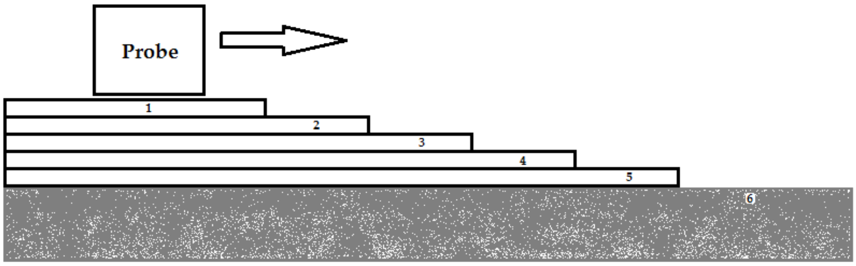


Figure 8-9 Non-conductive step plate or sheets create even measures of lift-off

As the probe is moved across the step plate the lift-off is decreased at each step. This creates a staircase- like response on the horizontal component, as shown in Figure 8-10 and Figure 8-11.

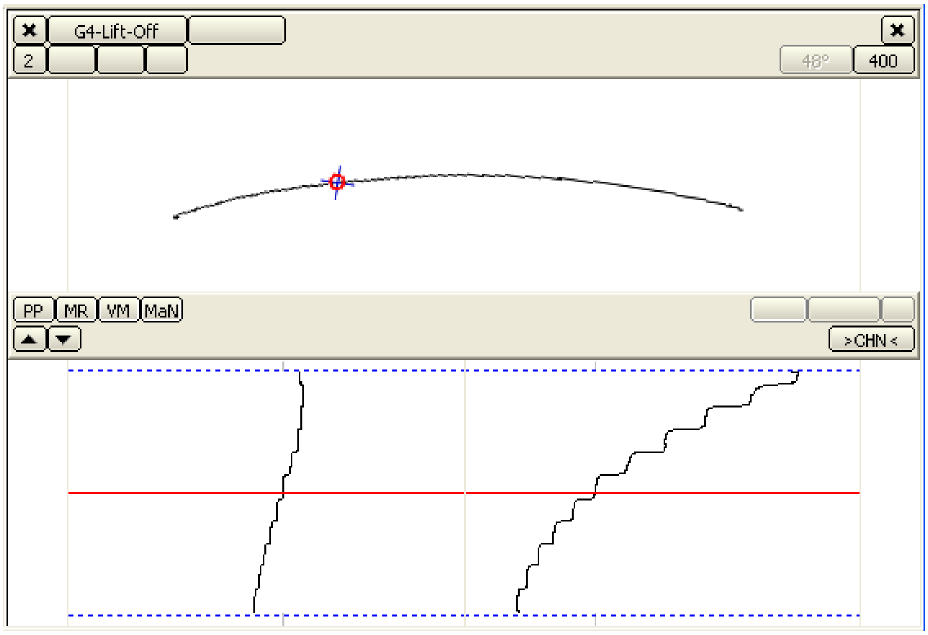


Figure 8-10 Lissajous response of non-conductive step plate showing each thickness variation

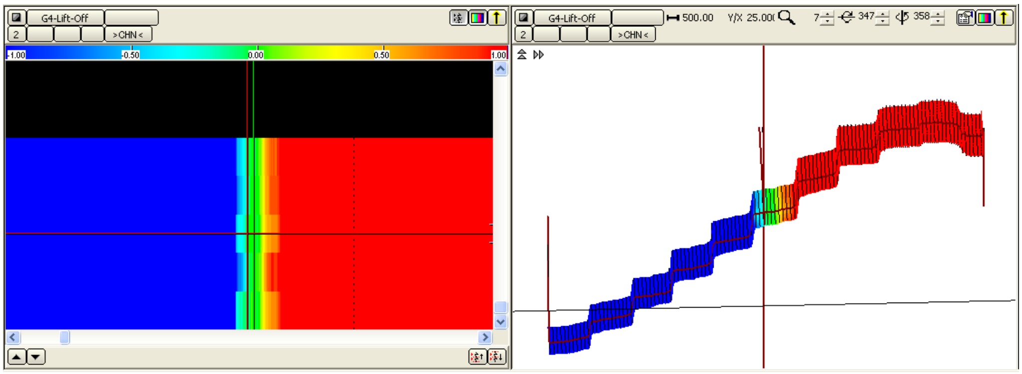


Figure 8-11 2D/3D C-Scan response of non-conductive step plate showing each thickness variation

This voltage relationship can be graphed, and the corresponding calibration curve can be created. Figure 8-12 shows an example lift-off curve.

Lift-off Calibration Curve		
Lift-Off (mm)	Percent	Voltage (Vpp)
0.80	10	100
1.60	20	159
2.40	30	205
3.20	40	230

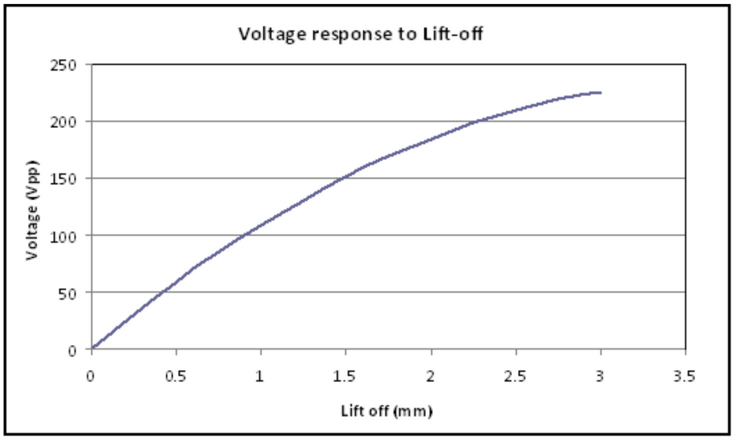
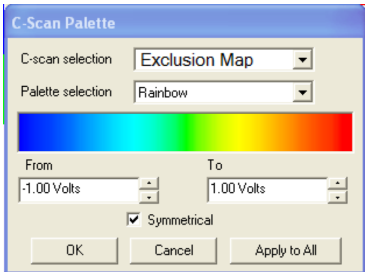


Figure 8-12 Lift-off based calibration curve that relates voltage to millimeters of lift-off

To have the color scale calibrated to the distance, the C-Scan palette should be set to the voltage level at the threshold distance. When using an alarm palette, the C-Scan can be a very quick tool to show areas where the data quality is poor.

The lift-off level at each mesh or grid location is very important to know. This is due to the reduction of flaw voltage as the lift-off increases. Figure 8-14 shows a typical reduction of flaw voltage with increasing lift-off. Figure 8-15 shows the typical flaw size vertical amplitude reduction with increasing lift-off. As the figures show, there will be a threshold lift-off that will shrink the flaw amplitude down to the noise level of the sample material. If there is a reduction in signal amplitude below the noise threshold, the flaw will be missed or mistaken for signal noise in the test material.


C-Scan Palette

C-scan selection: Exclusion Map

Palette selection: Rainbow

From: -1.00 Volts

To: 1.00 Volts

☑ Symmetrical

Figure 8-13 The color scale relates color to millimeters of lift-off

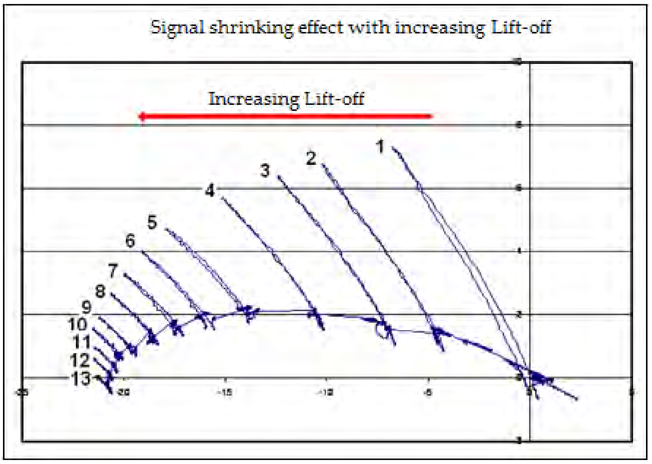


Figure 8-14 3 mm TWH scanned 13 times with 0.25 mm lift-off increment

Figure 8-15 shows the amplitude reduction for a 3 mm, 2 mm, and 1 mm through wall hole in the test material.

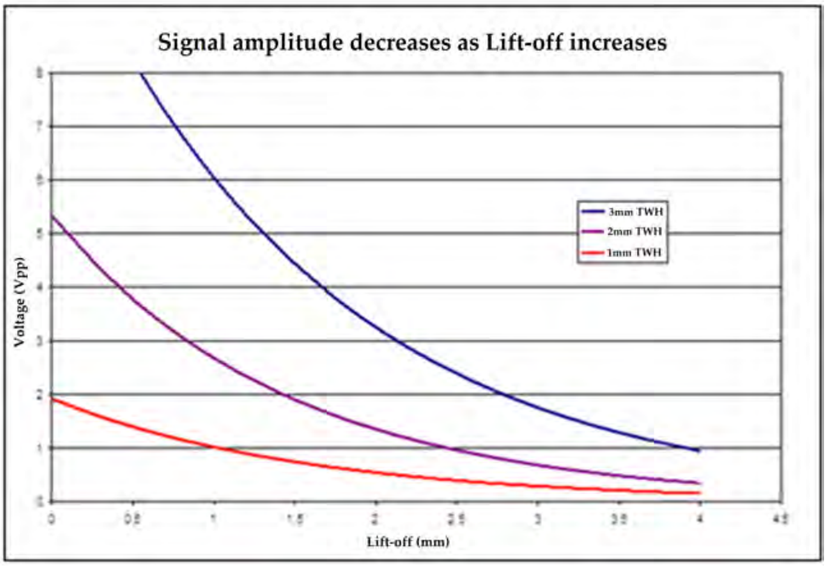


Figure 8-15 Lift-off test showing signal amplitude attenuation

The creation of color calibrated C-Scans is a relatively simple procedure. Understanding how this calibration is applied and works is somewhat more complicated.

Lift-off C-Scans are created the same way as any other C-Scan. The encoder data is processed to determine which slices of data to store in each C-Scan location. This process creates the slice to mesh relationship. When measuring any voltage values in the channel data a Lissajous applies a measurement process to the data. The most common measurement process is the peak-to-peak process (Vpp). This takes the start and end cursor positions, and determines a voltage value that reads the largest peak-to-peak change in voltage. This process uses two voltage values to determine a Vpp value. Even the maximum rate of change (MxR), or the maximum vertical amplitude (Vmx) processes measure their values from two points of data.

C-Scan data gets a color associated to a voltage value based on a single point of voltage to a single point in the color scale. This means that the process that determines which color to use for each mesh sample, is a one point to one point process. This is the reason that the null line cannot be applied to the C-Scan data, or the color scaling will not apply correctly.

When the null data shifting process shifts the data points, the shifting is evenly applied to Lissajous data, but not C-Scan color scaling. When the C-Scan data is measured, in a C-Scan Lissajous, the values are the same no matter where the null slice is located. This is due to the processing of the two points in the Lissajous measurement process. The shift applies to both points, and is subtracted out from both points, which results in the null process having no effect on the voltage. With only one point, there is no subtracting of this shifting value, and this creates an incorrectly calibrated color scale, or a shifted color scale.

When the null process is not applied to the C-Scan data, the color scale can be set to turn voltage values to specific color values. Commonly, this is done using an alarm-type of color scale. For an exclusion map, there is a threshold voltage level that represents the maximum amount of lift-off that an inspection can be performed with. If there is more lift-off, than the threshold limits the voltage from, the minimum flaw size will be below the reporting threshold. This results in flaws being missed, when they should have been reported. Sometimes it is not possible to scan a surface and keep the lift-off below the threshold level for the entire scan. There can be issues with the mechanical placement of the probe; geometric variations in the surface that prohibit the entire surface from being scanned below this threshold level. These areas should be reported as regions where the inspection requirements for detecting the minimum flaw size are not possible.

This process can be automated using a color scaling, where the alarm color scale is calibrated to the threshold voltage or the voltage response from the maximum amount of allowable lift-off. This is done by calibrating the data in a slightly different manner. The exclusion map channels are calibrated with the lift-off response moving down, or rotated to 270°, rather than the usual 0^{o}. Since the lift-off is almost exclusively a horizontal variation, the correlation between the horizontal distance and the Vpp from null to each point of data is very high. When the data is rotated down, the lift-off response becomes almost totally a change in vertical component. If the null process is not applied to the data set, then the Vmx component from each C-Scan location will be almost exactly the Vpp value. This is because the Vpp measurement is calculated from 0 volts to the Vertical component. If the null is applied, the 0 value shifts, and this shift responds with a shifted color scale. The end result is a C-Scan where each point very closely matches the Vpp value. This method creates C-Scan data that is mapped with a Vpp meshing; which is the same thing as an automated Vpp measurement for each point of data. Once the color scale is applied to the Vpp response from the threshold level, the alarm will show the alarming color. This color alarming occurs only when the C-Scan location measures more voltage than the lift-off threshold. This color calibration can be verified by using the typical lift-off C-Scan Lissajous window with the calibrated circles. Once the data point moves out of the threshold level circle, the color should alarm.

Exclusion C-Scan maps can also be set up in a similar manner using the horizontal component rather than the vertical component. The vertical component is used here mainly for analysis purposes. It might seem trivial, but it is very annoying to have to switch the C-Scans from horizontal to vertical each time you want to measure a point. With the value set vertically, switching between C-Scan windows is quick and helps the analysis process.

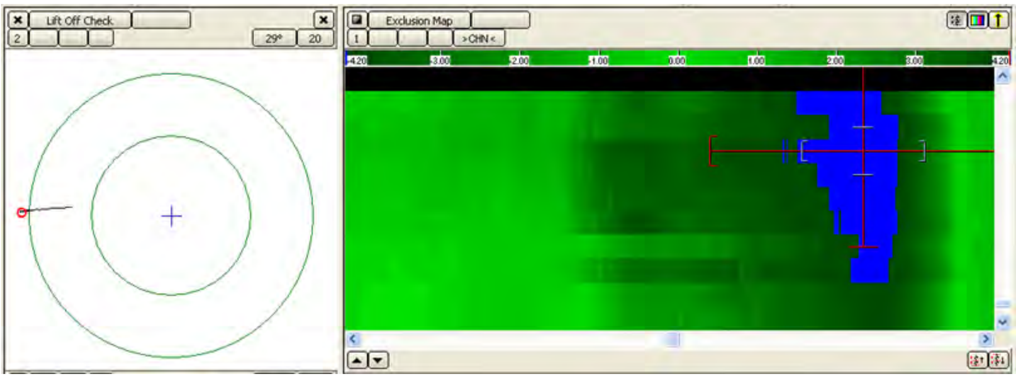


Figure 8-16 Exclusion map showing a region that is past the threshold level

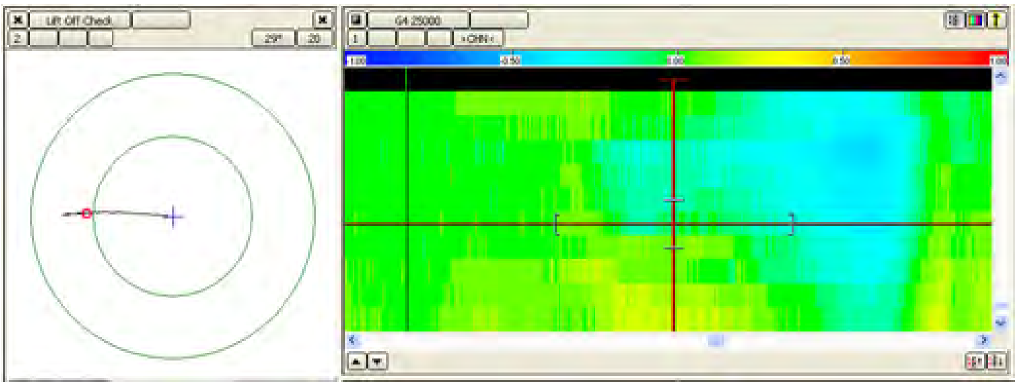


Figure 8-17 Exclusion map with null process shifting range to the data and the color scaling

8.4 PROBE CHECKS

Probe checks can refer to the verification of the current state of a probe during acquisition; and can also refer to the verification of the calibration.

There are many methods available to verify the state of a probe. The simplest is to perform a lift-off while scanning. If the probe is lifted from the material all of the channels should respond with the proper lift-off signal. This will quickly show coils that are dead.

Verifying that a calibration was done correctly is usually a simple procedure. No matter how many channels a probe has, all the channels are organised in a very convenient and logical order. The channels are grouped by frequency and other common trends in the C-Scan data. Once the calibration is performed on the channels, each channel has to be checked. This can be done quickly and easily in the C-Scan windows.

To verify that the probe is functioning properly is a little more complex. Figure 8-18 shows typical issues with noise or the calibration process.

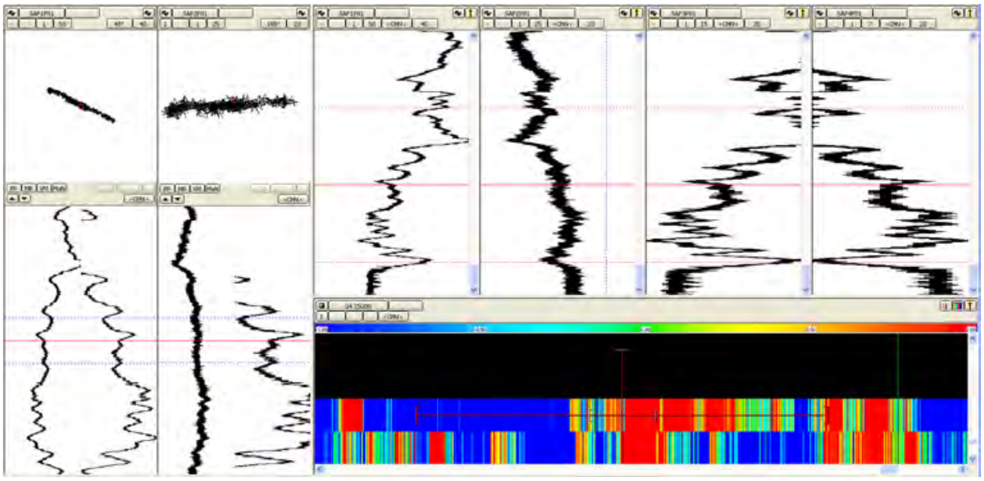


Figure 8-18 When the voltage calibration is incorrect it can be mistaken as probe noise

Figure 8-19 shows a typical scrambled C-Scan color palette appearance when the gains are not correctly applied. The Lissajous window is located on the near-surface groove which displays a normal signal response.

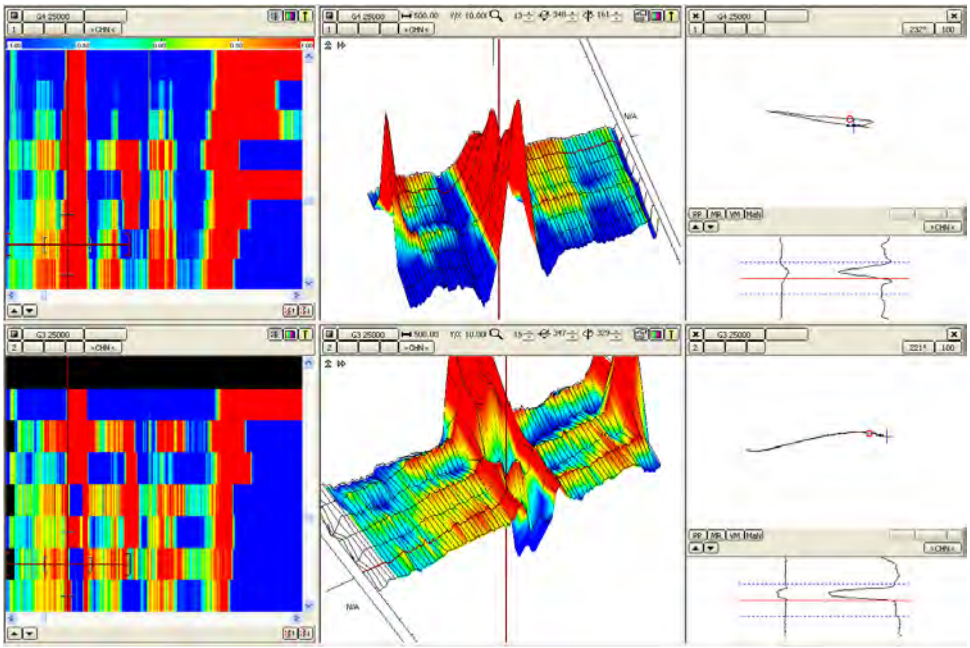


Figure 8-19 Typical calibration with the improper point used for setting voltage

At first, this setup seems good and clean. If the color scale is different than the rainbow palette, this calibration error might be hard to catch at first. The key to noticing the issue is in the Lissajous window. All the Lissajous will be 180° out of phase (see Figure 8-20). Never rely on the C-Scan color palette to reveal issues in the signal. The C-Scans are used as a means to quickly point out areas of change and help screen large quantities of data.

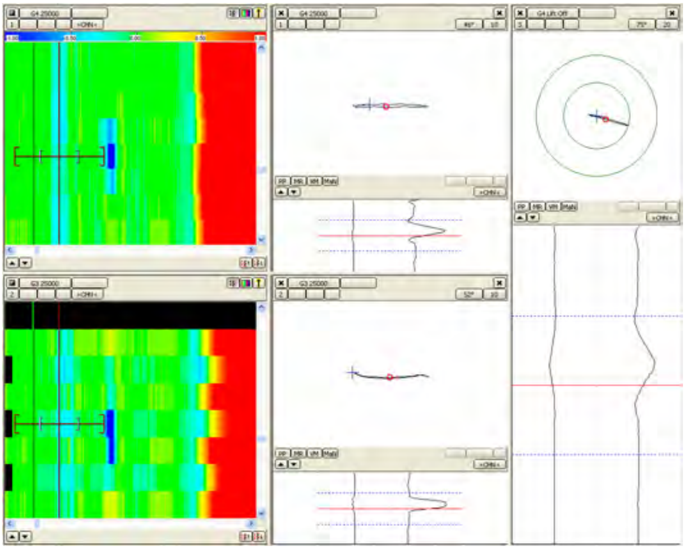


Figure 8-20 Entire setup is 180° out of phase

The N channels are 180° out of phase with the P channels. This is a front side / back side issue caused by the calibration point being set incorrectly. This is either called from the wrong side, or the setting window was opened too large and the backside had a Vpp measure that was larger than the front side measure.

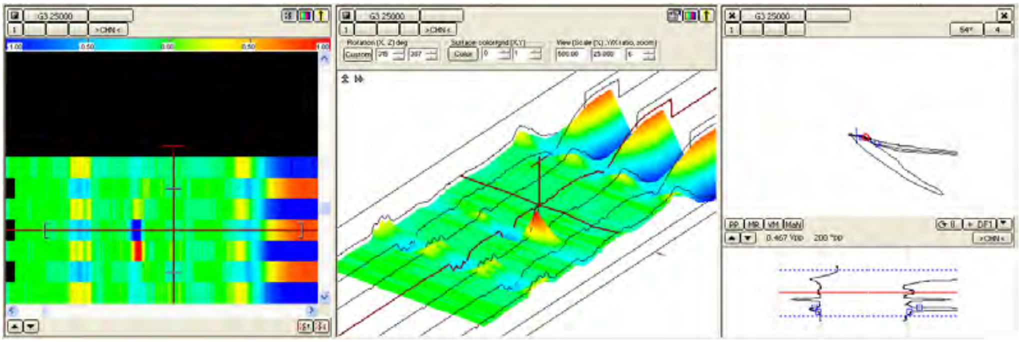


Figure 8-21 G3 Even or odd channels are 180° out of phase

Another common issue is the flipping of one channel (see Figure 8-22). This can be corrected by finding the channel that is out of phase, and manually rotating it in line with the other channels. The scale details widget will also show which channel is out of phase.

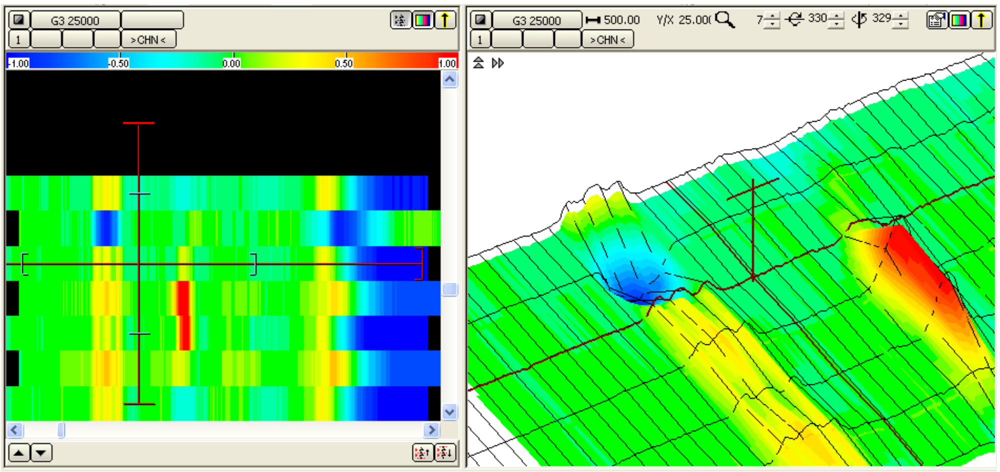


Figure 8-22 One N channel is flipped in the C-Scan