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Magnetic Near-field Evaluation Methodology for Integrated Circuit In-package Coupling Assessment

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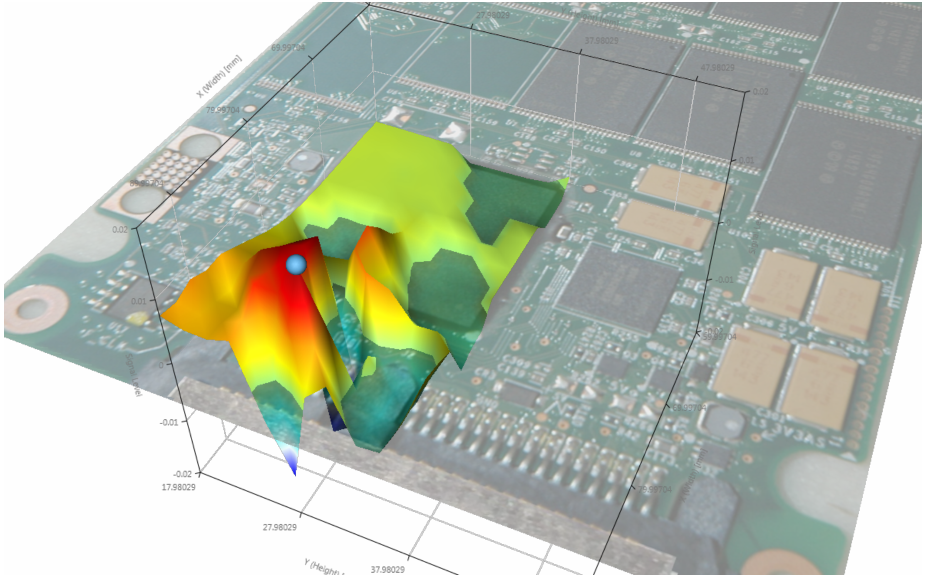
Stuart is the CEO of Aprel Inc, specializing in near-field measurement research and development and providing electromagnetic safety testing to the industry. He is leading a team of talented engineers in designing and implementing revolutionary technologies at the forefront of the industry. His creative vision of innovative instrumentation and measurement methodology tackles the many challenges of electromagnetic near-field testing.

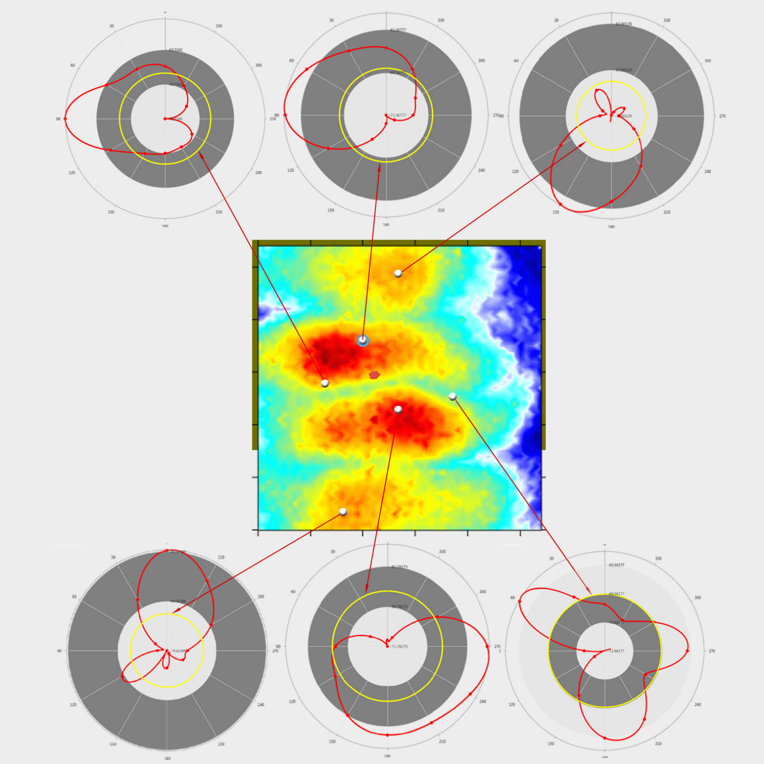
INTRODUCTION

- **Near-Field of Integrated Circuit:**
  - Reactive magnetic field
  - Coupling
  - Cross-talk
  - Standing waves
  - Power pockets
  - Backscattering
- **Any coupling event between different elements within an IC affects its performance.**



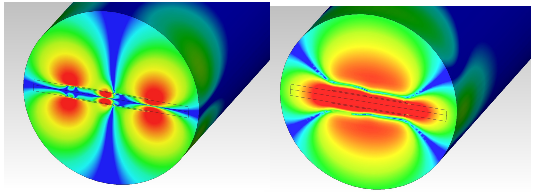
Near-Field Assessment Methodology

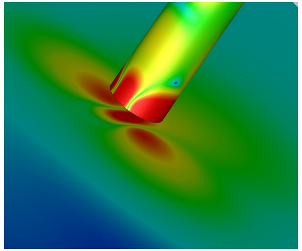
- **Direct measurements of decoupled magnetic fields using automatic measurement system**
- **Assessment of *H* field vector distributions**
  - Measurement of H field 360-dedree patterns
  - Quantification of the maximum amplitude vectors and their orientation on the evaluation plane
  - Measurement at 0º and 90º probe orientation in reactive near field is not enough for the detection of in-chip coupling events
  - The lossy low-Q *H*-field vector probe is ideal for the measurements in the reactive near-field area close to a device surface because its interference with a device under test is negligibly small.

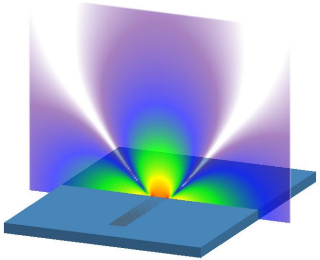


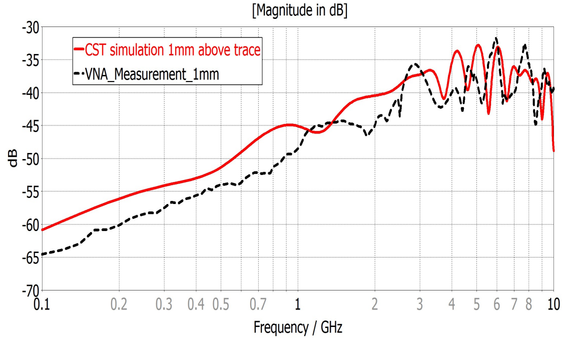
H-Probes

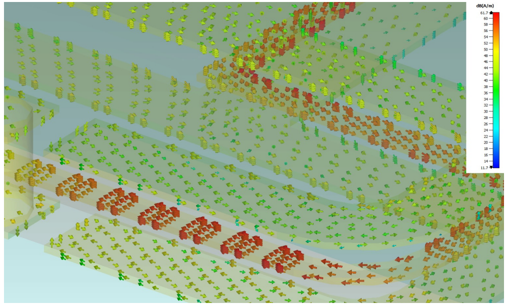
- H- vector probes are low-Q antennas designed to minimize any coupling with the field generated by a device
- The magnetic probe design is a printed version of so-called King type probe developed in 1965 by Whiteside and King
- The TDR comparison of measurement (black trace) and simulation results (red trace) demonstrated some differences although the coupling trend showed a good agreement in frequency domain





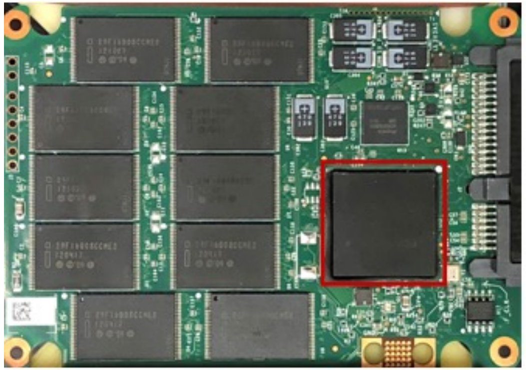




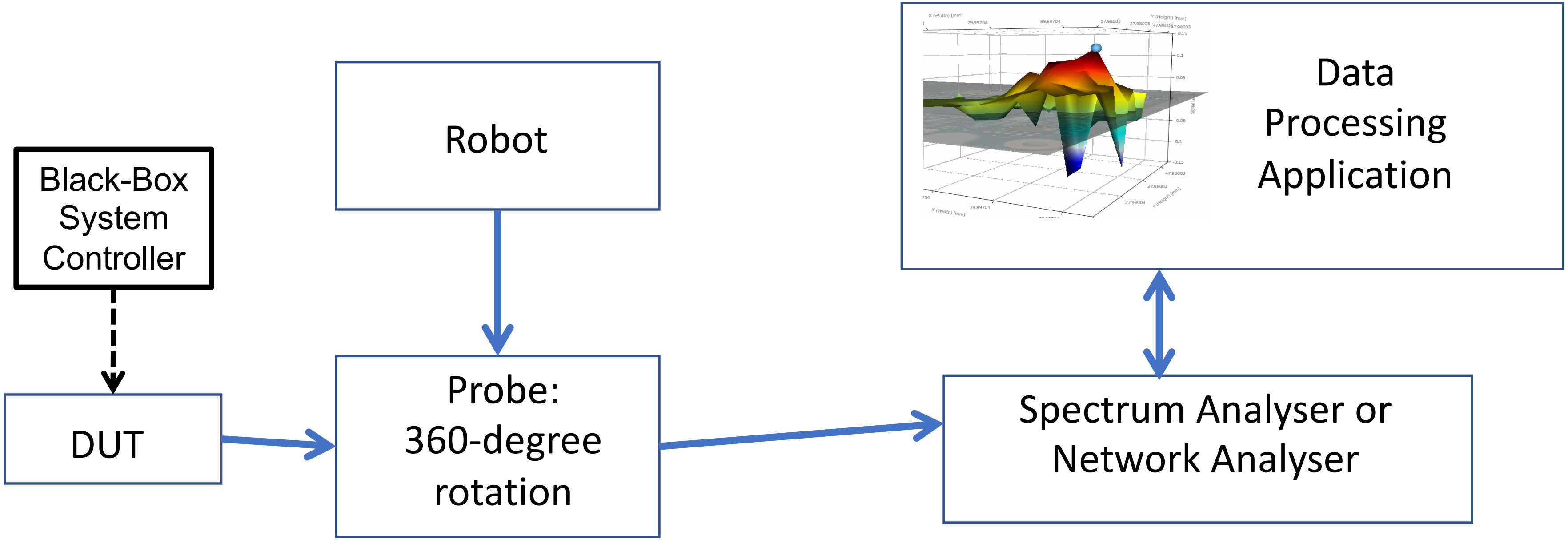


Device Under Test

- ASIC's IC chip on an SDD
- SI issue impacted the data rate over the USB C interface thus impacting optimal performance
- Test software controlled specific aspects of the IC

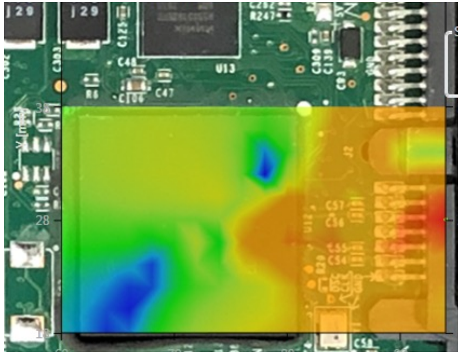


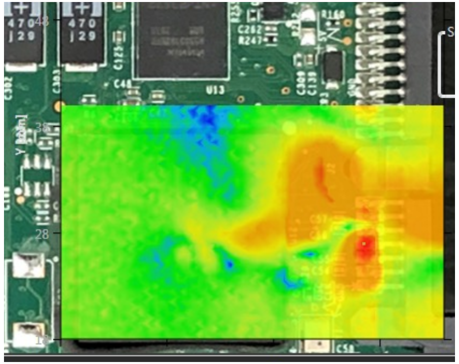
Test setup


Black-Box System Controller
Robot
Data Processing Application
DUT
Probe: 360-degree rotation
Spectrum Analyser or Network Analyser

Pre-Test

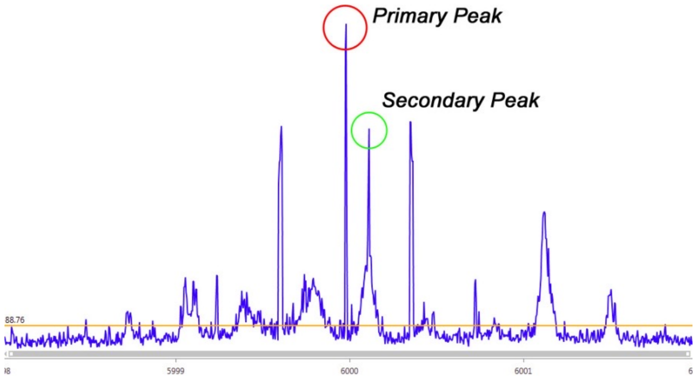
- Big scan area
- Two different-design H-probes
  - 2mm loop size
  - 1mm loop size
- Same scan grid setup – different field distribution results
  - 2mm-loop probe scan showed less details (top plot)
  - 1mm-loop probe provided clear information about H-field sources and their interactions (bottom plot)





Test Setup

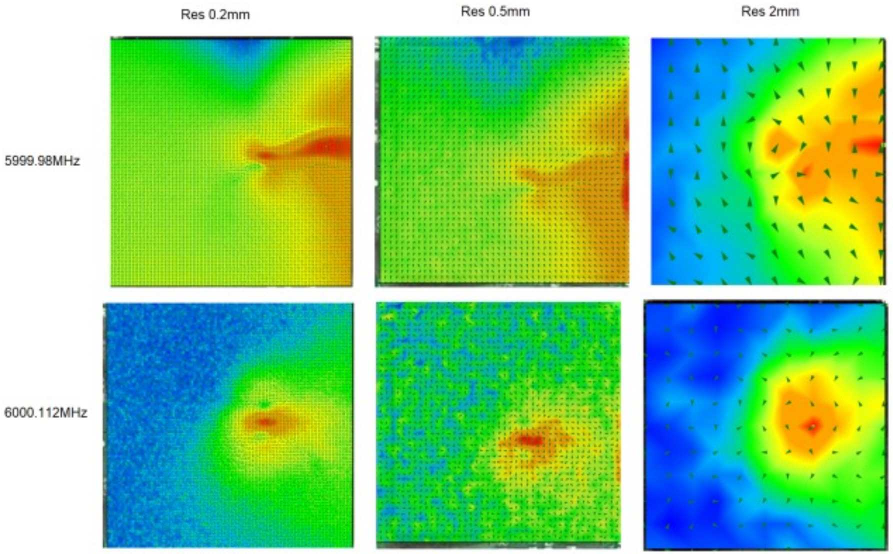
- Scan area covers the IC surface
- Three different resolution steps
  - 2 mm
  - 0.5 mm
  - 0.2 mm
- 360-degree probe rotation with 30-degree step
- Frequency range from 5998MHz to 6002MHz
  - focus on two frequency points: the maximum peak primary 5999.98 MHz and the secondary 6000.112 MHz.1mm-loop probe provided clear information about H-field sources



Other peaks have been found upon analysis to echo the primary peak

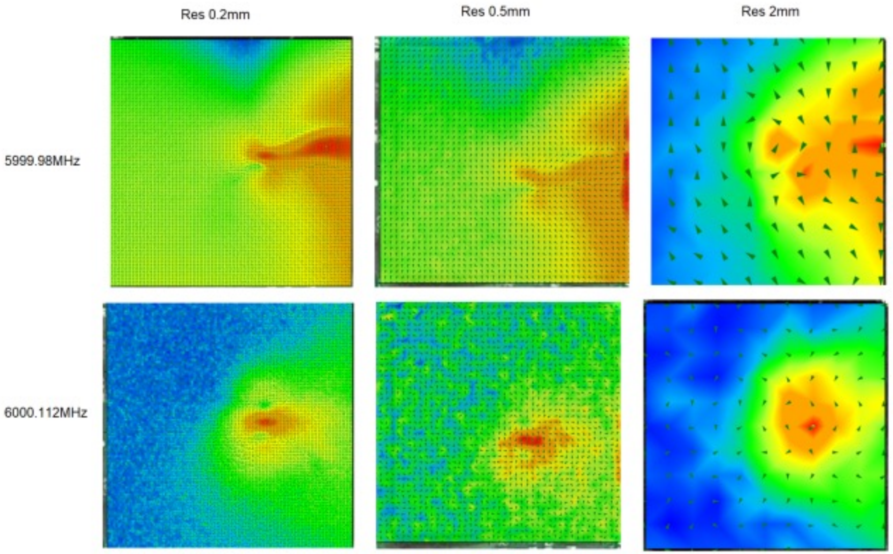
TEST RESULTS (1)

- **At the primary frequency point**
  - clear indication of the magnetic field coupling with out-of-chip elements of the device for all three resolution steps
  - 0.2-mm step provides the most accurate and detailed field distribution (a)
  - 0.5 mm step (b) show an irregular near-field cloud
  - 2 mm-resolution step measurement (c) indicates the general position of the field hotspot

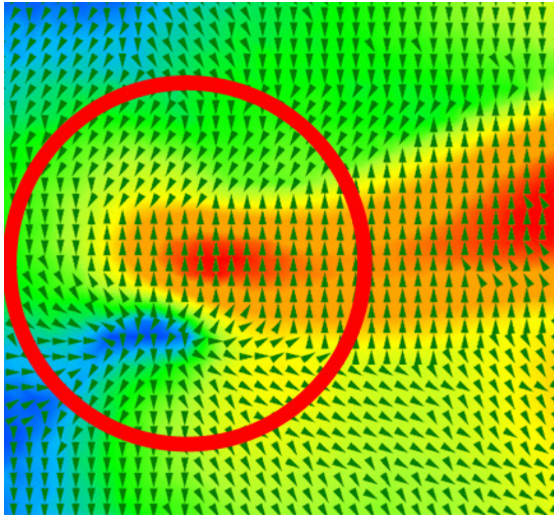


TEST RESULTS (2)

- **At the secondary frequency point**
  - field distribution plots look different for different resolution scans
  - 0.2-mm step provides a clean pattern of the inductor near-field (a)
  - 0.5 mm step plot (b) shows inhomogeneous distribution of the field
  - 2 mm-resolution step measurement (c) detected only a simple circular hotspot

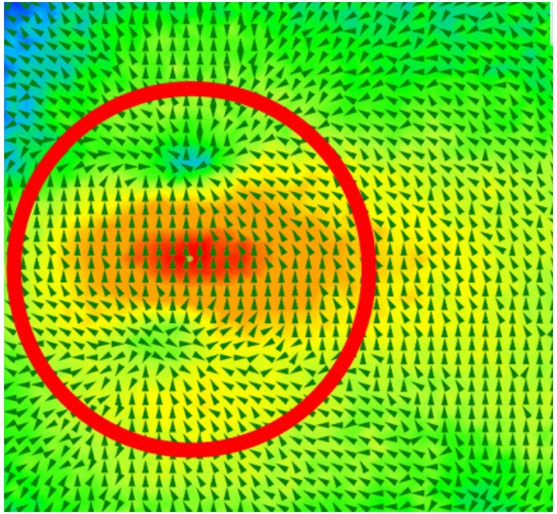


HOTSPOT COMPARISON



Primary peak @0.2mm resolution

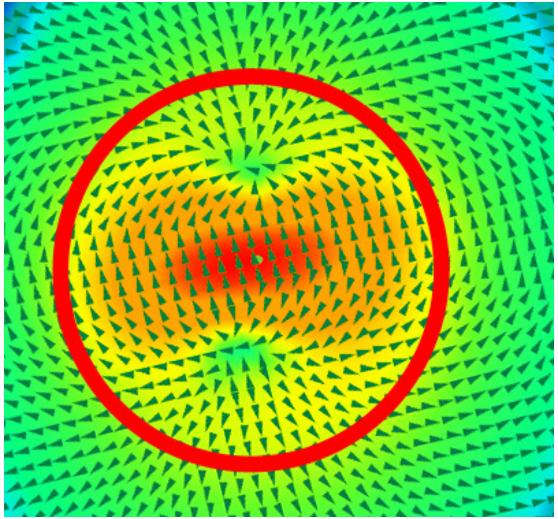
VS.



Secondary peak @2mm resolution

Hotspot at the same location for both frequencies, indicating that a component at this locality generates a near field registered at both frequencies.

INDUCTOR FIELD DISTRIBUTION



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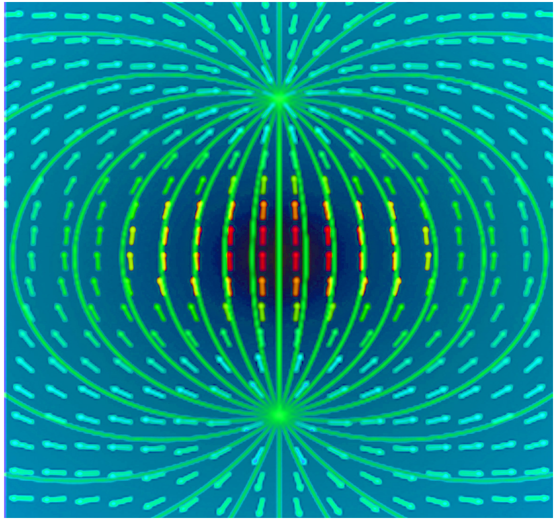

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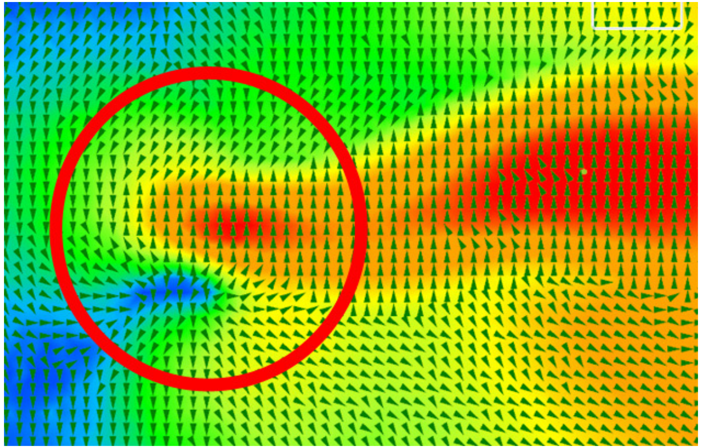
Vector gradient at the secondary frequency is a reasonable match with the measured and calculated vector pattern of an inductor

And in close agreement to that modelled theoretically as an elliptic pencil of circles, the family of curves of the form

$$x^2 + y^2 - tx = 1$$

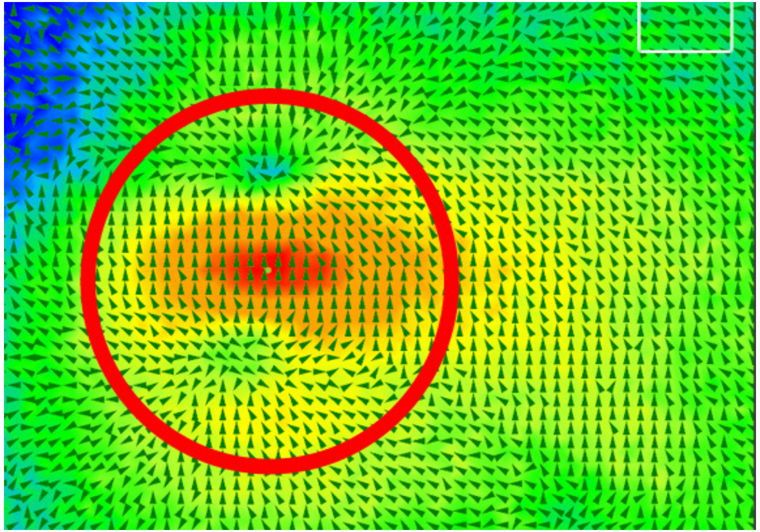
TEST RESULT ANALYSIS (1)

- **At the primary frequency point:**
- **distortion of the torus-like field bubble is due to the strong coupling with the PCB elements as seen on the plot**
- **the measured field is concentrated close to the edge of the IC with smooth connection to the inductor hotspot**
- **Coupling of the inductor in the IC with the components on the PCB outside the chip at 5999.98 MHz**



TEST RESULT ANALYSIS (2)

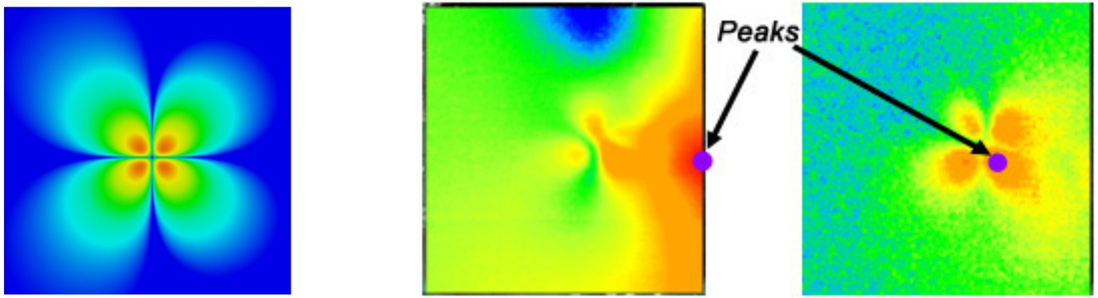
- At the secondary frequency point:
- Clean points of convergence and divergence as expected for the section of a vector field torus
- Magnetic field traces outside the inductor field circle indicate possible in-chip interference with one or several components.
- Possible coupling of the inductor in the IC with the with some element inside the chip at 6000.112 MHz



H_x FLUX ANALYSIS

- The plots of measured flux at primary and secondary frequencies demonstrate a significant difference in the field behaviour:
- for the secondary frequency the coil pattern is almost intact
- at the primary frequency the field magnitude peak is located on the edge of the scan, indicating a high likelihood that its source is located outside the IC

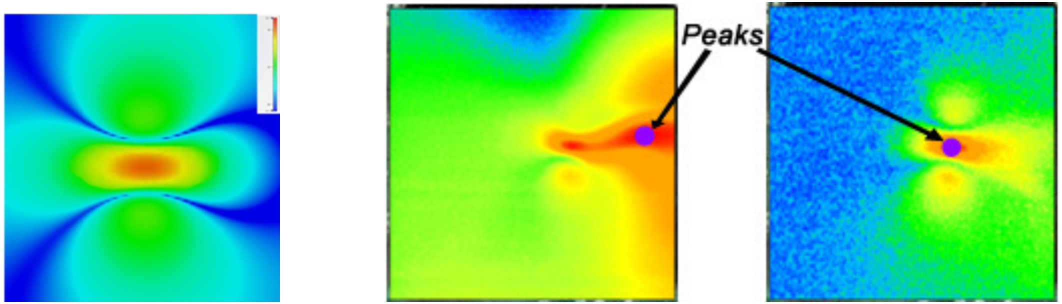
- The way the inductor field is deformed implies a coupling event.



Simulated | Primary peak | Secondary peak

H_y FLUX ANALYSIS

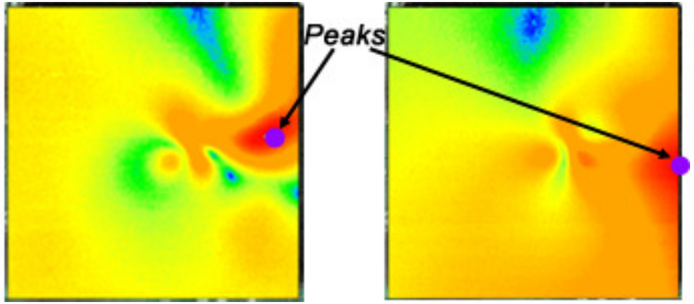
- At primary frequency the coupling event in the Y direction is asymmetrical to the one in the X direction: the Hy-flux magnitude is not on the edge of the scan but closer to the inductor with a narrow bridge.
- At the secondary frequency point the coil pattern has only minor distortions coherent with the Hx flux circulation.
- This scenario could be an indicator that not only the inductor but also some components inside the IC are involved in the interference process.



Simulated Primary peak Secondary peak

VECTOR ANALYSIS FOR PRIMARY PEAK

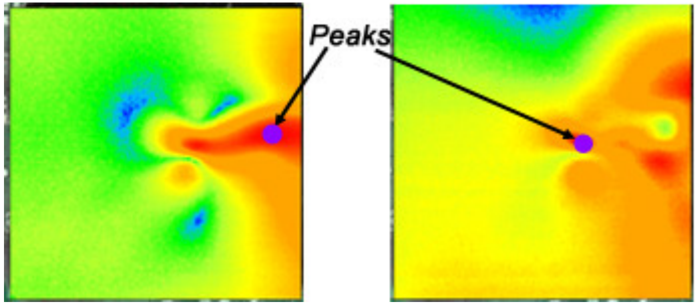
- In the reactive near-field zone the amplitude distribution for H-vectors oriented in opposite directions differs as a function of space and time: vectors in one direction couple with elements in one location on the board, while vectors in the opposite direction couple with elements in different location.
- Magnetic field vectors in the (H_{x+}) direction create a flare heading to the right top
- (H_{x-}) vectors of opposite orientation (right plot) indicate coupling in the lower right part of the scan edge.



$H_{(x+)}$ distribution $H_{(x-)}$ distribution

VECTOR ANALYSIS FOR PRIMARY PEAK

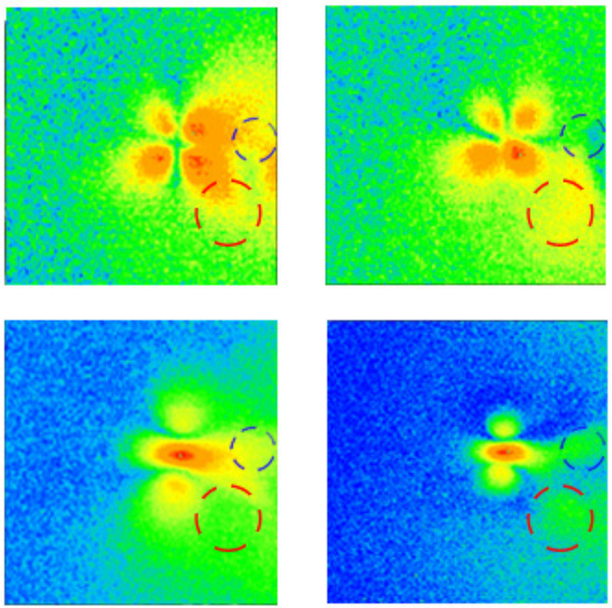
- Maximum magnitude peak points are located in different parts of the IC
- Magnetic field vectors in the (H_{y+}) gradient is smooth
- (H_{y-}) vector distribution is kind of patchy and disintegrated
- At the area of the (H_{y+}) peak the measured vector (H_{y-}) magnitude is about 7 dB lower. Thus, the vectors of opposite directions from differing sources are in-phase and cancelling each other.



$H_{(y+)}$ distribution $H_{(y-)}$ distribution

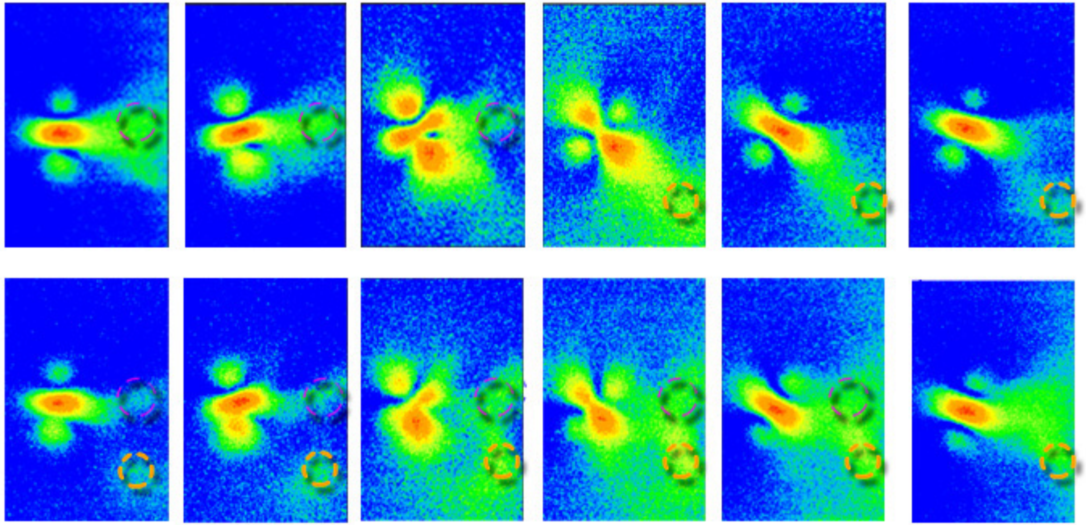
VECTOR ANALYSIS FOR SECONDARY PEAK

- **For the (H_{y-}) another source of magnetic field is registered in the IC (circled, bottom right plot).**
- **(H_{x-}) scan plot (circled, top right) shows that this field is interfering with the field created by the inductor.**
- **(H_{y+}) vector distribution plot (circled, bottom left), the area of the second source of the magnetic field is not evidenced: although it is noteworthy for showing no interference with the inductor in this vector orientation. In fact, the field seems to be pushing up in the indicated spot.**
- **(H_{x+}) vector plot (top left) indicates that the inductor field is “pulled” down-right causing visible distortion within the field of view.**



VECTOR ANALYSIS AT DIFFERENT ANGLES

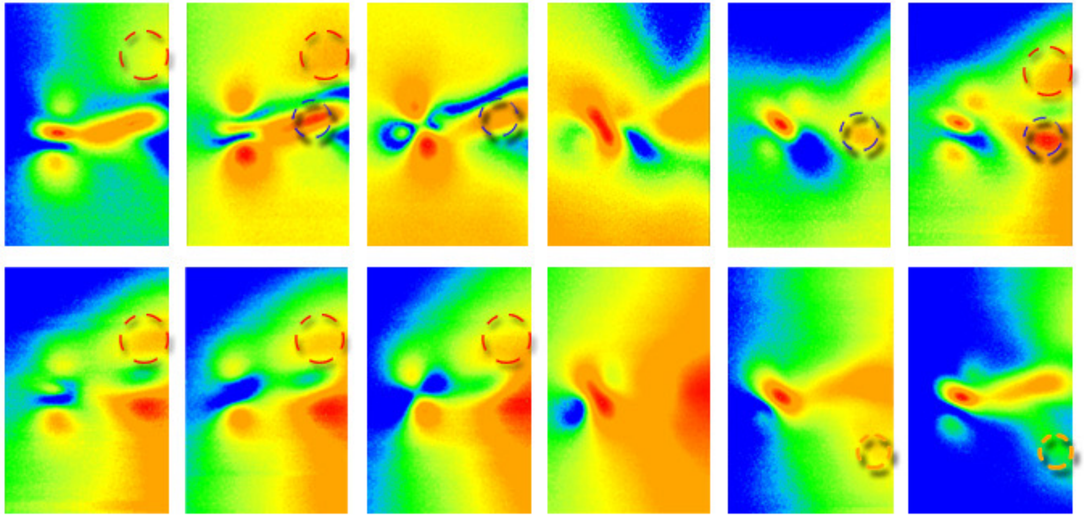
- **Several clusters of the field splashing and dissipating as the probe rotates.**
- **Some of these splashes are also registered at the primary frequency.**
- **This information can be obtained exclusively through the vector 360-degree measurement assessment.**



Plots for vectors at 360-degree probe orientation at the secondary frequency point

VECTOR ANALYSIS AT DIFFERENT ANGLES

- Numerical simulation applications provide only *Hx* and *Hy* flux patterns which could be not sufficient for an adequate assessment of reactive near-field of an IC.



Plots for vectors at 360-degree probe orientation at the primary frequency point

CONCLUSION

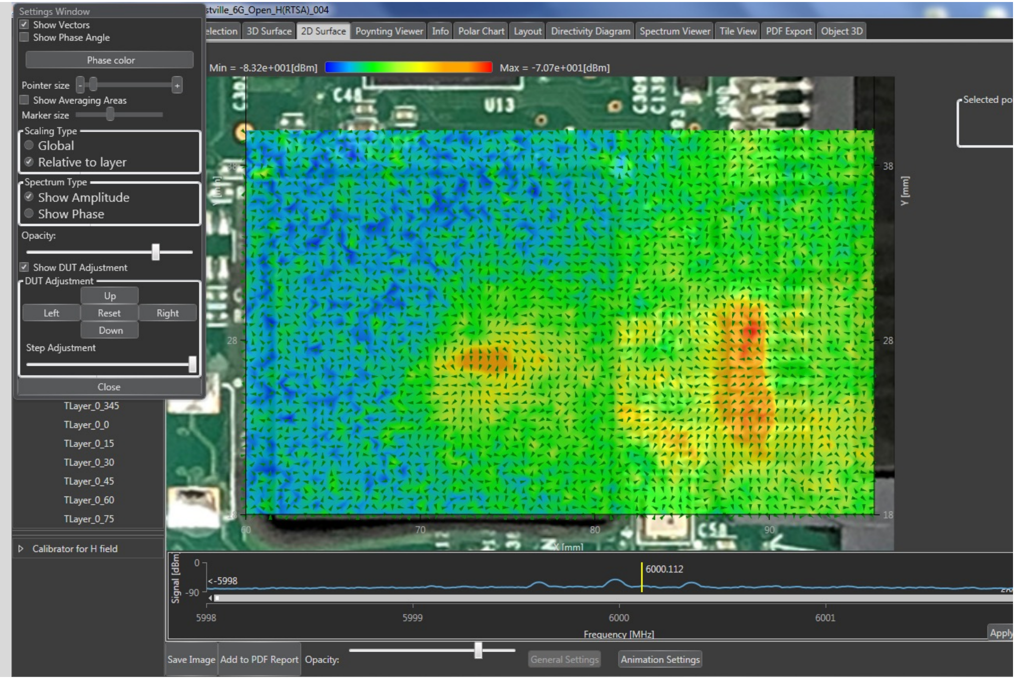
The presented study is “blind” as IC design layout is unknown. So our measurement methodology provided distinguished information about the magnetic field on-PCB interferences along with possible in-package couplings and locations of its sources.

This analysis has shown that it is essential to utilise a full 360-degree rotation of the vector probe to truly assess and identify problematic areas on the circuit.

For the IC design industry, this knowledge will help to develop balanced layouts avoiding potential in-chip coupling problems, which will lead to the shorter product development time and reduce the risk of EMC test failure.

MORE INFORMATION

- **www.aprel.com**
- StuartN@aprel.com



Thank you!

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QUESTIONS?