# The Impact of Chip and Package Design on Radiated EMI

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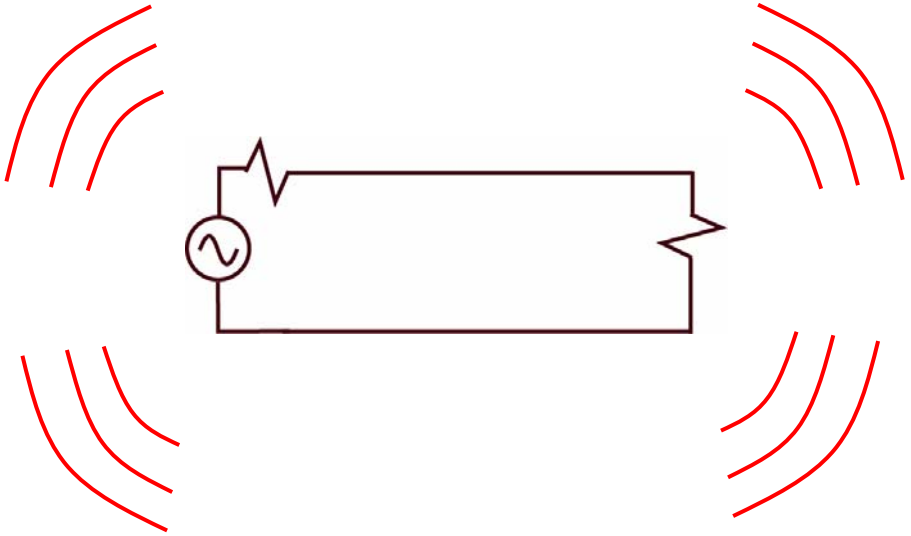
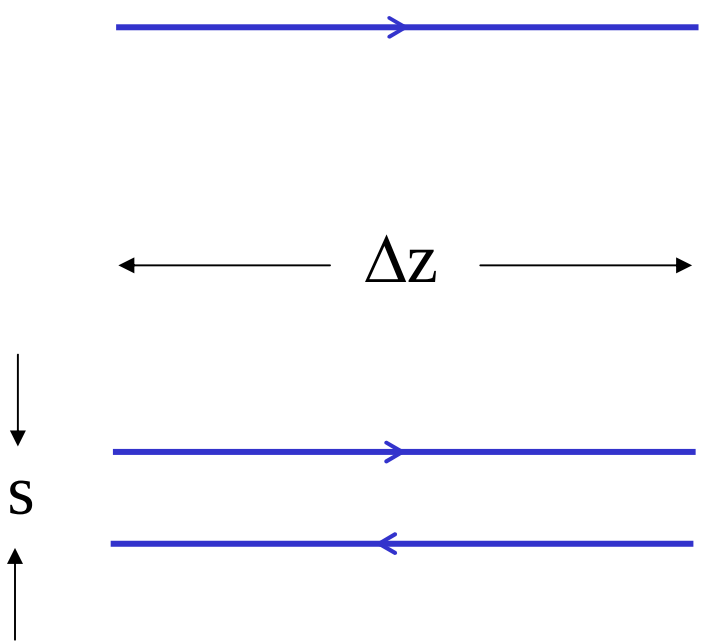
# Radiation from circuits



# Common-Mode vs. Differential Mode

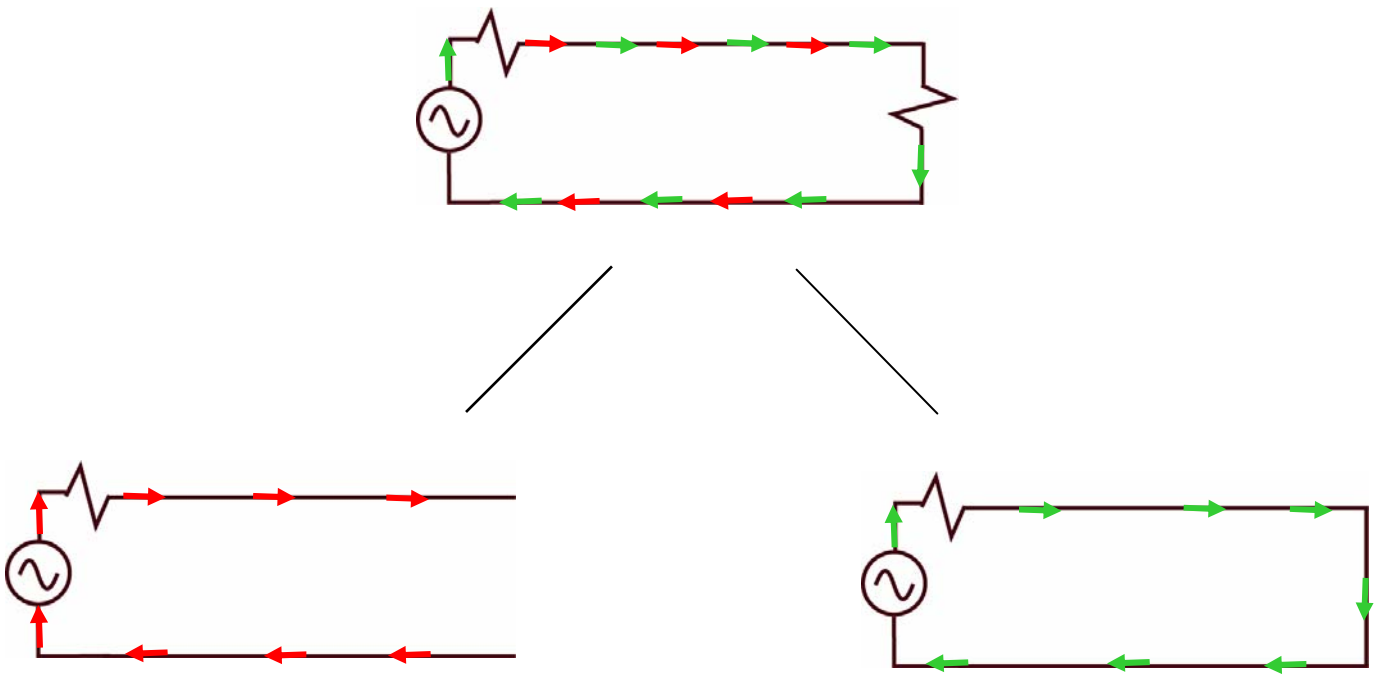



$$E_{max} = 1.26 \times 10^{-6} \frac{|I_c| f \Delta z}{r}$$

$$E_{max} = 1.32 \times 10^{-14} \frac{|I_d| f^2 s \Delta z}{r}$$

$$= 4 \times 10^{-6} \frac{|I_d| f \Delta z}{r} \left( \frac{s}{\lambda} \right)$$

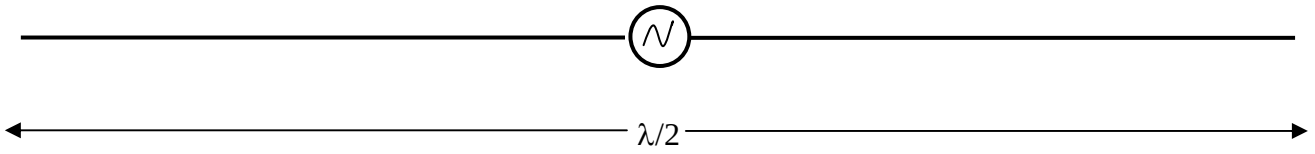
# Radiation from circuits



Short Loaded Dipole

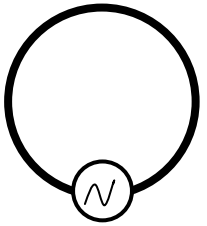
Small Loop

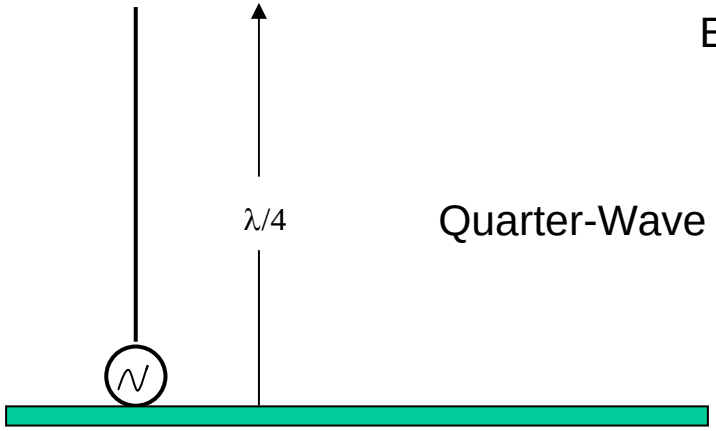
# What makes an efficient antenna?




Half-Wave Dipole

Electrically Small Loop

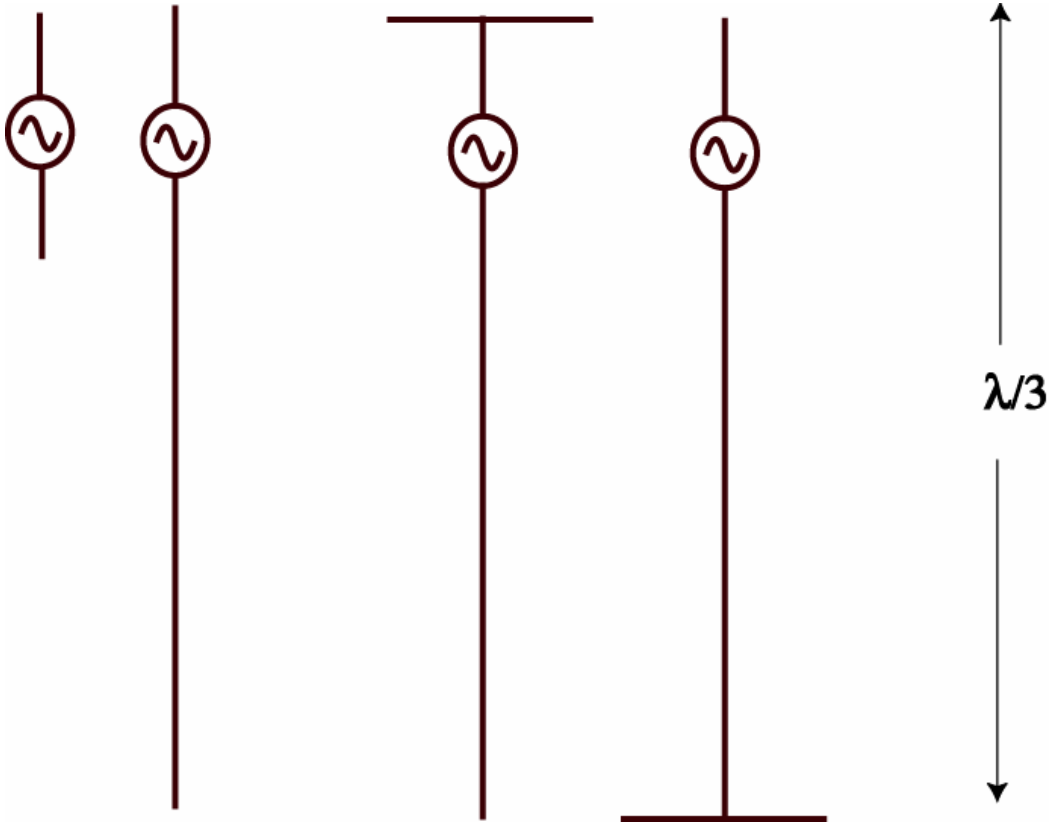





Quarter-Wave Monopole

- **Size**
- **Two Halves**

# What makes an efficient antenna?



# EMI Problems Below 100 MHz

**Wavelengths > 3 meters**

**Large Systems - It's probably the cables**

**Desktop Systems - It's definitely the cables**

**Handheld products - No problem (Unless you attach cables)**

# EMI Problems Above 1 GHz

At frequencies greater than a few hundred MHz, structures on a printed circuit board can resonate.

Example:

$V_s = 1 volt \,@\, 500\, MHz$

$E_{rad} \approx 360\, mV/m \,@\, 3 meters$

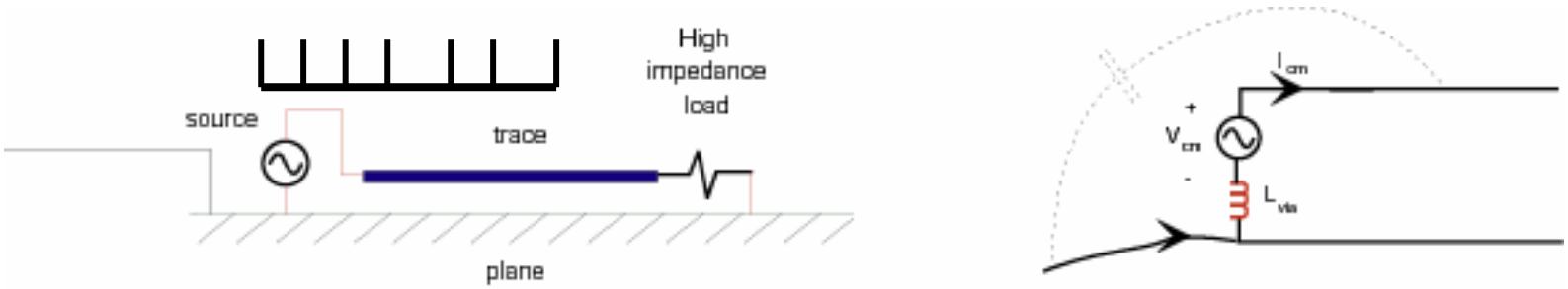
**More than 60 dB above the FCC Class B limit!**

# EMI Problems with Chips and Packages

Chips and packages are often the source of EMI problems, but they are rarely (if ever) the antenna.

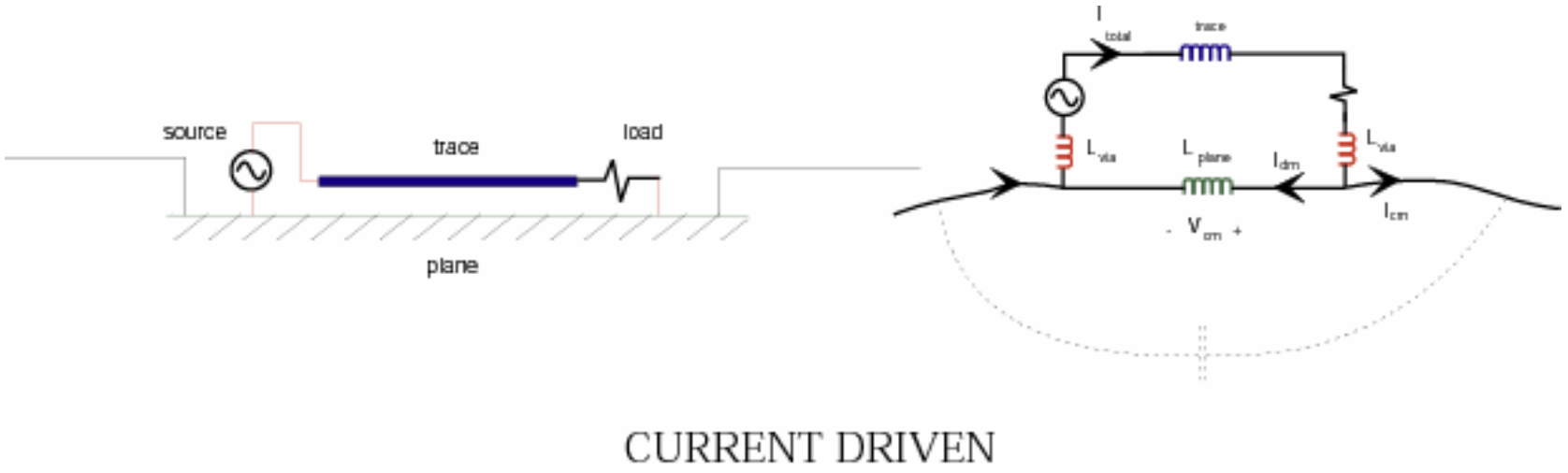
Chips and packages become a problem when they are a source of common-mode current.

# Sources of Common-Mode Current




VOLTAGE DRIVEN

# Sources of Common-Mode Current




CURRENT DRIVEN

# Sources of Common-Mode Current


CABLE IMBALANCE

# EMI Problems with Chips and Packages

There are three ways that chips and packages tend to contribute to radiated EMI.

- Noise (or the wrong signal) coming from signal pins
- Field coupling to heatsinks or nearby components
- Power bus noise

# Case Histories

Network Server

- Unacceptable emissions at 1.2 GHz
- $20^{th}$ harmonic of 60 MHz clock
- Coupling from processor board to heatsink
- Not due to processors drawing 2 Amps
- Due to clock driver drawing a few milliamps

# Case Histories

Automotive product

- Unacceptable emissions at harmonics of 16 MHz
- Internal processor frequency, no external signals
- Harmonic currents appeared on virtually every pin
- Low frequency traces were not routed adequately
- No good solution at the board level

# Case Histories

## LCD Display

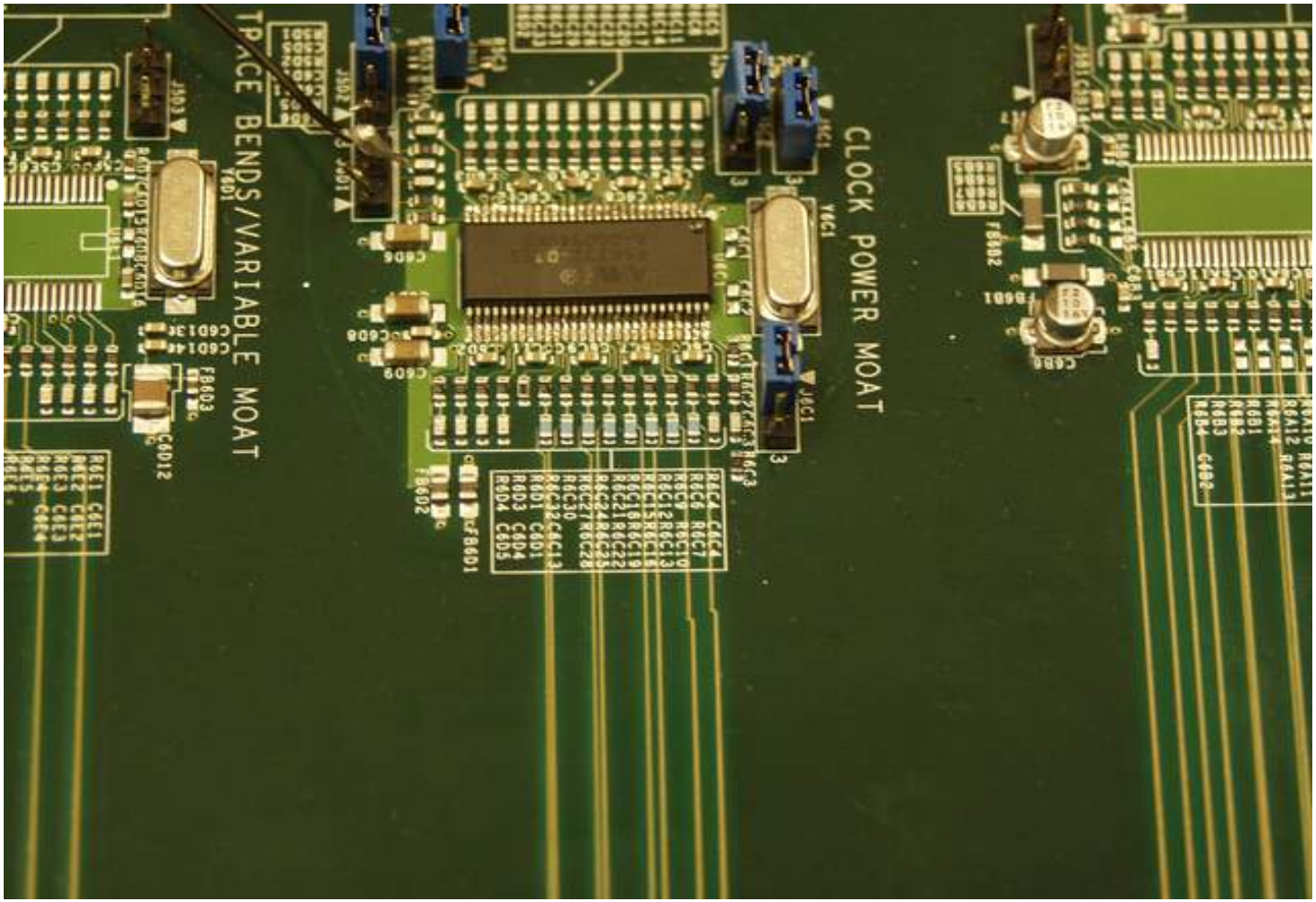
- Unacceptable emissions at a few harmonics of 60 MHz
- Emissions occurred even when all signal pins were disconnected
- Power bus decoupling had no effect on noise
- Power bus isolation was effective, but not an option

# Case Histories

## Differential Clock Drivers

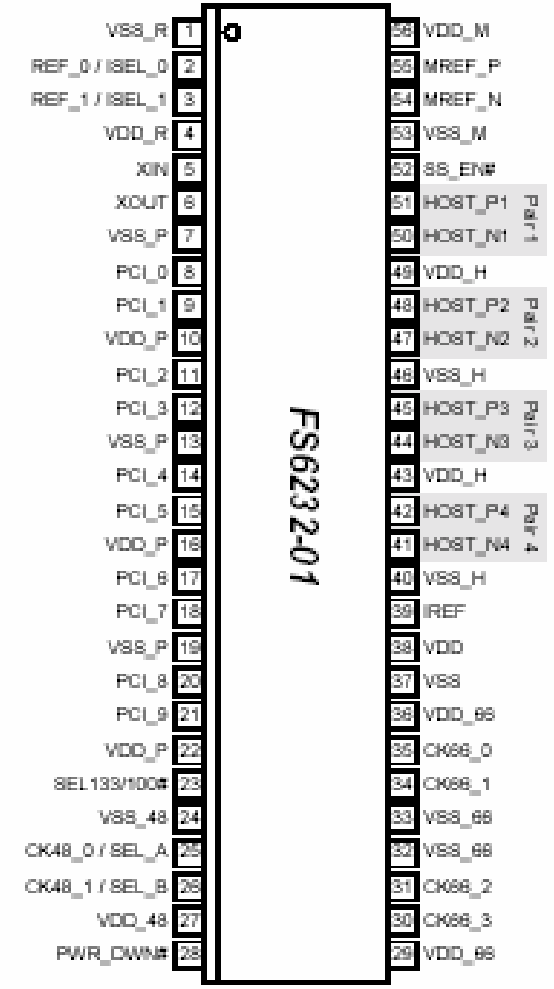
- Emissions at harmonics of clock frequency
- Rise and fall time differences create common-mode currents
- Imbalances in trace geometries and loads creates common-mode currents

# Differential Clock Trace Scanning Test

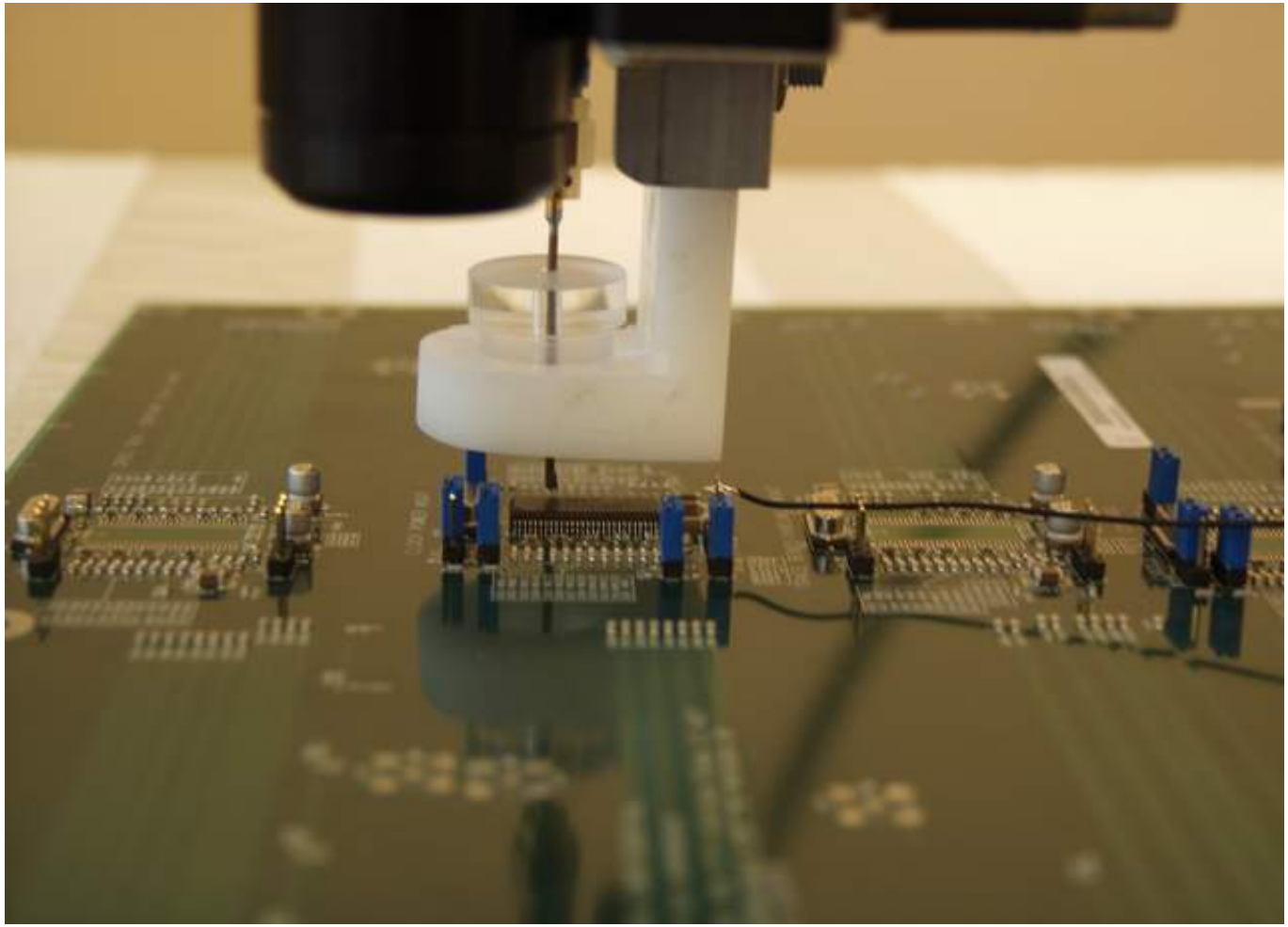


# FS6322-01 Features and Configuration

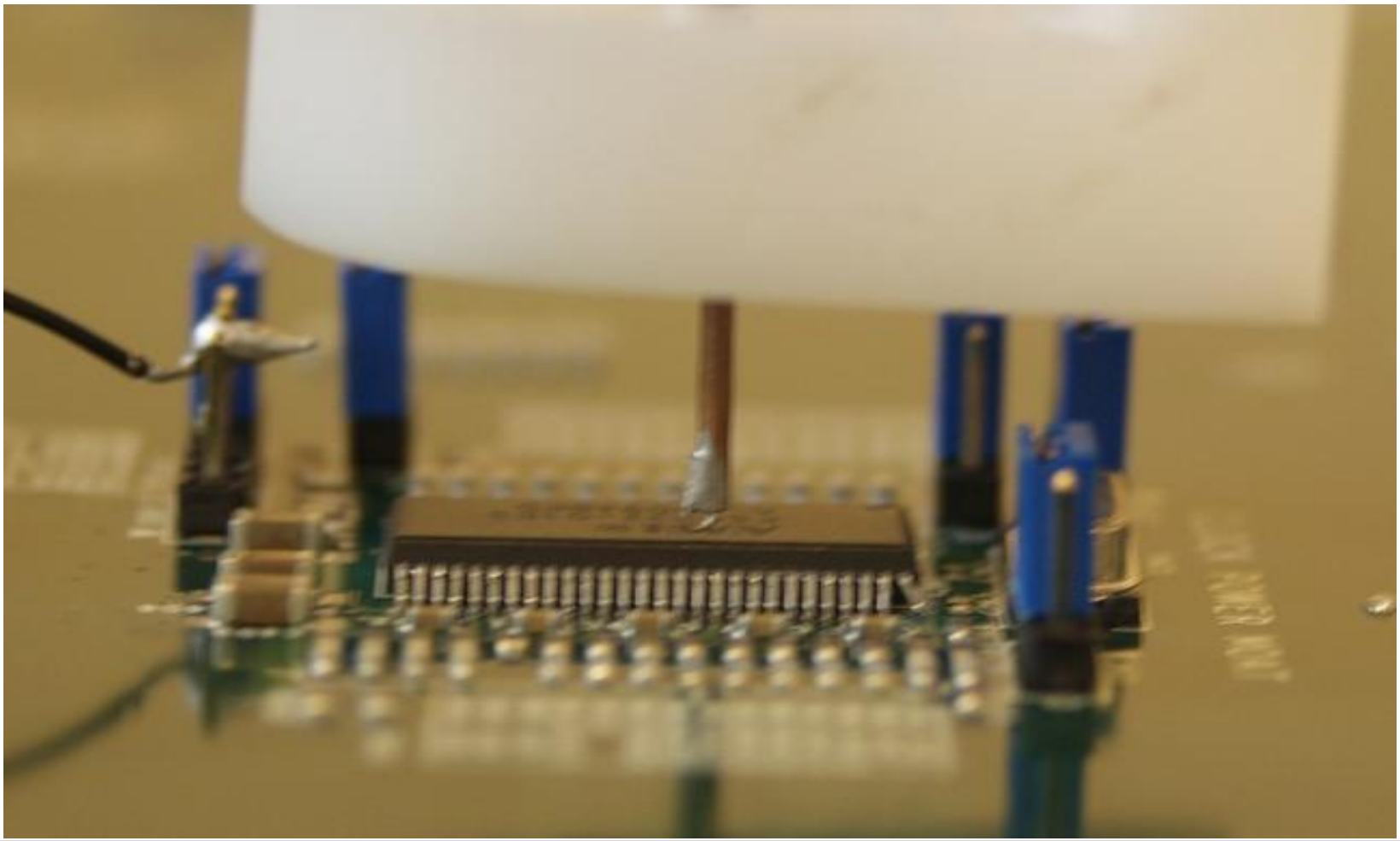
- **Four differential current-mode Host clock pairs**
- **Four 66.67 MHz 3.3 V CK66 clock outputs**
- **Ten 33.3 MHz 3.3 V PCI clock outputs**
- **Two 3.3 memory Reference Clock outputs**
- **Two 48 MHz 3.3 CK48 clock outputs**
- **Two buffered copies of the crystal reference**



# Measurement Equipment and Probe



# Differential Clock Trace Scanning Test



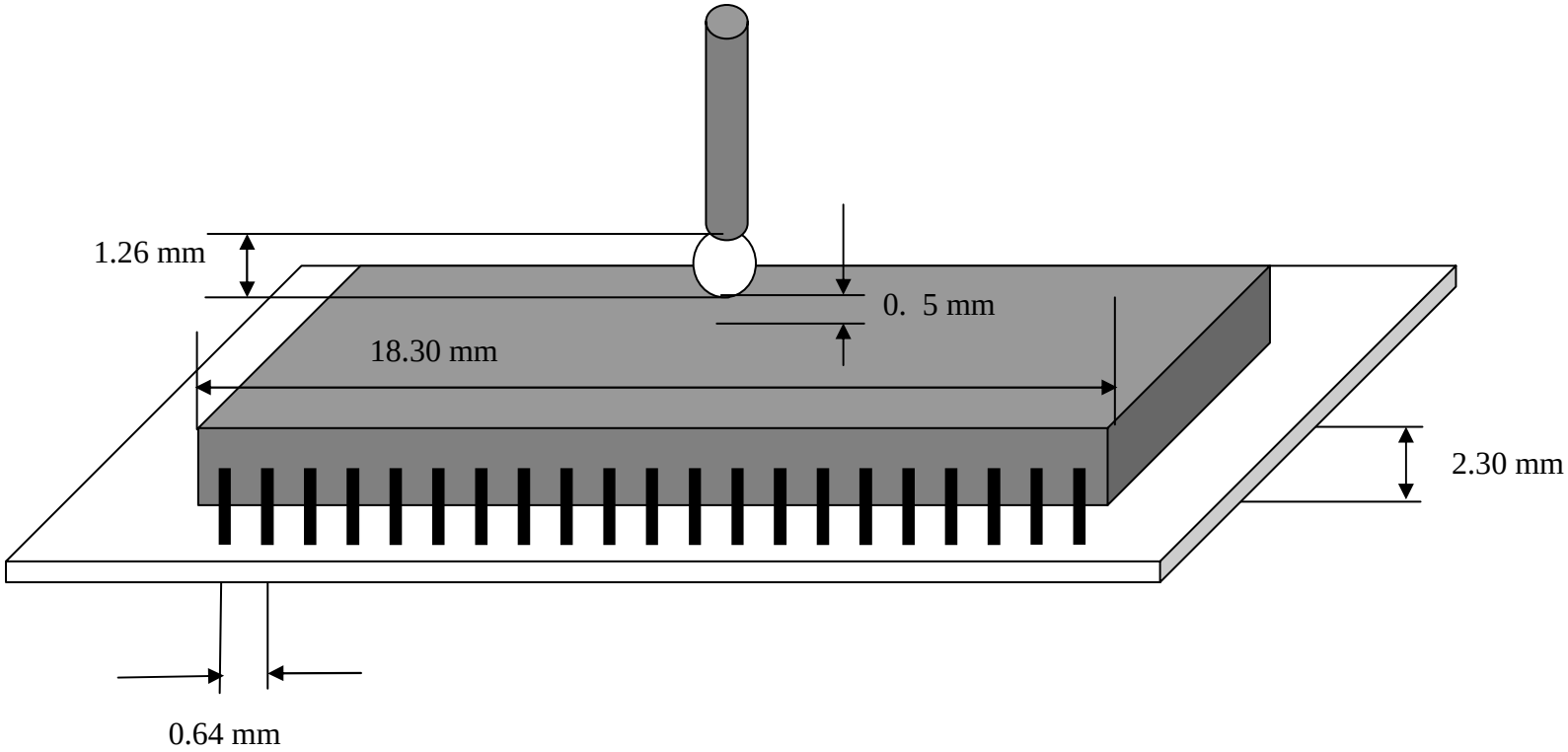
# Measurement Equipment and Probe

- **An automated X-Y scanning system was used with an HP8563E spectrum analyzer to measure the H-field.**
- **This is the loop probe.**

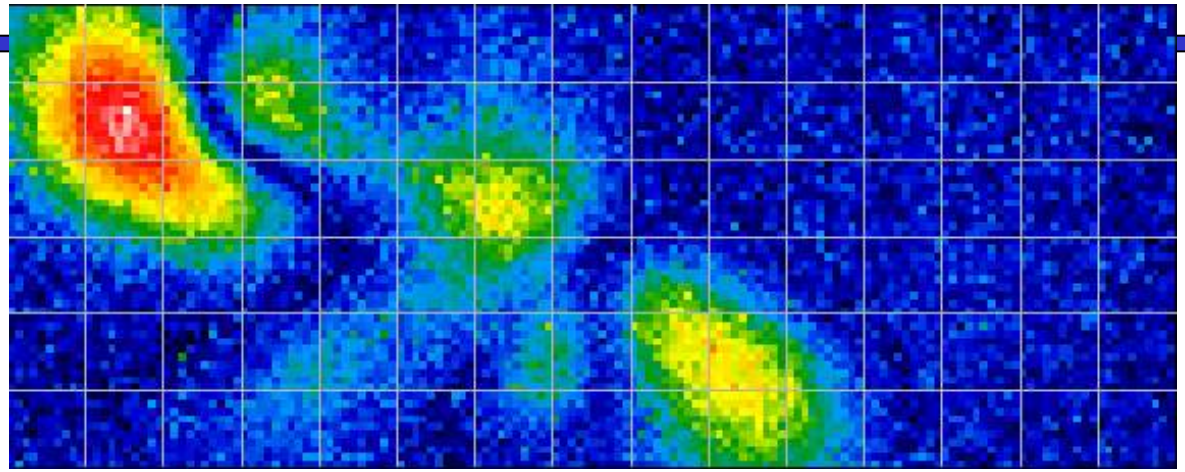
# Measurement Setup

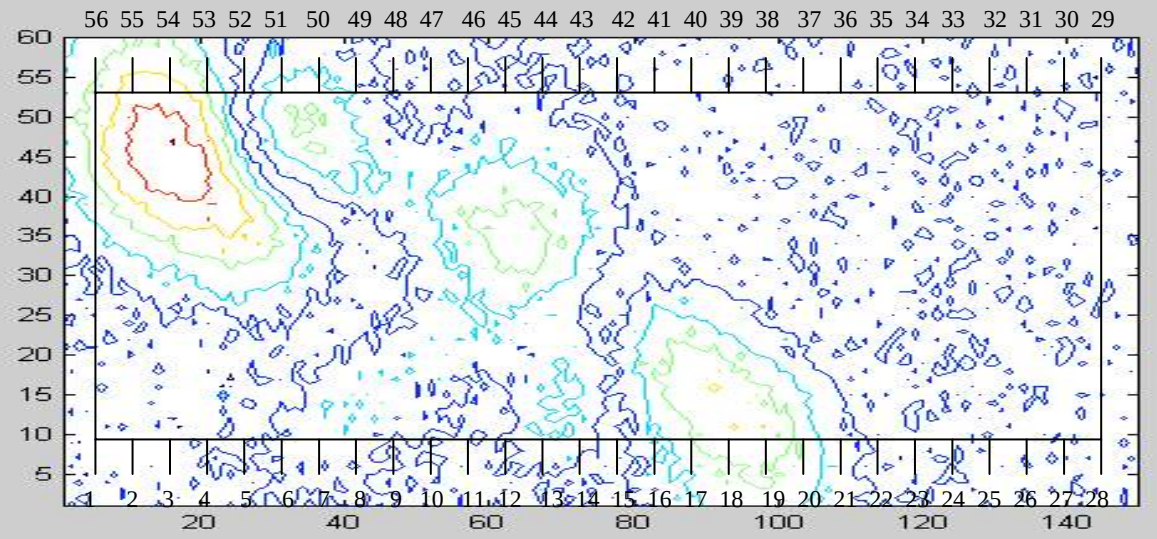
- Mounted on an Intel test board for measuring.
- The board is working normally (3.3 volts Vcc).
- The probe is placed about 1 mm above the device top surface.
- The chip is set to generate a 100-MHz differential clock output.
- Measurement frequency is 100 MHz and span frequency is 10 kHz.
- 9000 points (150 columns and 60 rows) are measured.
- The scanning area is slightly larger than the chip area.

# Probe and Device Dimensions

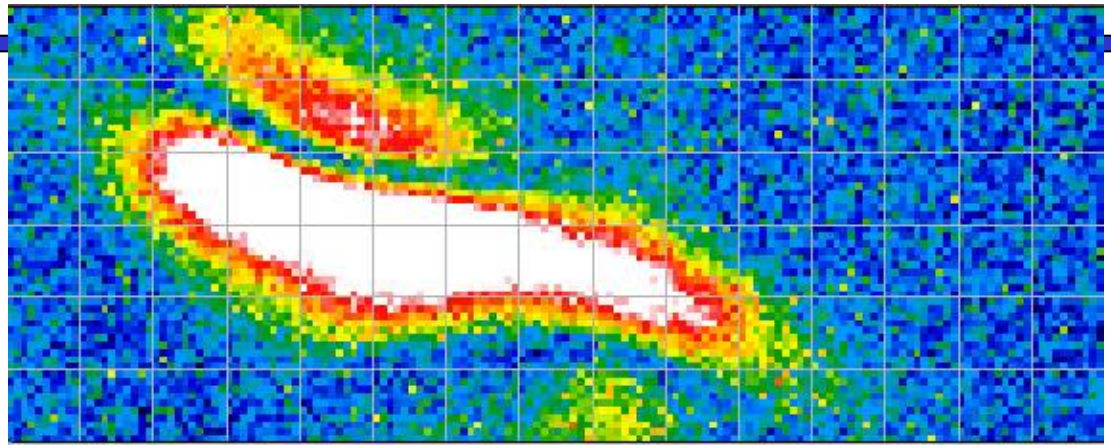


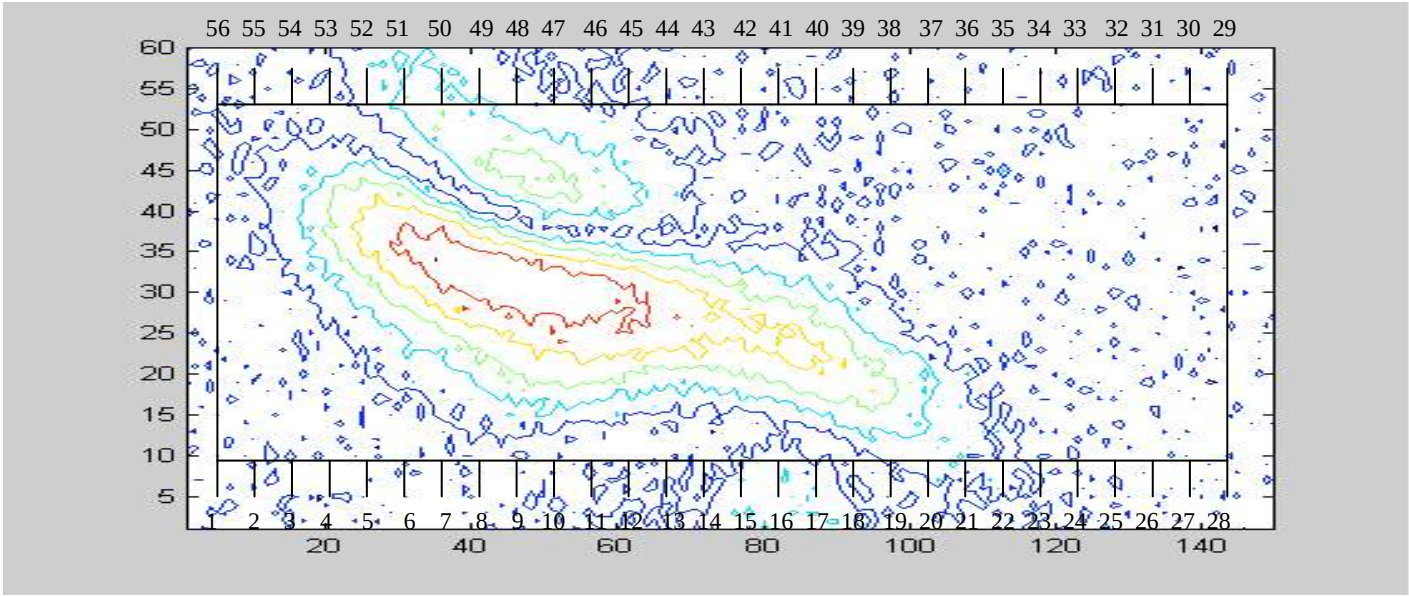
# Scan Result for Horizontal Loop





# Scan Result for vertical loop

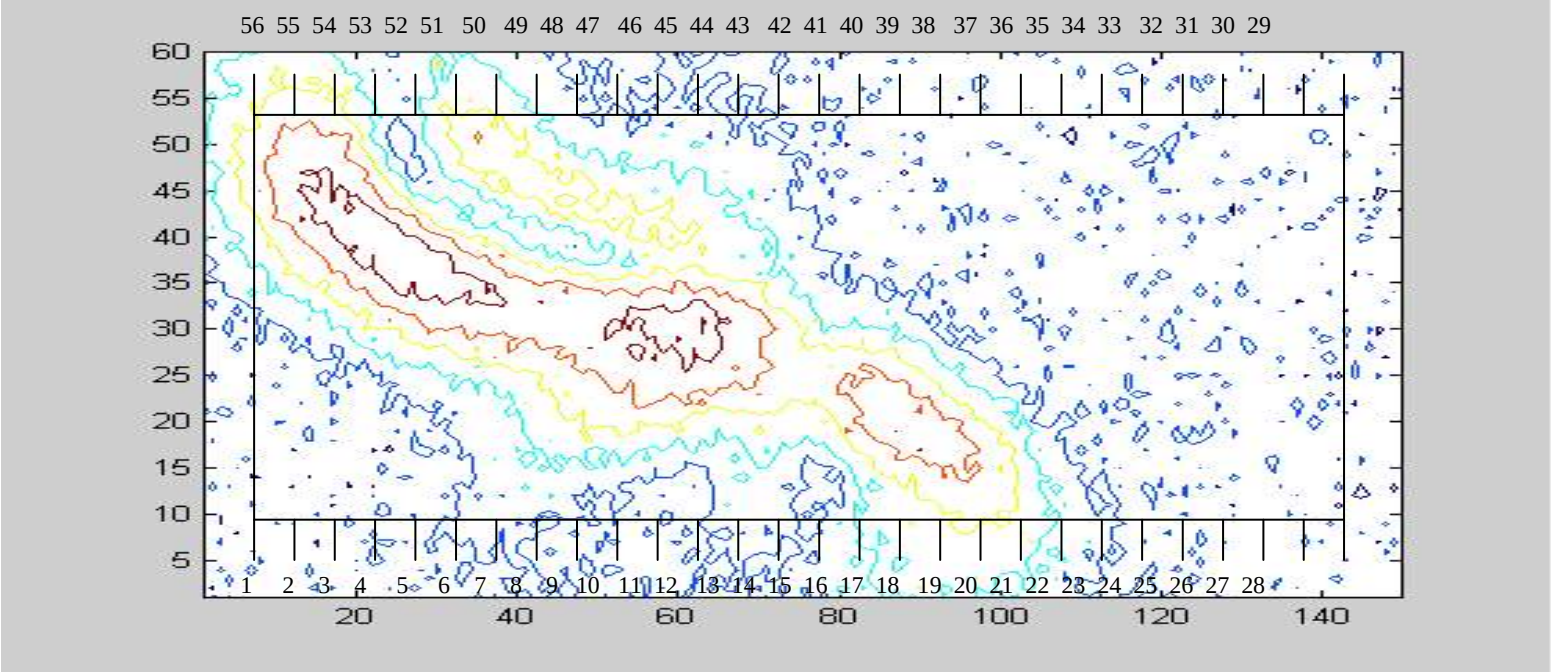




# Magnitude of the Magnetic Field

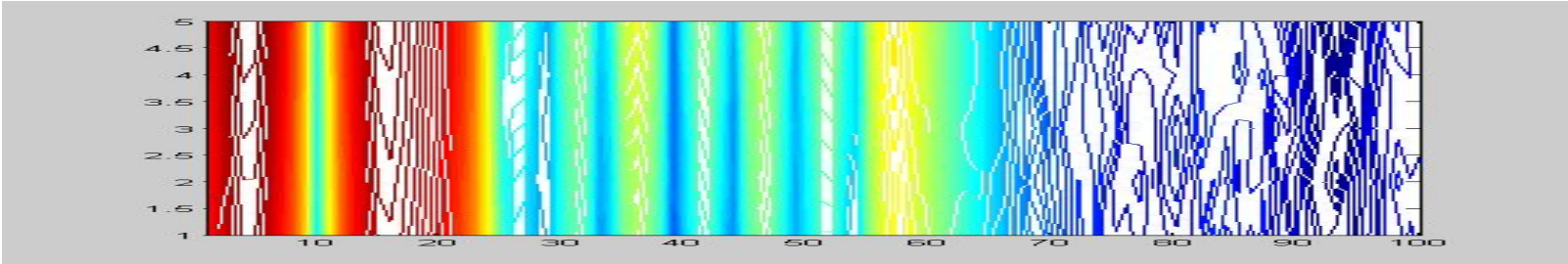
Calculate the magnitude of the H-field over the chip by applying

$$H = \sqrt{H_x^{\,2} + H_y^{\,2}}$$

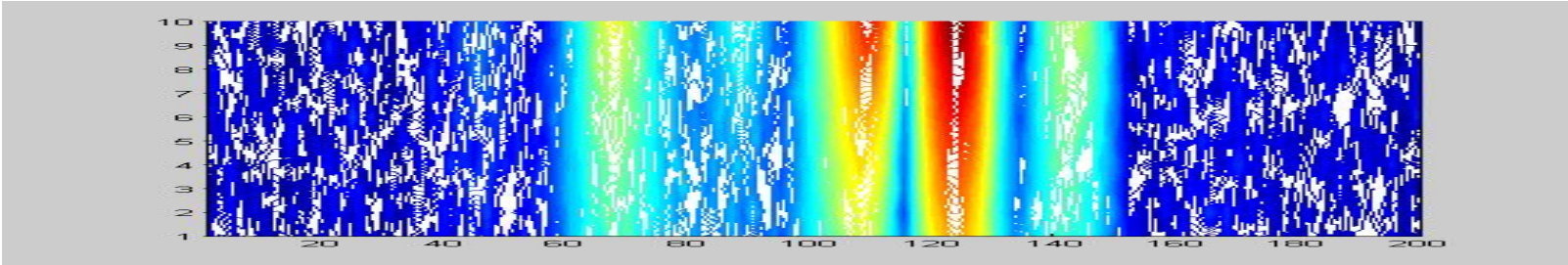



The measuring frequency is 100 MHz.

# The H-field Near the Pins

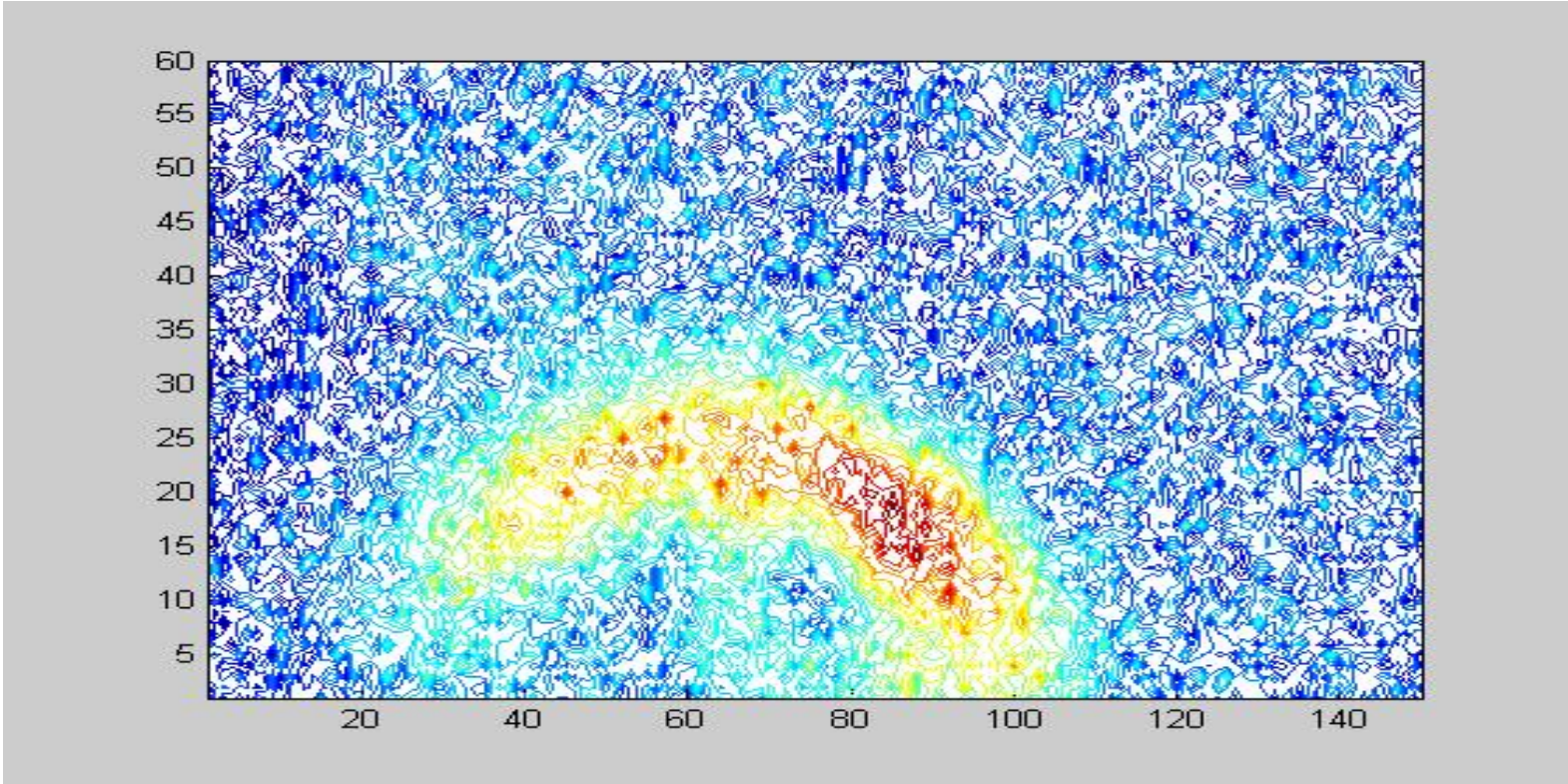



Pin 56 to Pin 29 (left to right)



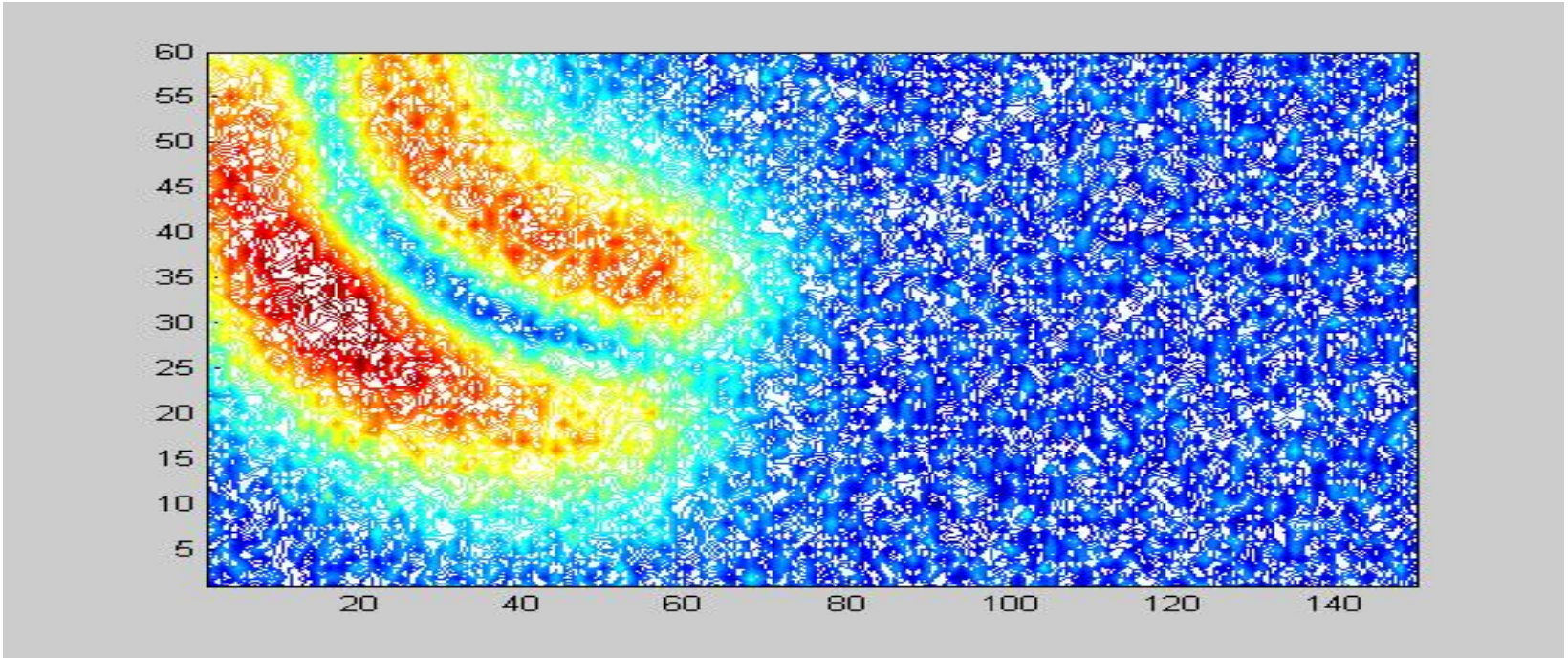

Pin 1 to Pin 28 (left to right)

# Magnitude of the Magnetic Field



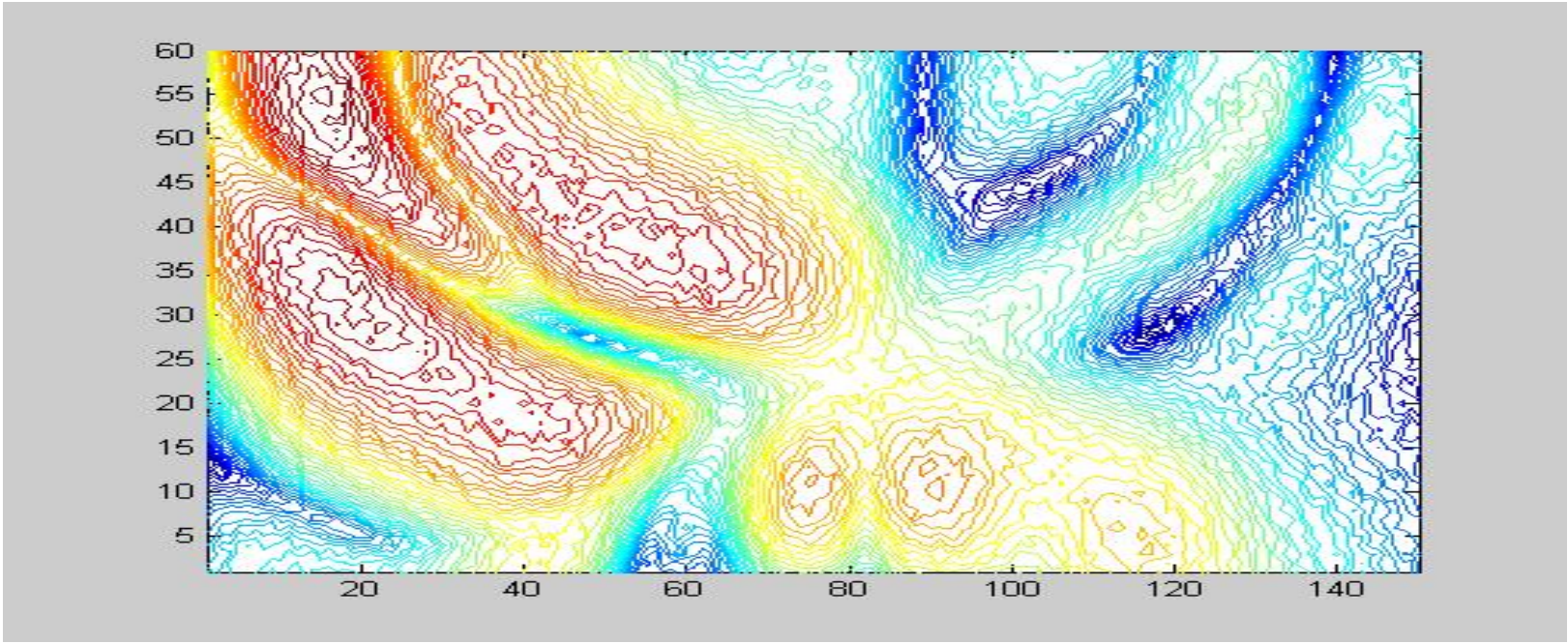

The scanned H-field when Memory Reference clock outputs effect is eliminated (Pin 56 MREF $V_{DD}$ is disconnected from the board).

# Scan with Different Measurement Frequency



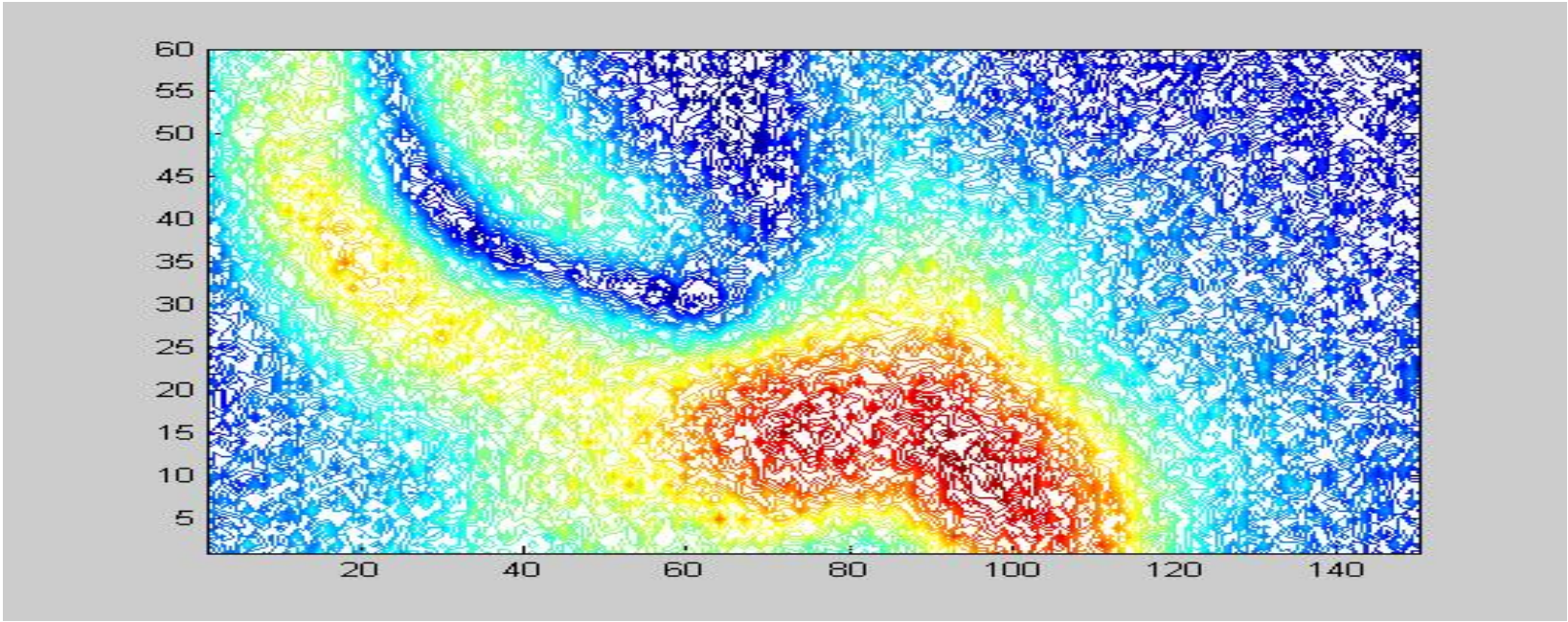

Scanned H-field at 50 MHz measurement frequency

# Scan with Different Measurement Frequency




Scanned H-field at 200 MHz measurement frequency

# Scan with Different Measurement Frequency



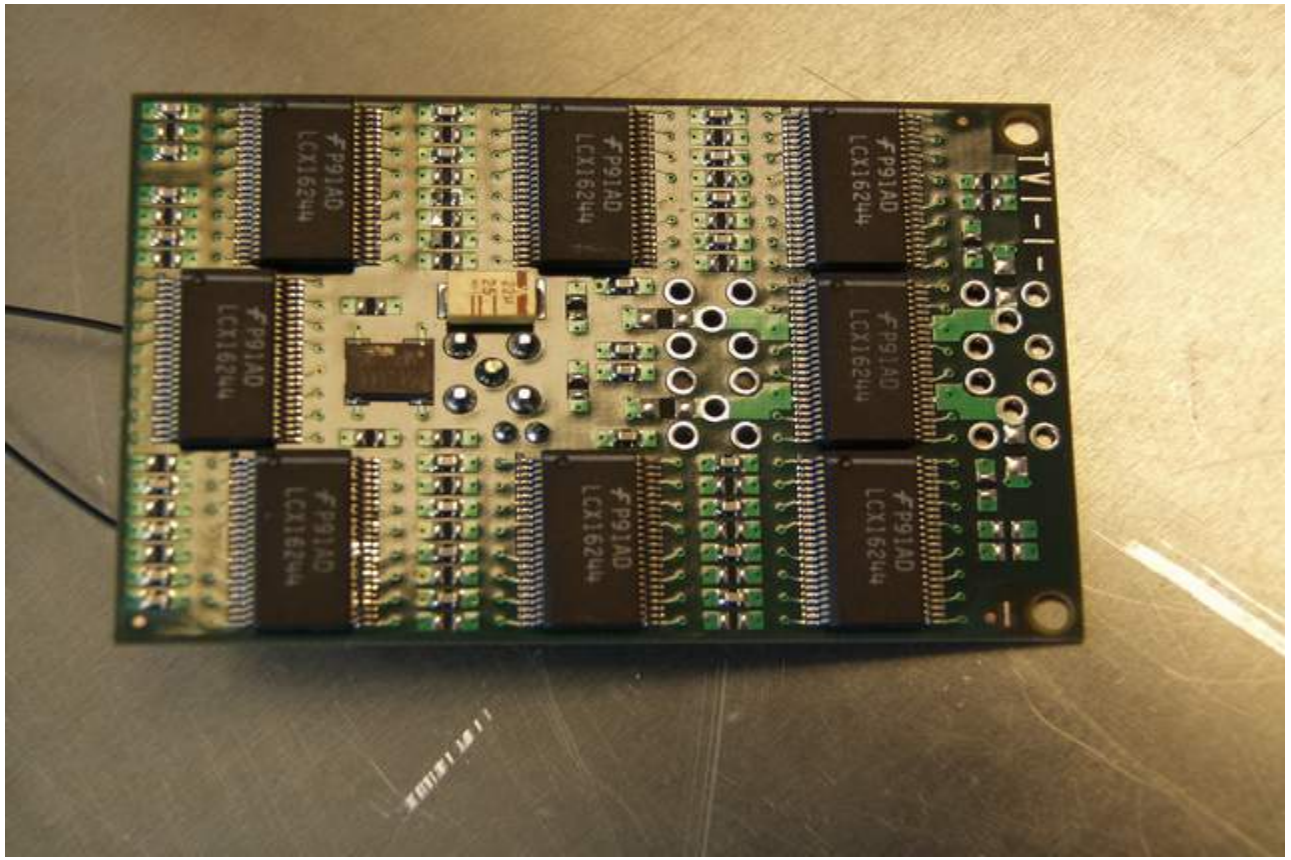

Scanned H-field at 500 MHz measuring frequency

# Observations about this particular device

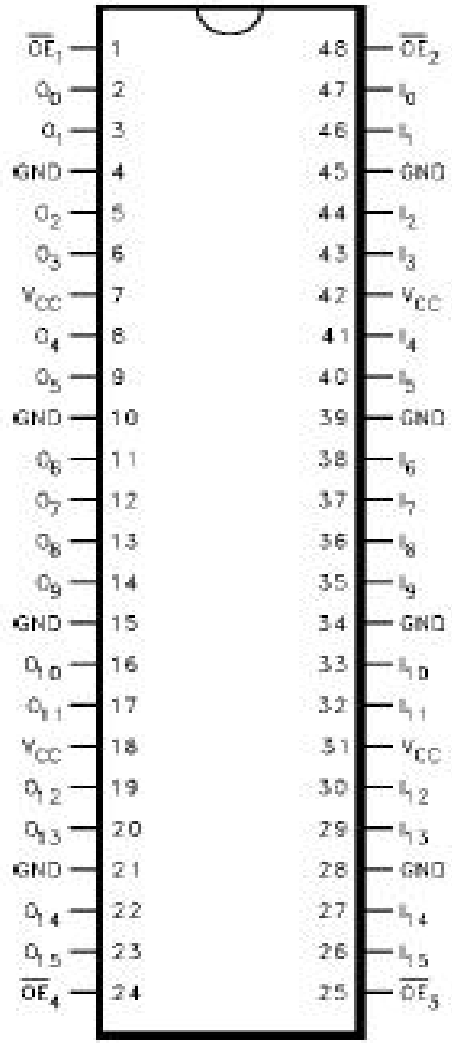
- Similar current patterns were observed on this clock driver when mounted to another board.
- Loading the differential or single-ended clock drivers does not appear to influence the predominant common-mode current.

# Measurements of Another Clock Driver

**A TV1-1-1 board with eight 74LCCX16244 (16-Bit buffer Driver).**

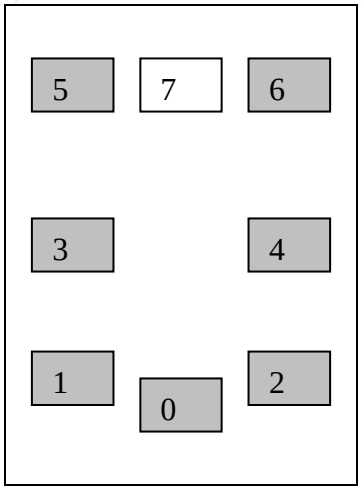


# 74LCCX16244 Pin Description



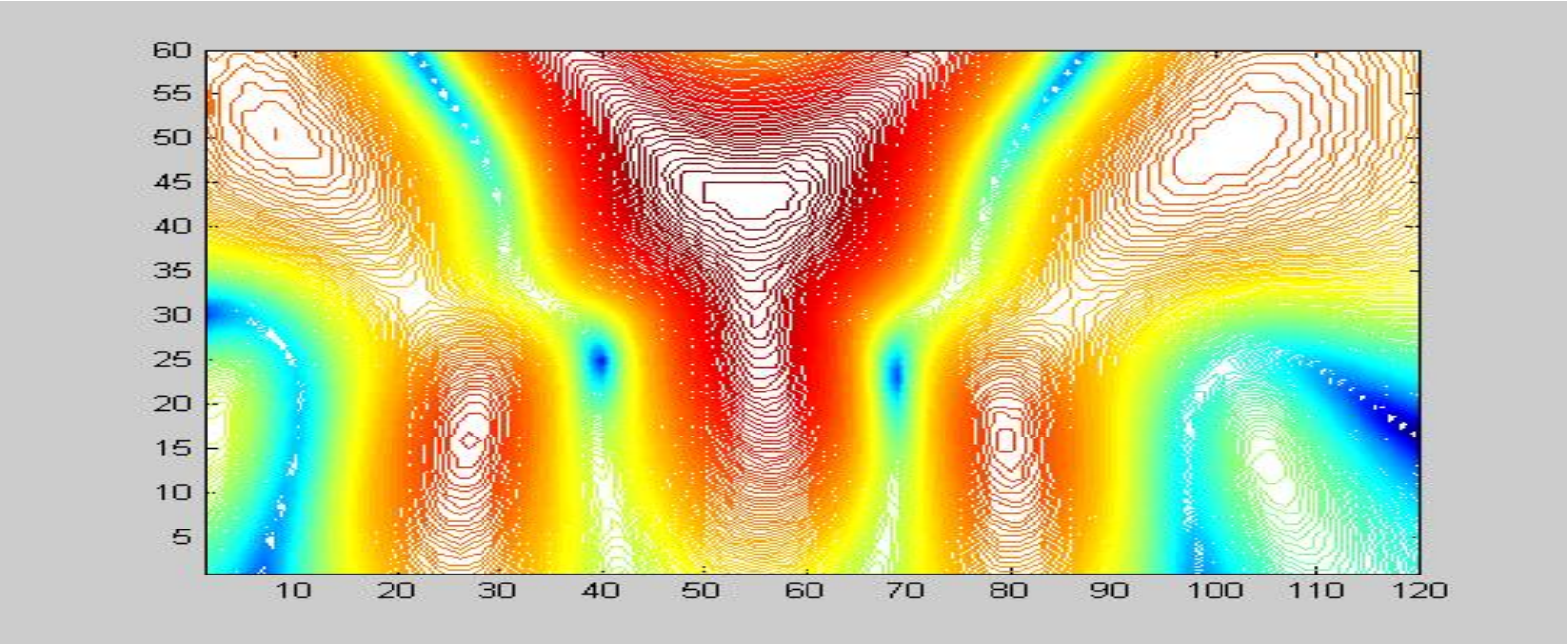

## Pin Descriptions

| Pin Names | Description |
|---|---|
| $\overline{OE}_n$ | Output Enable Input (Active LOW) |
| $I_0$–$I_{15}$ | Inputs |
| $O_0$–$O_{15}$ | Outputs |
| NC | No Connect |

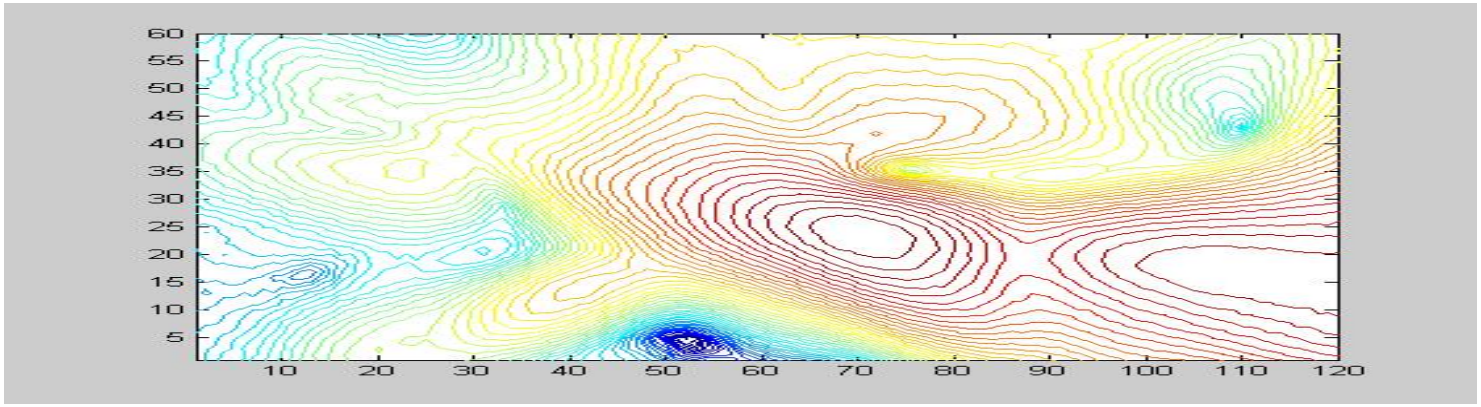



Measured 7 devices on the board

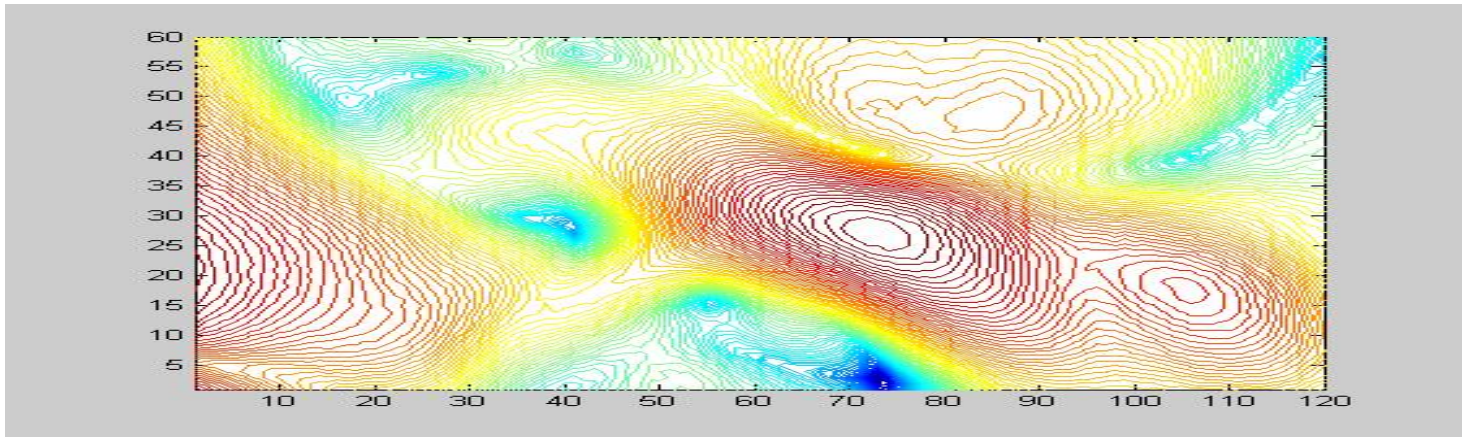
# Measurement Result for 74LCCX16244



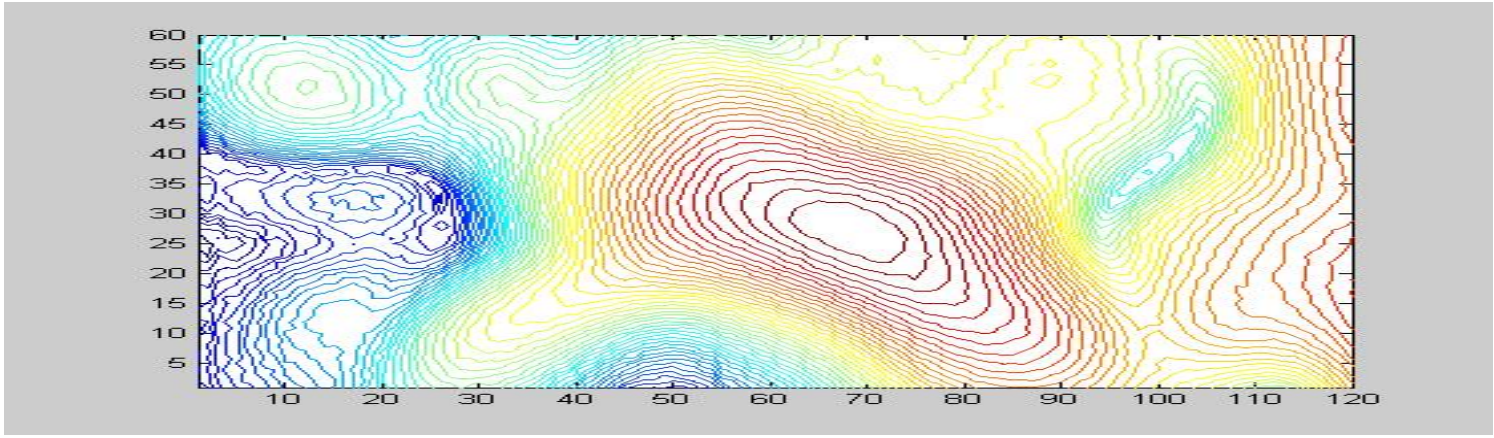

Scanned H-field over Device 0



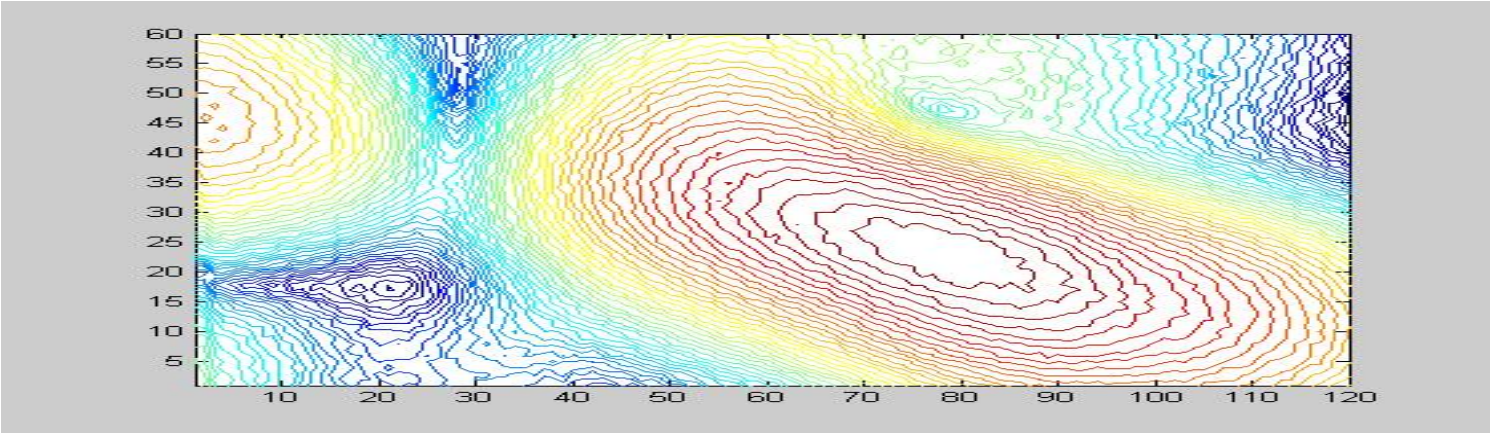

**Scanned H-field over Device 1 surface**



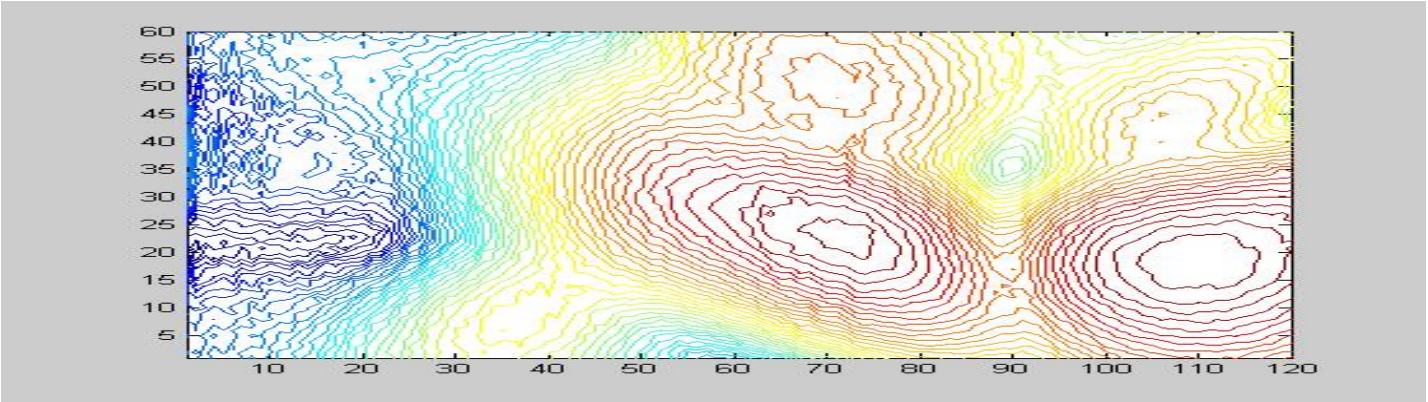

**Scanned H-field over Device 2 surface**



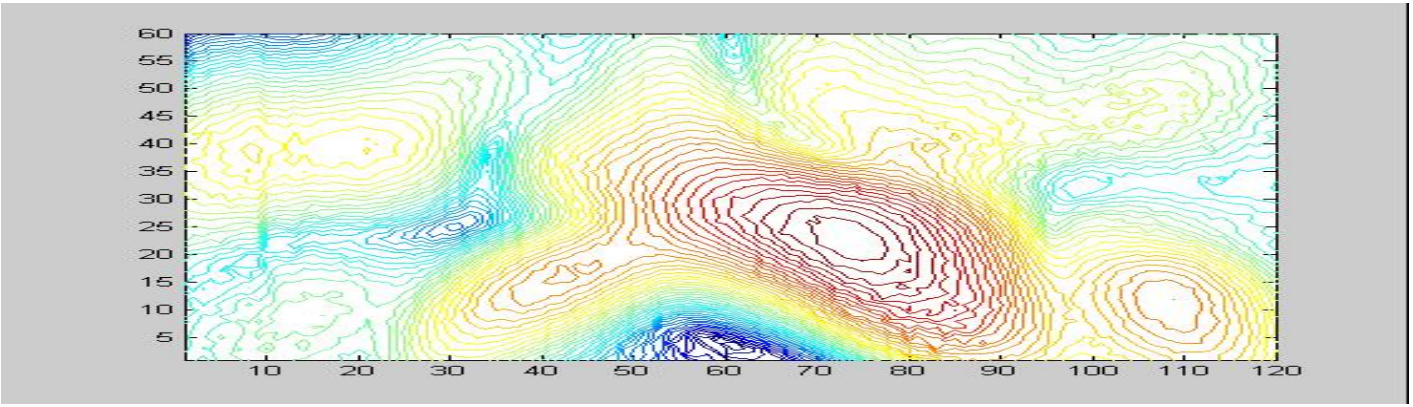

**Scanned H-field over Device 3 surface**




**Scanned H-field over Device 4 surface**




**Scanned H-field over Device 5 surface**




**Scanned H-field over Device 6 surface**

# Summary

There are three ways that chips and packages tend to contribute to radiated EMI.

- Noise (or the wrong signal) coming from signal pins
- Field coupling to heatsinks or nearby components
- Power bus noise

# Summary

Features that distinguish “good” devices from “bad” devices:

- On-chip or on-package decoupling!
- Adequate number of gnd pins
- Package layout
- Chip design and layout

More work needed here!