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Abstract

This thesis deals with test signal probing and fixturing techniques for wideband multiport measurements in digital packaging in the frequency range from a few MHz to 50 GHz. Three different signal launch techniques are investigated in time and frequency domains. At first, the performance of the coaxial surface mounted connector launch is explored in case of crosstalk measurements in a backplane connector via pin field. In the next step the recessed probe launch technique is briefly presented. After that the main focus is on the results obtained in recent investigations with respect to the launch calibration, application to measurements of embedded multilayer structures and modifications to improve the launch bandwidth. Finally, the concept of a novel multiport probing fixture is presented and its electrical performance explored. Using a simple two-tier calibration procedure, the effect of the probing fixture on measurements of dense via array structures is reduced and the results obtained are validated with microprobe based measurements. Based on 3D full-wave electromagnetic modeling, suggestions for layout optimization are made which will be needed to extend the applicability of these techniques to data rates of 20 Gbit/s and beyond.

Kurzfassung

Diese Arbeit befasst sich mit der Testsignalkontaktierung und Signaleinführungstechniken für breitbandige Multitor-Messungen im Bereich der Aufbau- und Verbindungstechnik für digitale Systeme im Frequenzbereich von wenigen MHz bis 50 GHz. Drei verschiedene Signaleinführungstechniken werden im Zeit- und Frequenzbereich untersucht. Zuerst wird die Leistungsfähigkeit der Kontaktierung mit koaxialen Steckern in Messungen des Übersprechens von Backplane-Stecker analysiert. Im nächsten Schritt wird die “Recessed Probe Launch“-Technik präsentiert, wobei die Ergebnisse aus aktuellen Untersuchungen in Bezug auf ihre Kalibration, ihre Anwendungen für Messungen von eingebetteten Multilagen-Strukturen und mögliche Modifizierungen für die Verbesserung der Messbandbreite im Mittelpunkt stehen. Schließlich wird das Konzept eines neuartigen Multitor-Adapters präsentiert und seine Hochfrequenz-Eigenschaften untersucht. Mittels eines zweistufigen Kalibrationsverfahrens wird der Einfluss des Multitor-Adapters in den Messungen von dichten Via Array Strukturen reduziert und die Ergebnisse mit Microprobe-Messspitzen basierten Messungen validiert. Basierend auf 3D Vollwellen-Simulationen werden Vorschläge für die Optimierung des Layouts gemacht, die für die Anwendbarkeit dieser Technik für Datenraten bis 20 Gbit/s und darüber hinaus notwendig sind.

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Contents

List of Symbols and Acronyms

Notation

x, y, z	Cartesian coordinates

Symbols

V_0	Amplitude of the inserted step voltage
V_r	Amplitude of the obtained reflected voltage
ω	Angular frequency
α	Attenuation constant
T_b	Bit time
F_{-3dB}	Bandwidth of the low-pass filter of a time domain oscilloscope
C	Capacitance
Z_0	Characteristic impedance
σ	Conductivity
I	Current
$tan\delta$	Dielectric loss tangent
$\Delta\varphi_{eff}$	Effective phase difference
f	Frequency
$f_{\lambda/4}$	Frequency at a quarter-wavelength
F_{notch}	Frequency where a deep notch appears in the transmission parameters
$\boldsymbol{I}$	Identity matrix
j	Imaginary unit
L	Inductance

f_{max}	Maximum frequency of interest
T_{signal}	Period
μ_0	Permeability of free space ($\sim 4\pi \cdot 10^{-7}$ H/m)
ε_0	Permittivity of free space ($\sim 8.854 \cdot 10^{-12}$ F/m)
β	Phase constant
γ	Propagation constant
T_{single}	Propagation time of a single discontinuity
μ_r	Relative permeability
ε_r	Relative permittivity
R	Resistance
t_r	Rise time
T_{meas}	Rise time delivered at the end of a probe or a fixture
T_{TDR}	Rise time in accordance with the TDR module data sheet
S	S-parameter
t	Time
Δl	Trace length mismatch
T	Transformation matrix for currents (modal decomposition)
l	Transmission line/ trace length
λ	Wavelength
Y	Y-parameter
Z	Z-parameter

Acronyms

2D	Two Dimensional
3D	Three Dimensional
ABCD	Microwave Network Chain Parameters
AC	Alternating Current
ATE	Automatic Test Equipment
BGA	Ball Grid Array

CM	Common-Mode
CPW	Coplanar Waveguide
CS	Calibration Substrate
DC	Direct Current
DDR	Dual Data Rate (for random access memories)
DR	Data Rate
DUT	Device Under Test
ECAL	Electronic Calibration Module
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FEM	Finite Element Method
FEXT	Far-end Crosstalk
FFT	Fast Fourier Transform
FIT	Finite Integration Method
GND	Ground
GS	Ground Signal
GSG	Ground Signal Ground
HDMI	High Definition Multimedia Interface
HFSS	High Frequency Structure Simulator (FEM Solver)
IBM	International Business Corporation
IC	Integrated Circuit (or chip)
IEEE	Institute of Electrical and Electronics Engineers
LGA	Land Grid Array
LRM	Line-Reflect-Match (Calibration Procedure)
LRRM	Line-Reflect-Reflect-Match (Calibration Procedure)
MMSNT	Microwave Measurement Software
NEXT	Near-end Crosstalk
PCB	Printed Circuit Board
PI	Power Integrity
PLTS	Physical Layer Test System
PTFE	Polytetrafluorethylen

QSOLT	Quick-Short-Open-Load-Thru (Calibration Procedure)
RF	Radio Frequency
RPL	Recessed Probe Launch
RPM	Revolutions Per Minute
S-	Microwave Network Scattering Parameters
SATA	Serial Advanced Technology Attachment
SG	Signal Ground
SI	Signal Integrity
SMA	SubMiniature version A
SMP	SubMiniature Push-On
SMT	Surface Mount Technology
SOL	Short-Open-Load (Calibration Procedure)
SOLR	Short-Open-Load-Reciprocal (Calibration Procedure)
SOLT	Short-Open-Load-Thru (Calibration Procedure)
SWR	Standing Wave Ratio
TDR	Time Domain Reflection
TDT	Time Domain Transmission
TEM	Transverse ElectroMagnetic
TET	Institut für Theoretische Elektrotechnik, TUHH
TL	Transmission Line
TRL	Thru-Reflect-Line
TUHH	Technische Universität Hamburg-Harburg
TV	Test Vehicle
VNA	Vector Network Analyzer

In this work board and structure dimensions are often given in mils, which are the typical units used in the electronic industry. The conversions to SI units are as follows:

$$1\,\text{inch} \approx 2.54 \cdot 10^{-2}\,\text{m}$$

$$1\,\text{mil} = 0.001\,\text{inch} \approx 25.4 \cdot 10^{-6}\,\text{m}$$