Designing EMC Compliant Industrial Ethernet Systems Using TI PHYs

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Agenda

• Ethernet application overview
• Roadmap update
• EMC standards overview
• Key products and reference designs
• Schematic and layout techniques
Ethernet Applications
Applications | Where are we?

- Motor Drivers
- E-meter Concentrators
- IP Network Cameras
- Power Relays

- Factory Robots
- Network Printers
- Inspection Equipment
- Medical Equipment

- Solar Panels
- Communication Repeaters
- Human Sensing Equipment
- Cash Machines

Factories and Manufacturing Industries
- Motor Drivers
- E-meter Concentrators
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Industrial Automation
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Smart Grid
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Test and Measurement
- Motor Drivers
- E-meter Concentrators
- IP Network Cameras
- Power Relays

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Ethernet PHY Applications in Industrial

Factory Automation
PLCs, Motor Drives

• Rugged and reliable
• Meet stringent regulatory requirements for ESD & EMC w/o expensive external components
• Improved accuracy down to <10ns

Smart Grid
E-meter Concentrators

• Integrated ESD protection >4kV
• Industrial temperature grade offering as well as p2p temp upgradable options allowing for -40°C to 105°C and even 125°C

Other Industrial
IPNC, Power Relays

• Low output power including magnetics, 16% lower than KZ8051
• Integrated ESD protection >4kV
• Offered in p2p temperature options allowing -40°C to 105°C and even 125°C

Why this is significant:
• Brand name providing tailored Ethernet PHYs for factory automation, motor drives, & power automation
• Easier to design-in and less external components
• Partnered with industry leaders to develop industry’s first industrial grade gigabit ENET
New Product Update
New Industrial Ethernet Product Portfolio

DP83822
- Lowest Power PHY
- 125C & Fiber

DP83867
- Industrial GbE

DP83869
- Fiber + Copper Support
- Media Convertor, Bridge Mode
- 125C

100BASE-T1 (DP83TC811)
- SGMII / RGMII / RMII / MII
- Low Latency

100BASE-TX (DP83825)
- Single Supply, EEE, small FF
- Low Power

Sampling
Production

2018
2019
What kind of wired communication is used in your application?

- CAN, RS232, RS234, etc.

Does customer want to upgrade to Ethernet?
Do they need higher bandwidth?

- CAN, RS232, RS234, etc.

Is the Ethernet port discrete?

- Yes

What are the required operating speeds?

1000 Mbps
10/100 Mbps

Automotive?

- No

Precision Timing?

- Yes

- No

- Automotive?

Precision Timing?

- Yes

- No

Automotive?

- No

- Yes

- No

- Precision Timing?

Ethernet PHY Selection Tree

DP83867 – Copper
DP83869 – Copper + Fiber

DP83848/49 – Basic functionality
DP83822 – Advanced functions (CU + FX)
DP83825 – RMII, Small FF

DP83848Q – OBD Applications
DP83TC811 – 100 BASE-T1

DP83630 – 1588 Hardware Time Stamping (Copper + Fiber)
DP83640 – 1588 Hardware Time Stamping (Copper + Fiber)
Common EMC Standards for Industrial Ethernet
Test for electrostatic discharge (ESD)

- ESD event causes large amount of charge to be dissipated in a electrical component in a short period of time.
- ESD tests consists of different standards to simulate different environments.
- Device Level Testing
  - Human Body Model (HBM)
  - Charge Device Model (CDM)
- System Level Testing
  - IEC61000-4-2

![IEC61000-4-2 test bench]
Radiated & conducted emissions

• Unintentional radiation generated by the system can cause disturbance in nearby systems by electromagnetic induction or coupling.

• These radiations are measured during Emissions testing.

• Emissions testing of a system is done by two methods;  
  – Radiated Emissions  
  – Conducted Emissions

• Examples of Emissions Standards  
  – EN55011 and CISPR11
Radiated & conducted immunity tests

• Ethernet systems need to operate in environments with electromagnetic noise.

• Sensitive applications need unbroken communication link.

• Two main immunity tests;
  – Radiated Immunity (IEC 61000-4-3)
  – Conducted Immunity (IEC 61000-4-6)

• Test Levels and Performance Class depend on end equipment.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No effect on EUT performance</td>
</tr>
<tr>
<td>B</td>
<td>Some effect during test. EUT self-recovers after interference is stopped.</td>
</tr>
<tr>
<td>C</td>
<td>Some effect during test. EUT needs user intervention for proper operation.</td>
</tr>
<tr>
<td>D</td>
<td>Device Damaged</td>
</tr>
</tbody>
</table>
Tests for electrical fast transients

- Electrical Fast Transient (EFT) are produced when inductive loads such as relays or heavy duty motors are switched off.
- Industrial environment can have potential EFT sources close to Ethernet PHYs.
- IEC61000-4-4 is the most common EFT Test Standard.

IEC61000-4 Test Bench
Test for surge

• Surge testing simulates extreme switching noise due to direct lightning strikes.
• Such high energy can affect system performance or damage critical components.
• Resilience of Ethernet system to surge can be measured by Surge testing.
• IEC61000-4-5 standard defines test bench and requirements for Surge testing.
Key products and reference designs
**Features**

- **Low power 10/100 Mbps PHY**
  - 1.8V single supply operation < 120mW
  - 3.3V single supply operation < 220mW
- Industry’s lowest latency < 280ns
- Power saving features: WoL, EEE (IEEE 802.3az)
- Exceeds IEC ±8kV ESD specifications
- Start of Frame Detect for IEEE 1588 time stamp
- Multiple MAC Interfaces: MII/RMII/RGMII
- Copper and Fiber support
- Wide Temperature Range (-40°C to 125°C)
- Small Package Size: QFN-32 (5x5mm)

**Benefits**

- Good for battery/low powered applications. Less heat dissipation.
- Low latency allows for faster response in time sensitive applications
- Can withstand harsh industrial environments
- Provides design flexibility via
  - Compatibility with RGMII Gigabit MAC interface
  - Compatible with copper and fiber optic cabling
- DP83822 is a replacement to the TLK105L (pin for pin compatible)

**Applications**

- Factory Automation & Control
- Motor Drive & Control
- Power Automation
- Automotive

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**Simplified Schematic**

- DP83822 10/100 Mbps Ethernet PHY
- MII RMII RGMII
- 10BASE-FX
- 10BASE-T
- RJ-45
- 25-MHz / 50-MHz Clock Source
- Status LEDs
- Magnetics
- Fiber Optic Transmitter
- MAC
DP83869 | Copper + fiber Ethernet PHY 10/100/1000
Industrial 100Base-FX/1000Base-X/100Base-TX/1000Base-T fiber Ethernet PHY

Features
- Dual Media Support: Fiber, Copper
  - Media Converter mode
- Meets EN55011 Class B Emission Standards
- Low power <500mW (Fiber Only Mode: <100mW)
- Integrated terminations & impedance matching on MAC IF
- ESD MDI: +/- 6KV
- Extremely low jitter & lowest latency <400ns
- FF and SW compatible with DP83867
- Multiple MAC Interfaces: MII, RGMII, SGMII
- Fast Link up / Link Drop Modes
- Multiple output clock options: 25MHz or 125MHz
- Industrial Temperature Range: -40°C to 125°C
- QFN48 (7x7mm)

Benefits
- Flexibility to use Cu or Fx to enhance noise immunity or electrical safety isolation
- Lower external BOM count & minimizes system ESD damage
- Low latency allows for faster bus cycles, enabling real-time field buses and enabling accurate TSN
- Faster link-up reduces system boot-up time.
- Reduced design time for designers already using DP83867
- Flexibility to use multiple MAC devices
- Support Field Buses with fast Link Up/Down requirements

Applications
- I/O Modules
- Field Buses
- Protection Relays
- Industrial Ethernet Switch
- Media Convertors
**TIDA-00928**

**DP83822 PHY based industrial Ethernet brick with copper or fiber interface**

### Solution Features

- Design tested with boards having the following interface
  - 10/100 Mb/s copper interface and 100Base-FX fiber interface
  - AFBR-5803TZ Transceivers for Fast Ethernet with SC connector and AFBR-5803Z Transceivers for Fast Ethernet with SC connector
- Host Tiva™ MCU Interface: TM4C129XNCZAD 32-Bit Arm® Cortex®-M4F MCU with an integrated MAC for Performance Evaluation & System Implementation
- Integrated cable diagnostic tools: BIST, TDR & loopback
- DP83822H Temperature Range: −40°C to +125°C
- QFN 32-pin 5.00-mm × 5.00-mm package

### Solution Benefits

- DP83822 provides all physical layer functions needed to transmit and receive data over both standard twisted pair cables or connect to an external fiber optic transceiver
- Pre-Compliance Testing Done and Meets:
  - EN55011 Class-B Radiated Emission Requirements
  - IEC 61000-4-2 Level 4, Criterion B
  - IEC 61000-4-4 Level 4, Criterion B
  - IEC 61000-4-4, Level 3, Criterion A
  - IEC 61000-4-3, IEC 61000-4-6 with Acceptance Criterion A

### Applications

- Protection Relay
- Serial-to-Ethernet Converters
- Merging unit
- Power Quality
- Feeder terminal Unit / Remote Terminal Unit
Schematic check
TIDA-00928 schematic

- Decoupling Cap
- MDIO Pull Up
- MAC I/F
- RBIAS
TIDA-00928 schematic

- Magnetics Isolation
- Strap Resistors
- ESD
- LED
Things to look out for

• Verify voltage levels are within spec
  – Check decoupling on power rails with device datasheet recommendations
• Verify if Power sequencing is required
• Verify Termination resistors if required
• Verify that Crystal/Oscillator and Magnetics meet the requirements ([SNLA079](#))
  – Check Loading capacitor with Crystal datasheet
  – Check recommended magnetics connections
• Confirm LEDs configured as per strapping options
• Check Power Down and Reset pins
• Verify MDI traces are differentially coupled
• Check unused pins
Layout requirements for PHYs
Board zoning

• Identify key components in the design
  – Centrally locate them
• Differential signaling should be routed first
• High frequency paths close to destination and away from analog signals
• Lower frequency can be moved further away
Board zoning (2)

• De-coupling capacitors close to pins
  – VDDIO
  – AVD25
  – AVD11

• 4 layer boards vs 2 layer boards
  – Signal return
  – Small loops
  – Buried lines
  – Fewer via
Visualizing the strike

- ESD/EFT/Surge events should not be allowed to find their own path to ground
- Careful control of PCB impedances is critical for high immunity performance
  - Present low impedance path to earth ground quickly!
Directing the energy

- Parasitics of PCB traces play a large role in where the energy of the strike flows
- In the example diagram, we can intuitively see that if L1>>L4, the current of the strike will mainly flow through the TVS device
  - This can be achieved by placing the TVS closer to the ESD source than the device
- Vias can also be used to control the impedance
  - See the example below where the lowest impedance path for the ESD source is through the TVS
Layout for ESD

- TVS diode array in-line
- Low capacitance
  - Return Loss
- Differential routing
  - Min effect on impedance control
- Placement between IC and Magnetic
Layout for EMI and EMC

Termination for RGMII RX on top layer
Length matching for RGMII RX on layer 3

Length matching for RGMII TX on layer 6
GND via to ensure GND matching when changing layers on signals
Termination for RGMII TX on top layer

TI TVS diode array TPD4E05U06 with easy routing pinout
Differential length matching and routing for signals from PHY to transformer

Differential length matching and routing for signals from transformer to RJ45
Clearance between signal lines and GND and Earth/ Shield
To ensure shortest routing of the signals a layer change was done due to pinout of RJ45
Things to look out for

• Solid return path beneath critical signal traces
  – No break in return path
• Termination Resistors, if needed, should be near the PHY
• PHY power supply decoupling caps should be kept near the device
• No metal between differential pair
• No floating metal
• No stubs on high frequency critical signals
  – If stubs are unavoidable, they should be short as possible
• No metal beneath the magnetics
• All TX traces should be matched and also the RX traces.
Resources
Collateral

- Design files can be downloaded from product page on ti.com.
  - For e.g. http://www.ti.com/tool/TIDA-00928
- Click on ‘Technical Documents’ section on the device product page.
  - For e.g. http://www.ti.com/product/DP83867E/technicaldocuments
  - Top Application Notes
    - DP83867 Compliance App note (SNLA239)
    - DP83822 Compliance App note (SNLA266)
    - Standard Ethernet Design and Layout Guide (SNLA079)
    - DP83TC811 Design and Layout Guide (SNLA292)
- Models and Driver
  - Linux drivers(http://www.ti.com/tool/ethernet-sw)
  - IBIS model
  - Altium Foot print
  - BSDL model
- E2E.TI.COM ti.com/ethernet
Thank You!