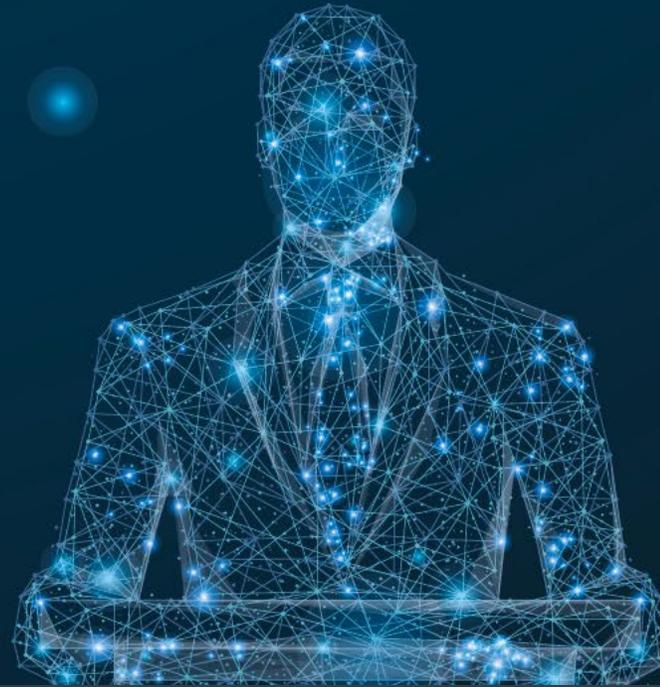


DIGITAL WE DAYS

2024



EMC/EMI OPTIMIZATIONS IN SINGLE PAIR ETHERNET (SPE) FOR INDUSTRIAL COMMUNICATION

Kristen Mogensen | Texas Instruments

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

EMC/EMI optimizations in Single Pair Ethernet (SPE) for industrial communication

Version 1.0

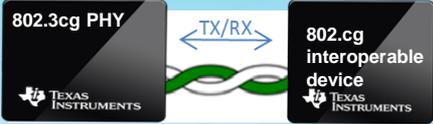
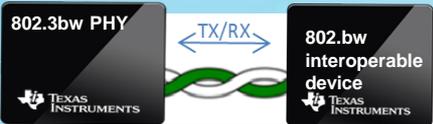
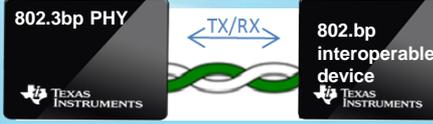
Industrial Systems

Kristen Mogensen

Content

- Overview: Single Twisted Pair Ethernet
- Single Twisted Pair Ethernet for industrial purpose
 - Key parameters for industrial customers
 - HW implementation
 - Test results
- Diagnostic features for predictive maintenance
- Overall system description and next steps

Single Pair Ethernet for Industrial Applications: 10M, 100M and 1000M

Speed	10 Mbps	100 Mbps	1000 Mbps
			
Standards based	IEEE 802.3cg 10Base-T1L	IEEE 802.3bw100Base-T1	IEEE 802.3bp 1000Base-T1
Cable Reach(UTP/STP)	1000 meters/2000 meters	50 meters/100 meters	15 meters/40 meters
Power Dissipation	< 110 mW	< 220 mW	< 600 mW
Communication	Full-duplex	Full-duplex	Full-duplex
MAC i/f	MII, RMII	MII, RMII, SGMII, RGMII	RGMII, SGMII
Temperature	-40 to 105C	-40 to 125C	-40 to 125C
Part Number	DP83TD510E	DP83TC812R-Q1	DP83TG720R-Q1
Part Status	In Production	In Production	In Production
Applications	Robotics, Building Automation, Factory Automation, Process Automation, Avionics		

DP83TC812/814 | Low-Power 100BASE-T1 Ethernet PHY

TC-10 Compliant

Available Now

Features

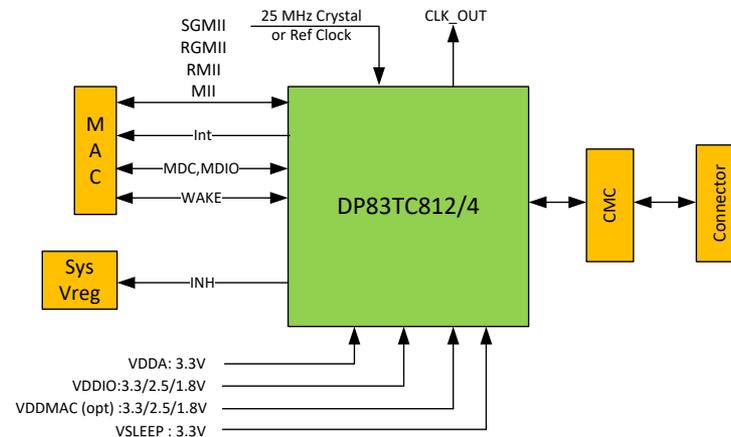
- **100BASE-T1** IEEE802.3bw compliant
 - **DP83TC812 only – Open Alliance TC-10 Low Power Compliant with low power wake and forwarding**
 - Sleep current < **15uA**
- 3.3V **single supply operation** with active power < **230mW**
- Link segment: 50m+ with **Integrated LPF**
- **Optional separate voltage domain for MAC interface**
- **Advanced Diagnostic Features**
 - SQI and SNR estimation (1 dB accuracy)
 - ESD, voltage, & temperature sensors, PRBS generator & checker
- Multiple MAC interfaces: **SGMII / RGMII / RMII / MII**
- Multiple IO Voltage: 1.8V/2.5V/3.3V
- Optional ground escape pins
- **49m cable reach** with 4 interconnects
- Package options
 - 36-QFN, 6mm x 6mm (wetable flank) **footprint compatible with DP83TG720 and DP83TC811**
- AEC-Q100 Grade 1 Qualified (-40 to 125° C)

Applications

- **Backbone/Gateway – Connects all domains**
- **Point-to-point sensors and compressed data**

Benefits

- Interoperable with other IEEE802.3bw 100BASE-T1 PHYs/Switch
- Enables system level power savings by remote sleep and wake
- Simplify system design by using single supply operation
- Reduced BOM cost: No external LPF & No level shifters for separate VDDMAC
- Easy upgrade path to 1000BASE-T1 while saving cost for 100BASE-T1



DP83TG720-Q1 | IEEE 802.3bp

Single Twisted Pair Ethernet PHY (1000BASE-T1)

Mass Production

Features

Coupling types: both galvanic and capacitive coupling supported

Robust EMC

- Tested capacitively for FTZ; compliant with UTP and no external filter components
- Tested galvanically for IEC61000-4-2, IEC61000-4-4, IEC61000-4-5, IEC61000-4-6; compliant

Enhanced diagnostics tool kit includes commonly available diagnostics plus :

- Signal quality indicator (SQI)
- Voltage, temperature & ESD strike monitoring

Daisy chain support via 25 MHz reference output clock

Power efficient

- Active power consumption <500 mW; sleep power <2 mW
- IO Voltage: 1.8V, 2.5V & 3.3V

Footprint compatible with TI 100BASE-T1 (DP83TC811/12/14-Q1)

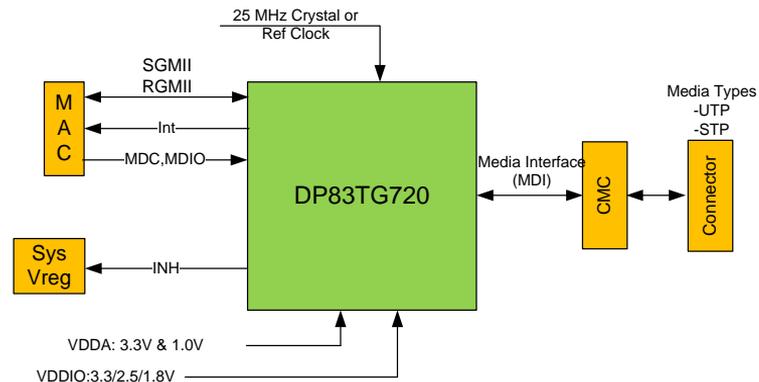
MAC I/F: SGMII & RGMII, with slew rate control

Applications

- Robot arms
- Edge nodes
- SONAR / RADAR / LIDAR
- PLC
- HVAC systems
- Fire & safety

Benefits

- Fewer, more flexible wires are possible
- Maximize cabling harness lifespan
- Minimize copper cost
- Reduce system weight
 - optimize system deployment and maintenance costs
- Interoperable with other IEEE802.3bp 1000BASE-T1 PHYs/switches



EMC compliant SPE Ethernet for industrial systems

Features

- Single Twisted Pair Ethernet(SPE) system optimized for EMC performance
- Processor and base-T1 phy able to show real time performance on a system level
- Power over Ethernet capability for 100BASE-T1 and 1000BASE-T1 solutions (SPoE/PoDL)

Benefits

- System test setup for EMC performance requirements based on industrial applications with Transformer based termination
- Connector to enable Power over Ethernet capability
- Easy MAC and PHY connection to Sitara ICSS real time Ethernet module able to show industrial protocols like Sorte_G
- Define latency and jitter performance and how this can influence industrial graded communication

Target Applications

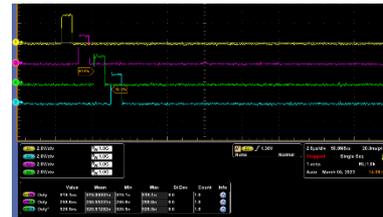
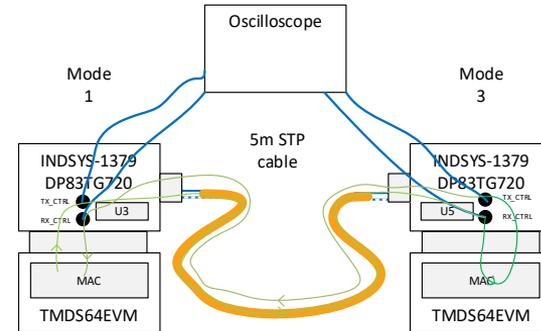
- [Mobile robot system controller](#)
- [Mobile robot motor control](#)
- [Robot CPU board](#)
- [Computer on module](#)

Tools & Resources



List outcome of project:

- HW available working with [TMD564EVM](#) - Available
- System test software on SD-card - Available
- Collateral: App note ([snla420](#)) - Available

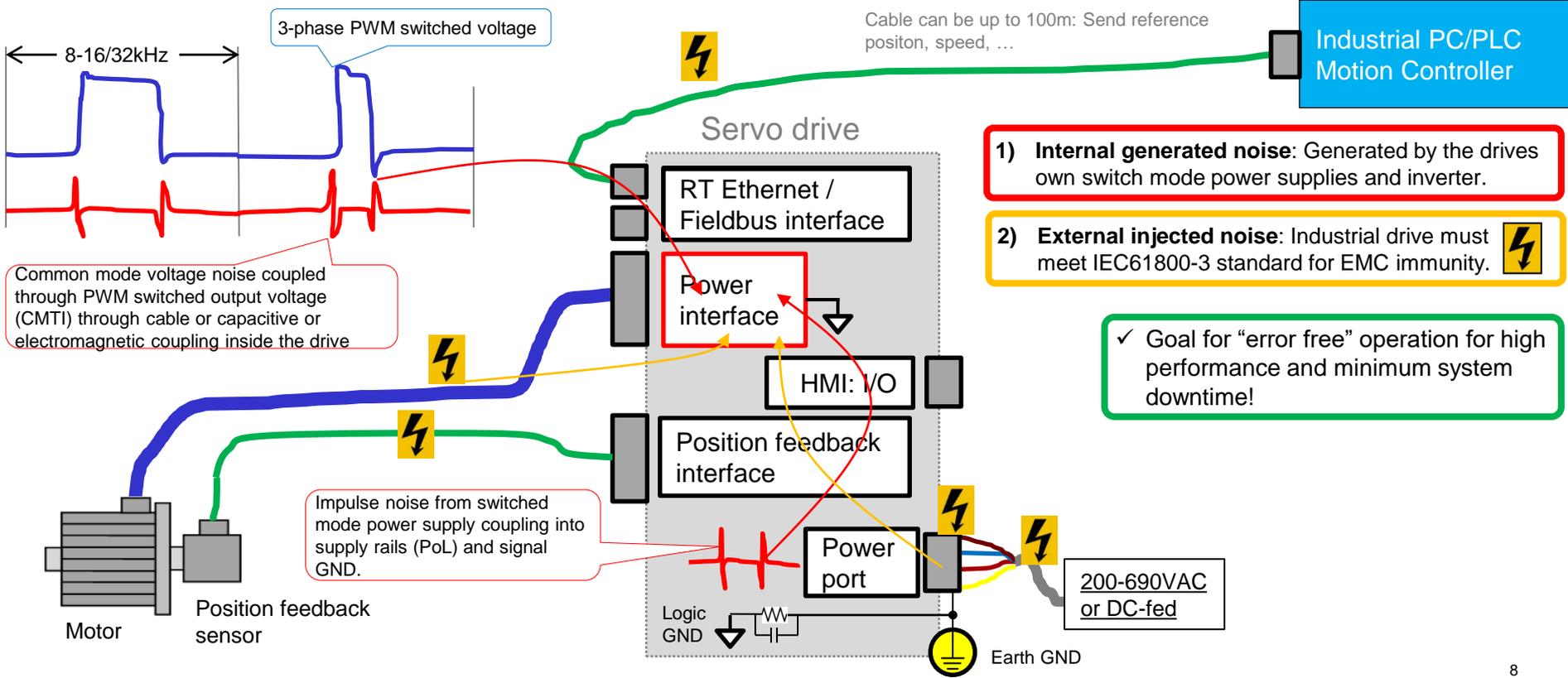


Round trip frame delay time	us	Packet size
100base-T1	14us	64 byte
1000base-T1 with decoder	15.2us	64 byte
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Design challenge: Why is EMC immunity and especially EFT important in industrial environments?



EMC immunity requirements 1

IEC 61800-3 is the relevant standard for variable speed drives and refers to IEC61000-4-x

Port	Phenomenon	Basic standard	Level	Performance (acceptance) criterion
Enclosure ports	ESD	IEC61000-4-2	+/-4kV CD or 8kV AD, if CD not possible	B
	RF electromagnetic field amplitude	EC61000-4-3	80MHz to 1GHz, 10V/m, 80% AM (1MHz)	A
Power port	Fast transient Burst (EFT)	IEC61000-4-4	+/-2kV/5kHz or 100kHz (a)	B
	Surge 1,2/50us, 8/20us	IEC61000-4-5	+/-1kV (c) +/-2kV (d)	B
	Conducted RF	IEC61000-4-6	0.15-80MHz, 10V/m, 80% AM (1kHz)	A
Power interface	Fast transient Burst (EFT)	IEC61000-4-4	+/-2kV/5kHz or 100kHz, capacitive clamp	B
Signal interfaces	Fast transient Burst (EFT)	IEC61000-4-4	+/-1kV/5kHz or 100kHz	B
	Conducted RF	IEC61000-4-6	0.15-80MHz, 10V/m, 80% AM (1kHz)	A
Ports for process measurement control lines	Fast transient Burst (EFT)	IEC61000-4-4	+/-2kV/5kHz or 100kHz	B
	Surge 1,2/50us, 8/20us	IEC61000-4-5	+/-1kV (d),(f)	B
	Conducted RF	IEC61000-4-6	0.15-80MHz, 10V/m, 80% AM (1kHz)	A

For more details refer to IEC61800-3, EMC requirements for second environment

Performance (acceptance) criterion	Description
A	Module shall continue to operate as intended. No loss of function or performance even during the test.
B	Temporary degradation of performance during test is accepted. After the test, module shall continue to operate as intended without manual intervention.
C	ICs (ESD) typically tested per criterion C. Instruction to operate as intended automatically, after manual restart, or power off, or power on. Not self-recoverable.

Definition of **Criterion A** is customer dependent:

- For communication interfaces often less than 3 consecutive errors are still considered Criterion A

- ✓ Customer typically test **twice the standard voltages**
- ✓ Achieving **criterion A especially with EFT is a competitive advantage!**
- Yields to more robust system with better performance and less down-time in harsh industrial environment

Content

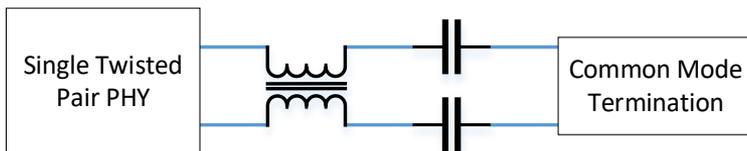
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100 / 1000Mbit – coupling concepts

Capacitive data coupling circuit

- Capacitive Isolation: typ. 50V to 100V rated capacitors
- Very sensitive pending noise source
- Matching of differential lines is difficult
- Size larger than galvanic

	Capacitive 50V	Capacitive 2kV
Decoupling	36mm ²	144mm ²
Common mode Choke	20mm ²	20mm ²
Common mode Termination	180mm ²	180mm ²
Total	236mm ²	344mm ²
Maximum height	2.8mm	2.8mm

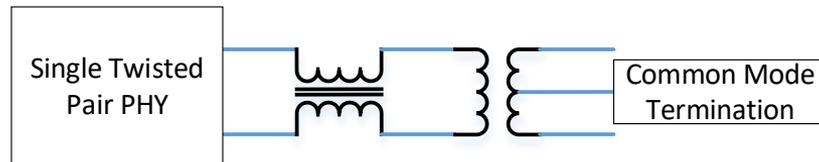


Capacitive coupling

Galvanic data coupling circuit

- Galvanic isolation: typ. 1.5kV rated
- Noise robust is able to pass IEC61000-4-x testing
- Matching of differential lines are easier
- Smaller than capacitive

Galvanic
28mm ²
8mm ²
90mm ²
126mm ²
2.9mm



Galvanic coupling

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Motor system test results



	Shield	Link
20 m cable	Shielded	Connected

Capacitive coupling 100V rated caps

DCLink / [V]	0V	50V	150V	300V	350V	400V	450V	500V
CRC error Mode 1	No errors	No errors	Link Drop					
CRC error Mode 3	No errors	No errors	Link Drop					

Galvanic coupling

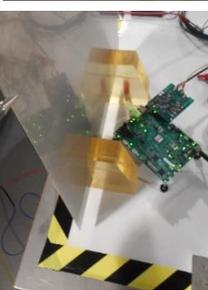
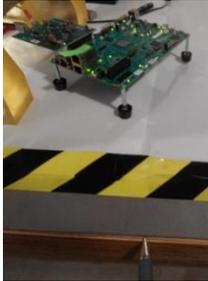
DCLink / [V]	0V	50V	150V	300V	350V	400V	450V	500V
CRC error Mode 1	No errors							
CRC error Mode 3	No errors							

Industrial compliance testing for EMC/EMI

EMC test setup according to IEC61000-4-x and CISPR-xx

IEC61000-4-2 ESD

Contact and
Air Discharge



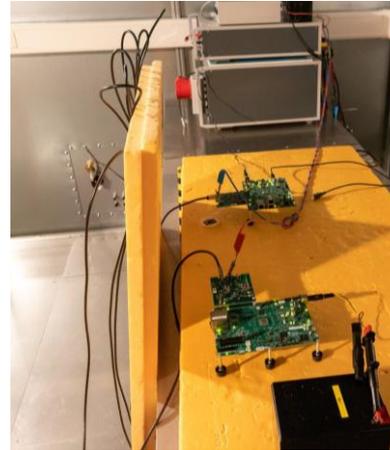
IEC61000-4-4 EFT



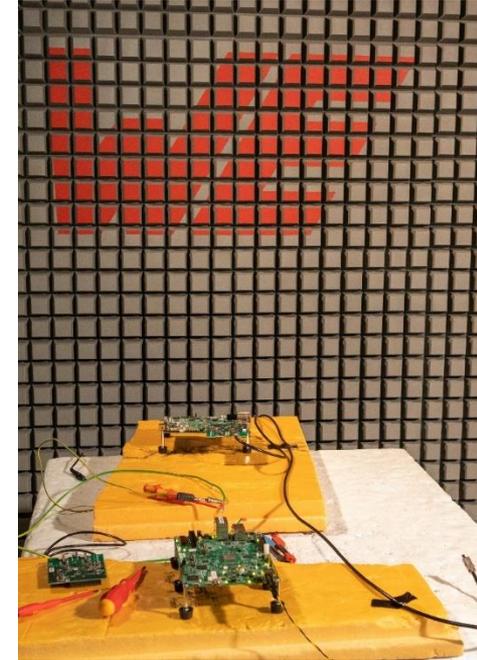
IEC61000-4-6 Conducted
RF



IEC61000-4-5
Surge



CISPR-xx



EMC Immunity Tests

Reference to IEC 61800-3 is EMC immunity for variable speed drives

Port	Phenomenon	Basic standard	Level	Performance (acceptance) criterion
Enclosure ports	ESD	IEC61000-4-2	+/-4kV CD or 8kV AD, if CD not possible	B
	RF electromagnetic field amplitude	EC61000-4-3	80MHz to 1GHz, 10V/m, 80% AM (1MHz)	A
Power port	Fast transient Burst (EFT)	IEC61000-4-4	+/-2kV / 5kHz or 100kHz (a)	B
	Surge 1,2/50us, 8/20us	IEC61000-4-5	+/-1kV (c) +/-2kV (d)	B
	Conducted RF	IEC61000-4-6	0.15-80Mhz, 10V/m, 80% AM (1kHz)	A
Power interface	Fast transient Burst (EFT)	IEC61000-4-4	+/-2kV / 5kHz or 100kHz capacitive clamp	B
Signal interfaces	Fast transient Burst (EFT)	IEC61000-4-4	+/-1kV / 5kHz or 100kHz	B
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Performance (acceptance) criterion	Description
A	Module shall continue to operate as intended. No loss of function or performance even during the test.
B	Temporary degradation of performance during test is accepted. After the test, module shall continue to operate as intended without manual intervention .
C	During the test, loss of functions accepted, but no destruction of hardware or software. After the test, the module shall continue to operate as intended automatically, after manual restart, or power off, or power on. Not self-recoverable .

For more details refer to IEC61800-3, EMC requirements for second environment

Executive summary - EMC test results

- The EMC test has been performed at Wuerth internal EMC test facility (Waldenburg, Germany)

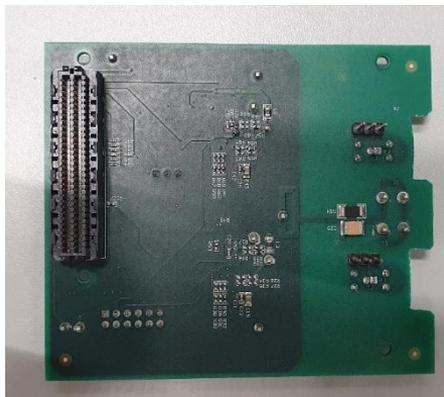
IEC61800-3 EMC immunity requirements

Requirements					DUT Measurements	
Port	Phenomenon	Basic standard	Level	Performance (acceptance) criterion	Performance Criterion	Test
Enclosure ports	ESD	IEC61000-4-2	+/-4kV CD or 8kV AD, if CD not possible	B	B (6kV to 8kV) AD A (4kV) AD A (4kV) CD	PASS
Ports for control lines and DC auxiliary supplies <60V	Fast transient Burst (EFT)	IEC61000-4-4	+/-2kV/5kHz or 100kHz, capacitive clamp	B	B (4kV) A (2kV)	PASS
	Surge 1,2/50us, 8/20us	IEC61000-4-5	+/-1kV. Since shielded cable >20m, direct coupling to shield (2Ohm/500A)	B	A (3kV) (4kV destroyed PCB trace)	PASS
	Conducted RF	IEC61000-4-6	0.15-80MHz, 10V/m, 80% AM (1kHz)	A	A (20 V/m)	PASS
Power port	Fast transient Burst (EFT)	IEC61000-4-4	+/-2kV/5kHz or 100kHz	B	A (3kV)	PASS
					B (4kV)	PASS

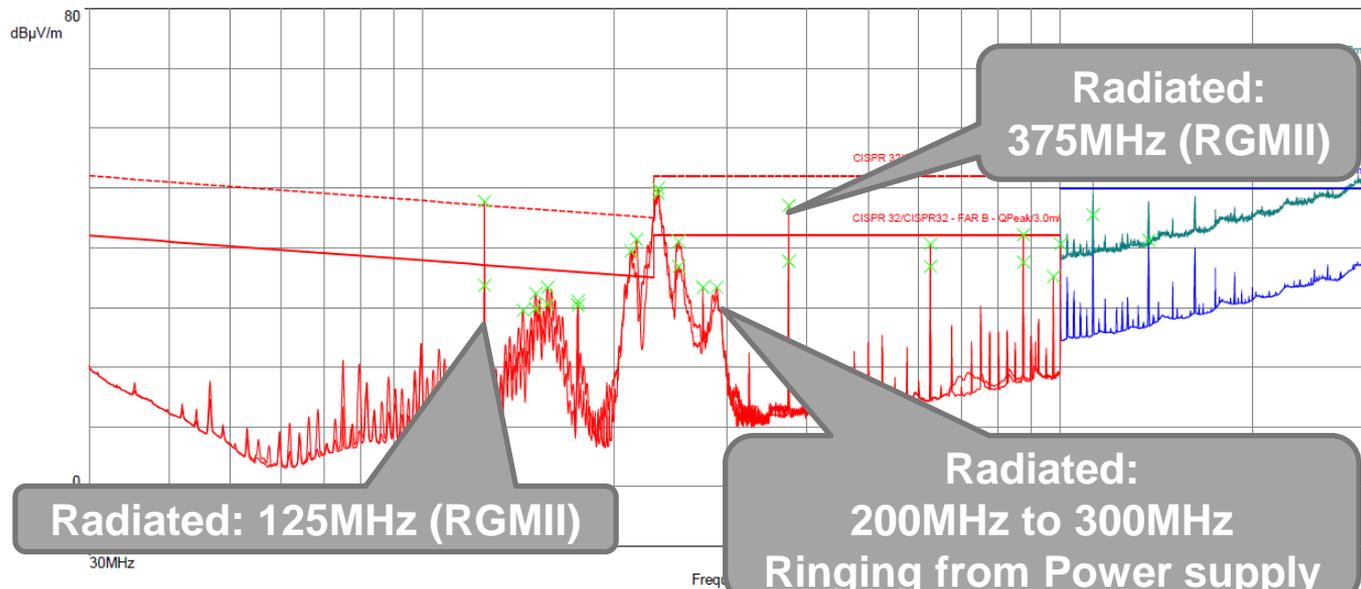
IEC61800-3 EMI requirements

Basic Standard	Category 2 electric field strength quasi-peak dB(uV/m)	DUT measured at 3m antenna distance minimum margin to limit	Result
EN55032/ CISPR 32 class B	Conducted 3m <ul style="list-style-type: none"> 46 (500k – 5MHz) 50 (5MHz – 30MHz) Radiated 3m <ul style="list-style-type: none"> 50 (30MHz to 225MHz) 58 (225MHz to 1GHz) 70 (1GHz to 3GHz) 	Radiated: 225 6.81 dB margin	Pass

EMI Results – Rev 1 – DP83TG720R-Q1



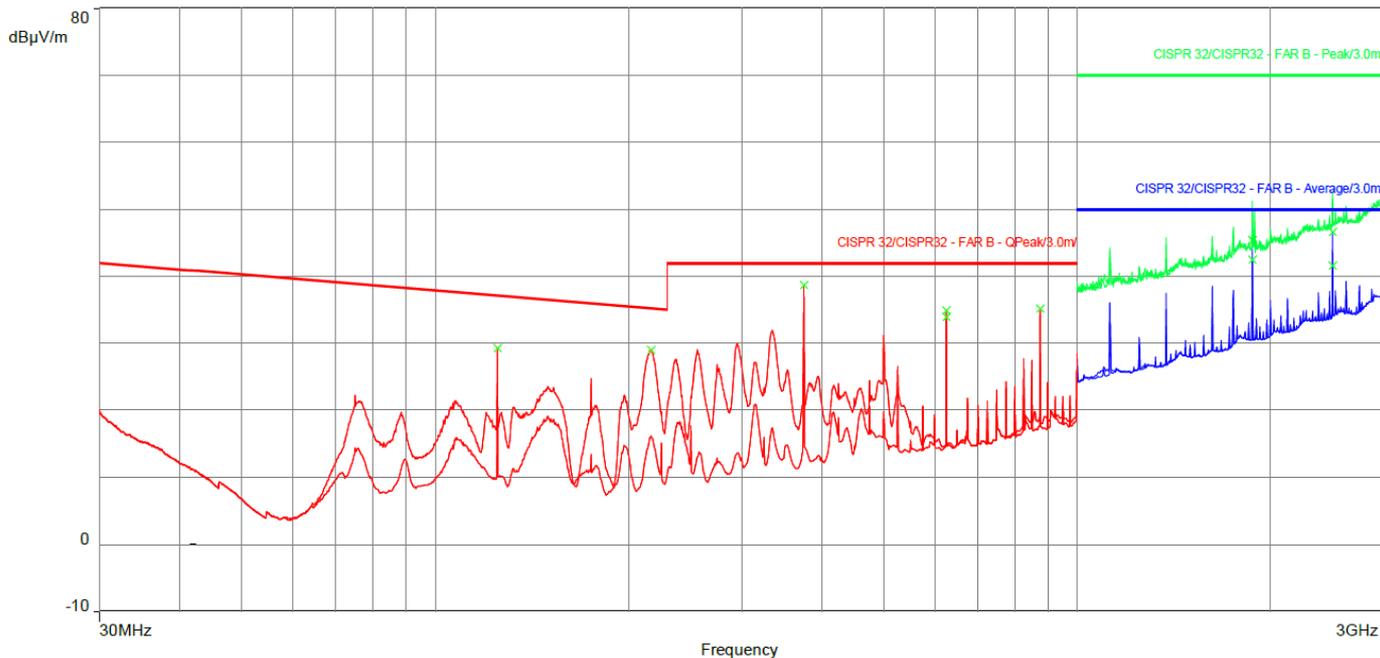
HW update on system



EMI Results – Rev 1 – DP83TG720R-Q1

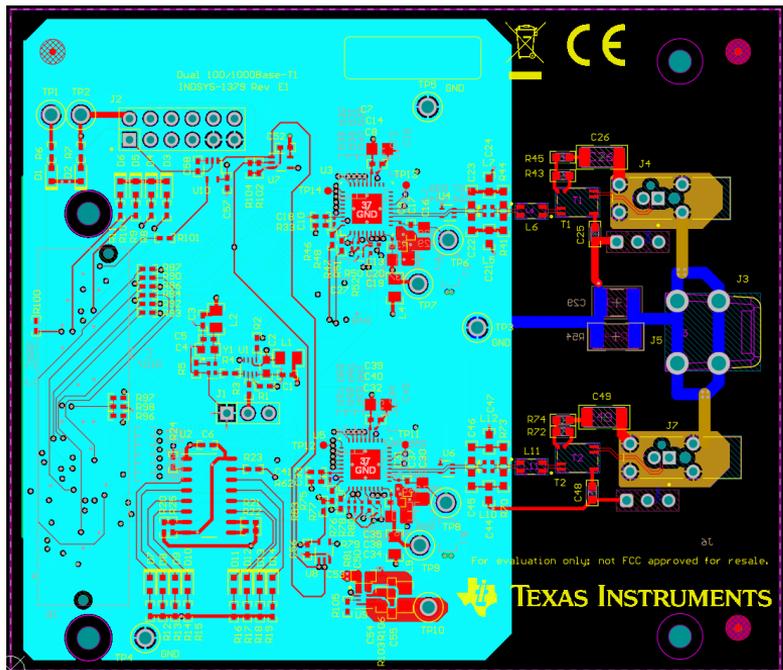


HW update on system

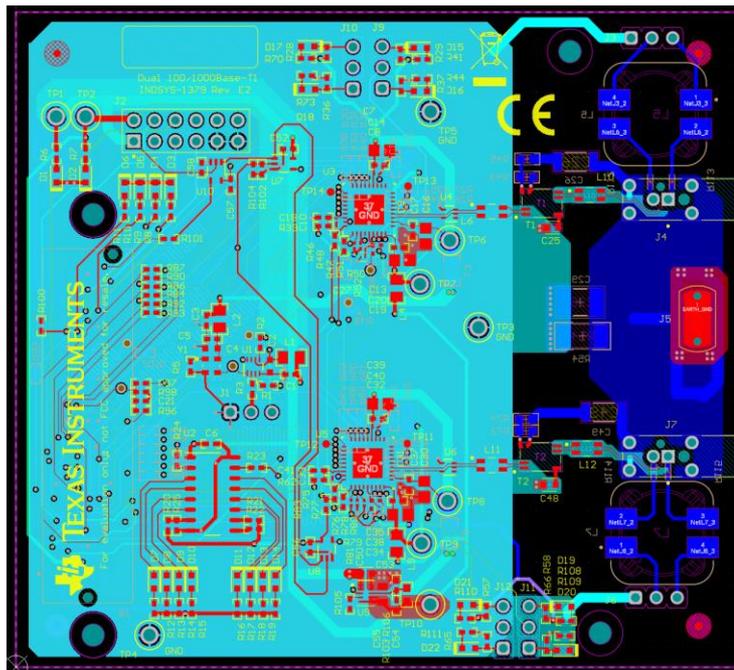


Layout updates – Rev 1 to Rev 2 – DP83TG720R-Q1

Rev 1 layout



Rev 2 layout



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- Processor and base-T1 phy able to show real time performance on a system level
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Benefits

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- Connector to enable Power over Ethernet capability
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Target Applications

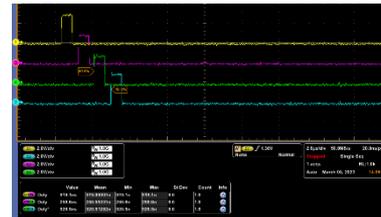
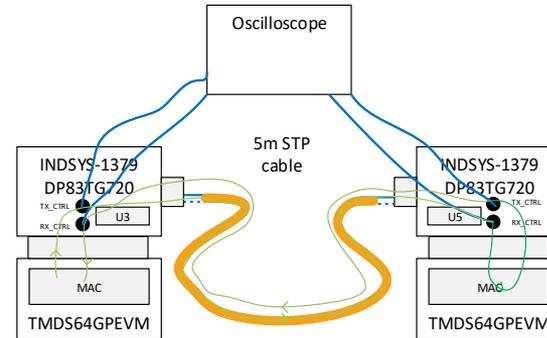
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Tools & Resources



List outcome of project:

- HW available working with [TMD564GPEVM](#) - **Available**
- System test software on SD-card - **Available**
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Conclusion

- Industrial usage of Single Twisted Pair Ethernet is happening
- Understanding the limitations of the technology will help define how to use it
- Key care about is latency and EMC performance
- TI has done additional testing to support customers on this journey

Questions

& Answers



We are here for you now!
Ask us directly via our chat or via E-Mail.

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timur.uludag@we-online.de