TI Designs
Certified PROFINET IRT v2.3 Device With 1-GHz ARM Application Processor

TI Designs

This design describes the Texas Instruments certified hardware and software components for PROFINET® IRT v2.3 device applications. This design integrates the Industrial Ethernet PHYs, PROFINET IRT switch, PROFINET IRT stack, and application example in a single package. PROFINET is the leading Industrial Ethernet standard used in numerous Industrial segments and end-equipments that require real-time deterministic exchange of IO data and additional bandwidth for service and diagnostics.

Design Resources

TIDEP0029	Design Folder
AM3359	Product Folder
TLK110	Product Folder
TPS65910	Product Folder
TMDSICE3359	Tools Folder
Industrial SDK	Software Folder

TI E2E™ Community

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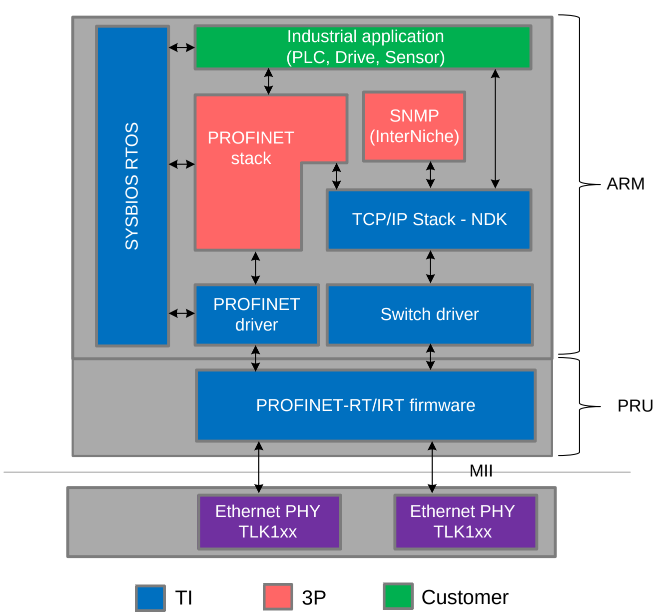
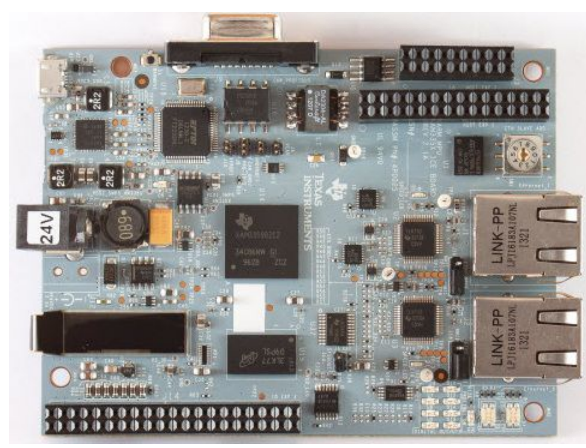
Design Features

- PROFINET Conformance Class A/B/C
- 250-µs Cycle Time
- One Step Time Synchronization (PTCP)
- Eight Consumer and Provide Protocol Machines
- Media Redundancy Protocol (MRP)
- Integrated With Molex PROFINET Stack
- Integrated With InterNiche SNMP Stack

Featured Applications

- Industrial Ethernet
- PLC Bus Coupler
- Industrial Drive
- Industrial Sensor





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1 PROFINET IRT Technology Overview

Industrial Ethernet is one of the key components that enable the manufacturing process to be more efficient and flexible. This protocol provides the foundation for new architectures in Industrial Automation where the Industrial Ethernet is the backbone for a wide range of end-equipment like sensors, drives, PLCs, and HMIs. The PROFINET Isochronous Real-time (IRT) provides the performance and robustness required to connect these devices for IO data exchange and service functions. With the integration of the PROFINET IRT v2.3 switch into the Sitara AM335x ARM® MPU, customers get a scalable architecture that is able to serve a wide range of applications.

PROFINET is the leading Industrial Ethernet standard used in Industrial Automation markets. Its predecessor is PROFIBUS DP, a 12-Mb serial fieldbus communication over RS-485 transceivers. PROFINET uses 100-Mb full-duplex Industrial Ethernet PHYs and is standardized in IEC 61158 and IEC 61784. Compared to standard Ethernet switches defined under IEEE 802.1Q, PROFINET defines real-time enhancements, which guarantee deterministic operation in delivering IO data in a master/slave type of network connection. In particular, the IRT adds the capability to protect IO data exchange within a reserved time window. Under IRT, every IO packet that is sent in the protected communication phase has a delivery accuracy of few nanoseconds. This requires synchronization between a timing master and all slaves participating in an IRT domain using a peer-to-peer transparent clock.

Figure 1 shows the scheme of PROFINET IRT communication. There is a range of possible cyclic execution communication periods from 31.25 µs up to 4 ms. Most of the applications today run at 1 ms. In motion control application areas the cycle times become faster, in the range of 250 µs. A new communication cycle starts with a red period, which is reserved for time triggered communication of PROFINET IO data packets with Real-time Class 3 (RTC3). Every RTC3 packet is pre-engineered with a frame send offset (FSO) timing parameter. The very first packet in red period also maintains the minimum FSO to prepare the send list for a new communication cycle. A red communication period always starts at time zero which is derived from time synchronization function of the PROFINET IRT switch. The duration or end of red period is described by the timing parameter StartOfGreen. This timing parameter can vary for up to 16 different IRT communication phases. Five profiles can be mapped to the 16 communication phases. One profile is a special case with StartOfGreen set to zero, meaning no red period in this phase.

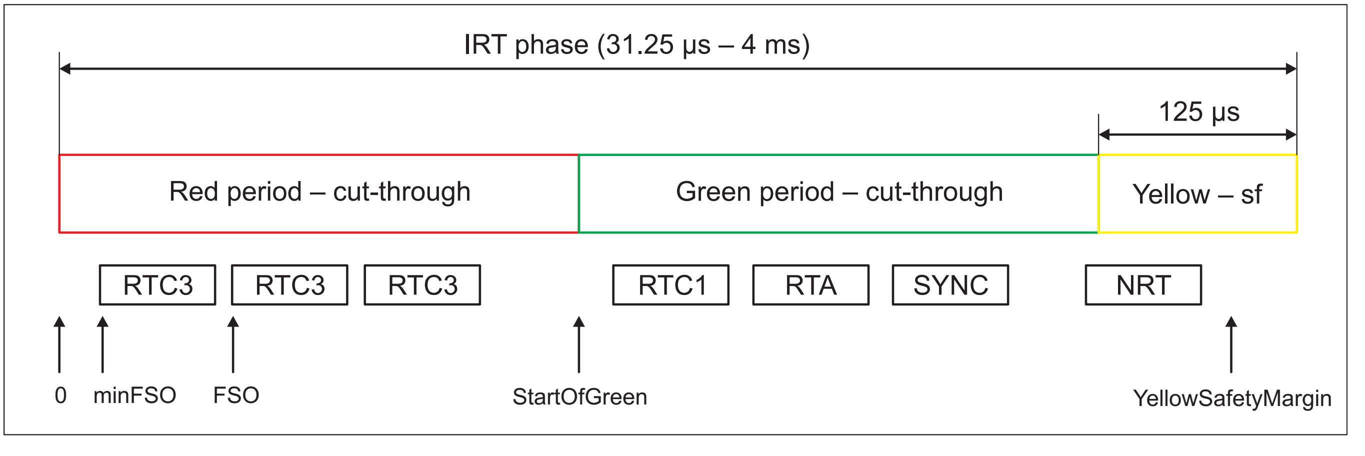

Figure 1. PROFINET IRT Communication

The green period is reserved for IO data packets of Real-time Class 1 (RTC1), PROFINET alarm packets (RTA), time synchronization packets, PROFINET related protocol packets, and standard TPC/IP packets. The communication of green packets is not time triggered but strict priority based. If there are still packets available in send queues at the end of the green period, the transmission of packets is interrupted until the green phase of the next communication phase. A special case is the transition from green period to red period, which is separated by a yellow period. During the yellow period, the PROFINET IRT switch operates in a store and forward mode to protect the boundary to the red period. The maximum duration of a 1500-byte Ethernet packet defines the length of the yellow period as 125 µs. The PROFINET IRT switch needs to check the length of a packet in yellow period to determine whether this packet still fits in the remaining time before a new communication phase starts.

As time and hardware synchronization on each PROFINET device is not without jitter, an additional YellowSafetyMargin of 640 ns is introduced to protect transition into next red period. To minimize the delay through a PROFINET IRT switch, packets in the red and green periods are processed in a cut-through mode. The delay through a PROFINET device includes physical layer delay, synchronization delay on Media Independent Interface (MII), decision time of the PROFINET switch, and frame delay of cut-through decision point. For RTC3 packets, the FrameID field classifies the packet for receive or forward processing, which comes after 1920 ns including the pre-amble and Ethernet header. The MaxBridgeDelay of a PROFINET device needs to be constant during the red period to ensure that devices further down the IRT line topology do not receive the packet outside the red period.

PROFINET IRT communication follows a cyclic pattern where different communication profiles can be defined for up to 16 phases. If PROFINET IO packets are not generated at the same rate as the cycle time, a reduction ratio and phase number when a packet starts is configured. For example, when the communication cycle is set to 250 µs and a provider generates new data every 1 ms, the reduction ratio is set to 4 and the start timing can be any of the four phases. This flexible timing gives the PLC application the ability to distribute the IO communication intervals for different applications and devices.

Another enhancement of PROFINET compared to standard Ethernet is the format of an IO packet, which does not use UDP or IP packets but its own format with an identifier, sequence number, and connection status. Direct addressing of PROFINET IO packets bypass queued-based network processing and connect directly with application buffers. Figure 2 shows the PROFINET IO packet format, which is used for RTC3 and RTC1 frames.

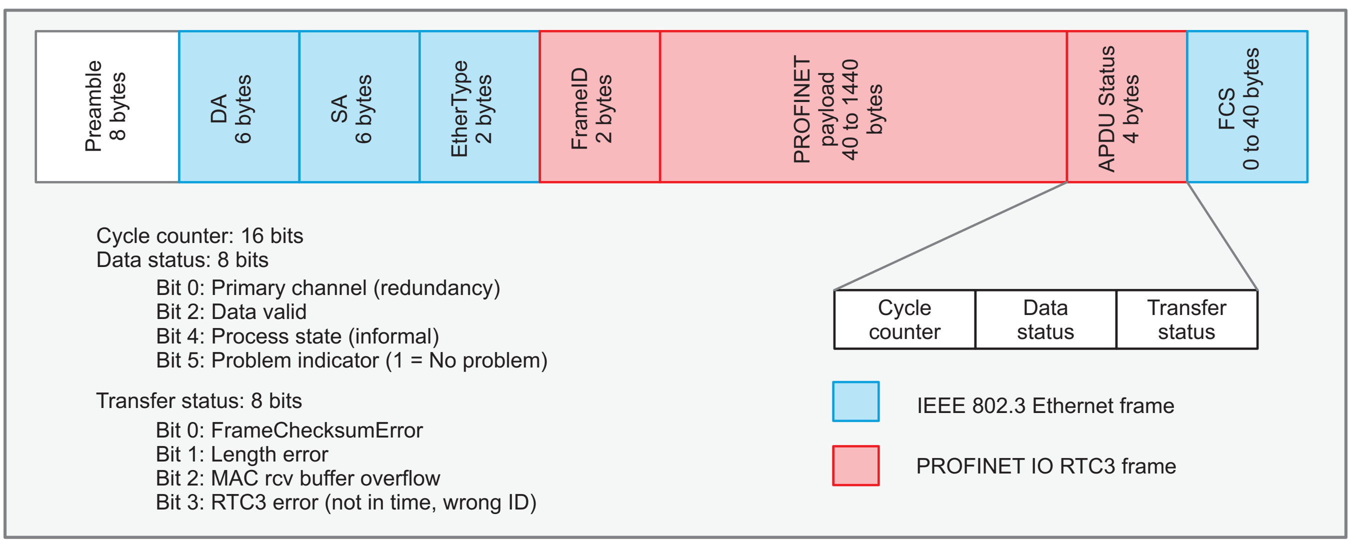

Figure 2. PROFINET IO Packet Format

Like all Ethernet frames, the packet is prepended with 8 bytes of preamble followed by the Ethernet header with destination MAC address and source MAC address. PROFINET packets are identified through EtherType field with the value of 0x8892. The EtherType for PROFINET is used for IO packets and PROFINET related protocols like Dynamic Configuration Protocol (DCP). Other protocols used for PROFINET, like Link Layer Discovery Protocol (LLDP), use their own EtherType value (0x88CC). After the EtherType field, there can be a VLAN tag field according to the IEEE 802.1Q standard. RTC3 packets do not have a VLAN tag field and the next field is the FrameID, which serves as an address of PROFINET data packets. A PROFINET device compares incoming RTC3 FID with a local connection to decide on consuming the packet or forwarding the packet on the other port. There is a certain range for the 16-bit FID that indicates valid RTC3 and RTC1 packets. There is special handling of PROFINET IRT related packets at the boundary to non-IRT domain. In this case, the PROFINET switch ensures that the IRT communication phase is not corrupted by external Ethernet traffic of any type and IRT related traffic does not leave the IRT domain. After the FrameID, there is the actual PROFINET IO data field. For outgoing packets, this field contains provider data. For incoming packets, the field contains consumer data.

PROFINET defines protocol machines for both directions that are called Consumer Protocol Machine (CPM) and Provider Protocol Machine (PPM). The Application Protocol Data Unit (APDU) status is used by these protocol machines in combination with additional status information like port state, redundancy state, and time synchronization status. A 16-bit cycle counter continuously increments by a cycle time in multiples of 31.25 µs. This cycle counter is verified at the receiver (consumer) to see whether provider of the data is still alive. If the cycle counter is not updated properly, the data hold timer (DHT) for this connection is increased and typically expires with three missing updates.

Two bit fields provide status about the PROFINET data and the transfer of PROFINET data: the Data Status and the Transfer Status. The data valid bit in the Data Status field is also used by the connection monitoring function. Control of system redundancy uses the Data Status bit 0 to indicate primary or backup channel. Bit 4 of the Data Status field indicates the provider status, which can be RUN or STOP. Bit 5 signals whether a fault is detected. The Transfer Status bit field describes of the error sources and is implementation specific. After the APDU status, there are 4 bytes of Ethernet frame check sum, which is part of standard 802.3 Ethernet frame.

A more detailed description of the PROFINET technology and PROFINET standard are available on the PROFIBUS international website at http://www.profibus.com:

- For PROFINET technology: *Download → Technical Descriptions & Books*
- For PROFINET standards: *Download → Specifications & Standards*

2 Robustness of PROFINET IRT Implementation

PROFINET IRT is not a closed communication system and allows standard Ethernet traffic inside the IRT domain as well as any Ethernet traffic on the boundary ports of the IRT domain. Besides the controller (PLC CPU) and devices (IOs, HMIs), there can be additional Ethernet switches in the network, which may have an impact on the timing and order packets are delivered. The PROFINET IRT switch described in this design has two physical ports and one host port. Each of the ports follow Quality of Service (QoS) rules when receiving and transmitting certain packet types. The timely separation of the red and green period protects the RTC3 packets and enough bandwidth to make delivery of PROFINET IO packets 100% deterministic. In addition, RTC1 packets, which are transferred in the green period, have dedicated resources to ensure that all packets are transferred and monitored without interference from other Ethernet packets.

Figure 3 outlines the QoS architecture of the PROFINET IRT switch on AM335x. It separates PROFINET IO packets from other packets when receiving a packet with PROFINET EtherType and FrameID, which is associated with local CPM connection. The RTC1 and RTC3 packets have their own RTC descriptors and dedicated triple buffers. There are additional control and status registers to manage CPM and PPM that allow for dynamic addition and removal of a PROFINET data connection. When a new connection is added, the host CPU prepares the configuration in shadow registers and provides a smooth transition from the active list to the shadow list at the communication cycle boundary. There are separate interrupts to the host CPU to indicate a change in buffer index, a change in active list, and the data hold timer expiration. The real-time application can take the IO data directly from the triple buffer without additional software layers like a networking stack. This provides the lowest latency and eliminates overhead while the application consumes and provides IO data. Before PROFINET starts with the exchange of IO data, there is a configuration and start-up phase that can be split into the following categories.

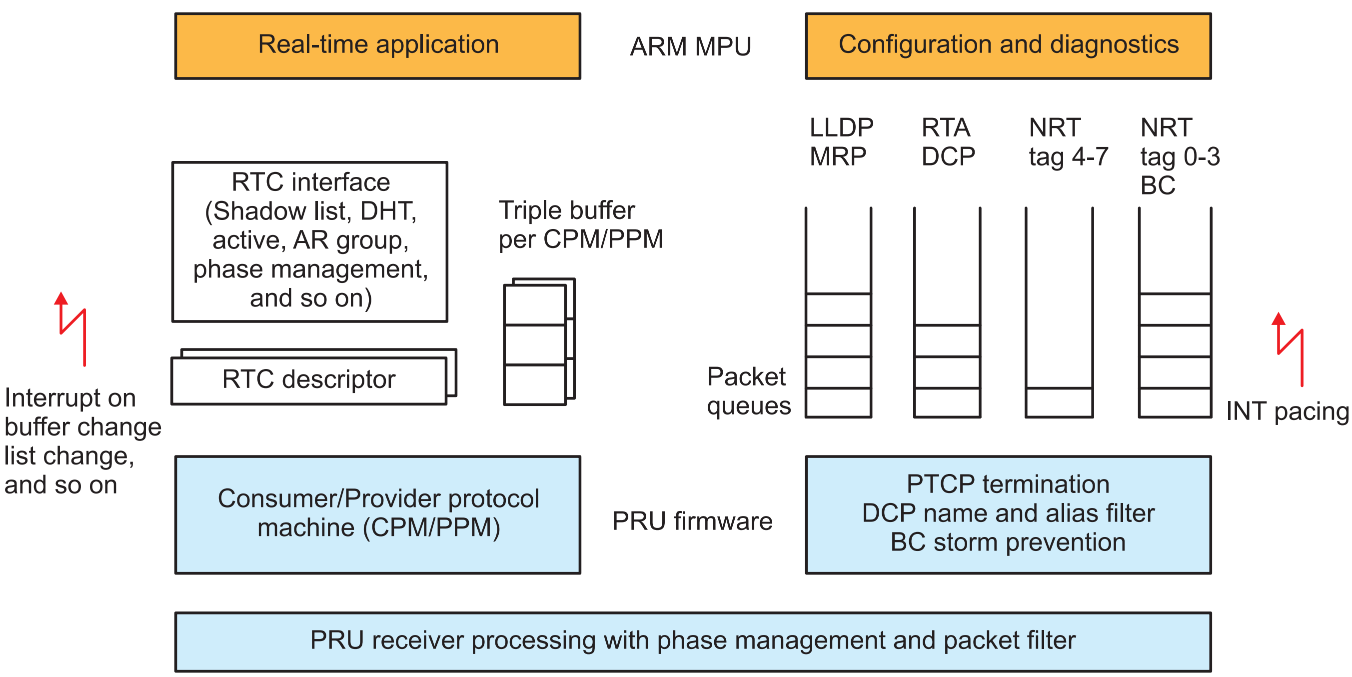

Figure 3. QoS for Received Packets

According to Precision Transparent Clock Protocol (PTCP), time synchronization provides two types of packets. One type is for peer-to-peer line delay measurement, which periodically repeats independently of the PROFINET connection state. The second type is the PTCP sync packet, which distributes system time from the controller to all devices. Each device adds line delay and bridge delay to the time reference to the synch packet. As time synchronization is a critical function for IRT communication timing, the PTCP packets are directly terminated in PRU firmware and not passed to the queue-based host side processing. This ensures that no other packet impacts the time synchronization capability of the PROFINET IRT switch.

The Link Layer Discovery Protocol (LLDP) exchanges information about the other physical port, which includes PROFINET related information like measured delay values, port status, alias, MRP port status, interface MAC address, and PTCP status. Every time there is change in the port information, an immediate LLDP packet is sent to the other port. In case the port information does not change, LLDP packets are periodically sent every couple of seconds. Some of the LLDP data is time critical for the PROFINET connection and must be processed with the highest priority, which is why LLDP packets are transferred in the highest priority queue. Media Redundancy Protocol (MRP) is another network management type of traffic that is routed to the highest priority queue. In case of a ring break, the PROFINET switch immediately flushes its filter data base (FDB) and starts sending standard TCP/IP traffic and PROFINET traffic on both ports to ensure that the packet can take an alternate path to the controller. Depending on the PROFINET cycle time and timing parameters of CPM/PPM pair, the connection will not drop because the data hold timer can cope with two missing packets before it expires.

In the second highest priority queue, there are two packet types used for PROFINET addressing and PROFINET alarms. The Discovery Configuration Protocol (DCP) identifies, queries, and sets the address of a device. The DCP identify is a multicast packet that checks on the name of a station. To avoid significant host load when identifying a name, there is a name filter in the PRU firmware that compares the local name and length with the data in the packet. The PROFINET alarm packets (RTA) are part of the PROFINET diagnostics and in certain cases require immediate action or response. RTA packets signal asynchronous events such as device removal, insertion, or error conditions on an application level.

The next priority level is reserved for non-real-time packets (NRT) with VLAN priority tag values between 4 and 7. This allows non-PROFINET services a higher classification from all of the remaining traffic, which goes on the lowest priority queue. During broadcast storms, which go into lowest queue, there is the possibility to limit the number of broadcast packets at a time in PRU firmware. In this case, depending on the host operating system, network stack, and application load, the interrupt load to the ARM processor can be reduced because not every received packet generates an interrupt, which gives the host more time to process multiple packets with each interrupt.

In summary, the robustness of the integrated IRT switch is supported by a combination of features:

- Protected transfer window for RTC3 packet
- Dedicated resources for PROFINET IO packets
- PRU-based packet filters and limiter for critical packets in terms of timing and load
- PRU protocol termination for PTCP
- Four priority queues with two dedicated queues for PROFINET IRT
- Interrupt pacing to control host interaction on heavy packet load

3 PROFINET IRT Firmware Architecture

All real-time dependent functions of the PROFINET IRT switch on AM335x MPU are implemented either in hardware or firmware using Programmable Real-time Unit – Industrial Communication Subsystem (PRU-ICSS). The PRU is a non-pipelined 32-bit RISC CPU optimized for low latency and low jitter processing of packets. The ICSS has two PRUs and additional hardware support for real-time Ethernet packet processing such as CRC32, time synchronization unit (IEP Timer), and real-time media independent interface (MII_RT). System events inside and outside the ICSS can be mapped to an interrupt controller (INTC) and generate interrupts for ARM CPU and PRU cores. In addition, the PRU has a special register to trigger events to INTC and therefore generate host interrupts.

Figure 4 provides an overview of the PROFINET IRT firmware architecture implemented on the ICSS for one direction. The same set of functionalities exist for the other direction. This means that for one port, the receive processing is done by the first PRU and transmit processing is done by the second PRU. Processing packets is event driven and a micro scheduler periodically checks on receive and transmit events to ensure real-time processing of Ethernet packets. Certain functions like statistics, collision handling, and scheduling for the next communication phase run as background tasks when there is no active receive or transmit task.

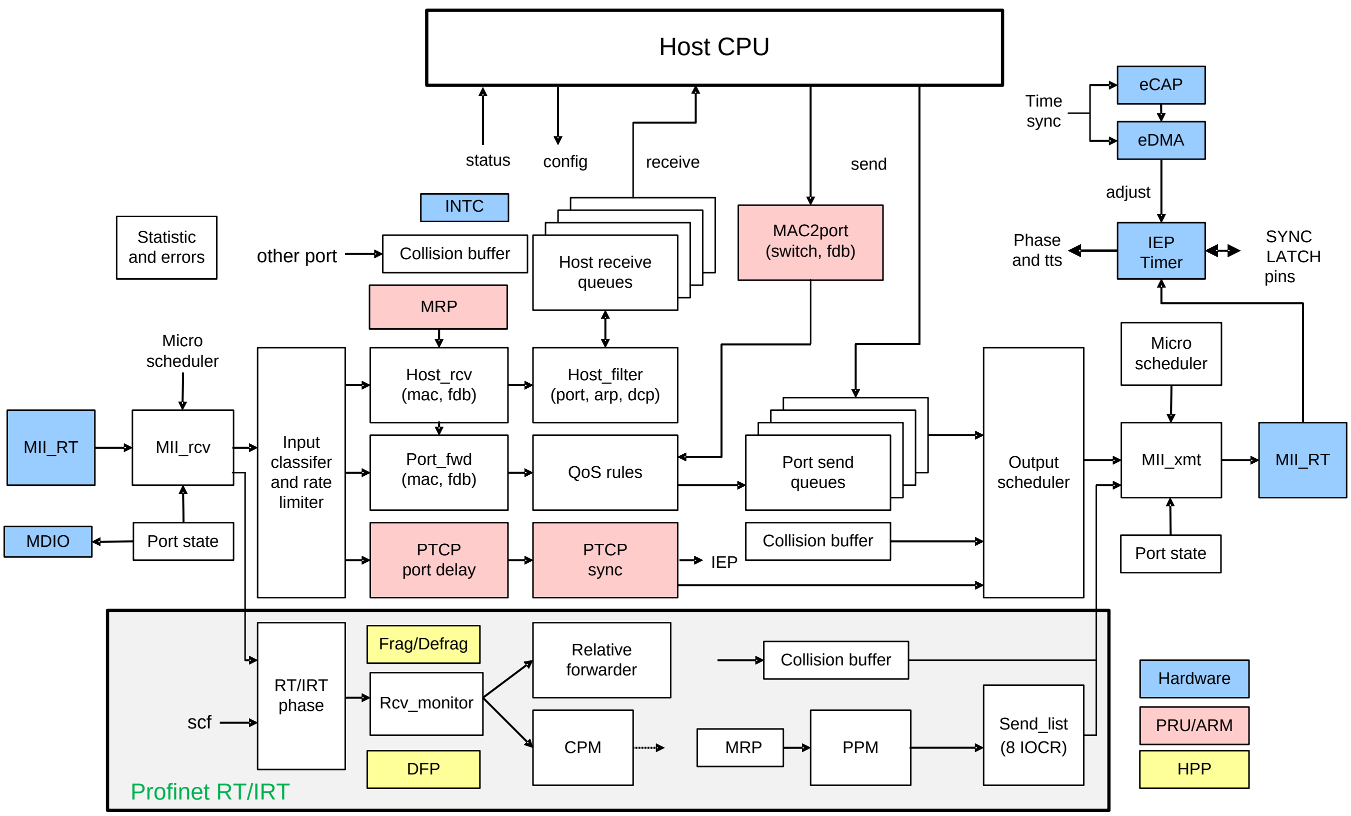

Figure 4. PROFINET IRT Firmware Architecture

When a new packet arrives on a physical port, certain conditions about port state, redundancy state, and communication phase are checked before the PRU takes a decision for receive and forward. The MII_rcv processing block handles packets in three different phases. On first block, there is only a classification of packet. On second block and the following blocks, except the last block, the PRU takes frame data in blocks of 32 bytes. On the last block, any size between 1 and 32 bytes can be transferred. The last block processing also updates descriptors and generates events. The input classifier checks on packet type first before it makes a decision to forward and receive. It also applies the quality of service rules as discussed in Section 2. If the received packet is a broadcast frame, the rate limit of broadcast frames is checked.

For packets that go out on the physical port, the PRU checks the port state, redundancy state, and communication phase. PPM packets of the red and green periods are sent first before queued traffic is sent according to priority. If the transmit port is not busy, a received packet from other port will be forwarded in cut-through mode. There is a delayed cut-through for PTPC sync packets, which are modified to include the bridge delay before going out. A device is bound to max one sync domain, which is referenced by a sync master MAC and UUID. Only the time reference of a sync packet that is registered as a sync master for the IRT domain is used for local time adjustments. PTCP line delay measurements and synchronization are performed in one step; however, the other side only supports follow-up packets.

For the MRP feature, the switch provides the corresponding blocking state and FDB operation to flush learned connections on a ring break. CPM/PPM connections are handled outside FDB operation. There is a special mode in the IRT switch that sends redundant PPM packets until corresponding CPM packet is received on a port. With the fast re-action time of the PRU-based switch, it is possible to support MRP ring breaks and recovery without losing the communication relation with CPM and PPM.

The IEP Timer module plays an important role for scheduling packets. It is used as time reference for the communication phases and for setting the FSO for outgoing RT3 packets. As the PRU starts filling the TX-FIFO, the transmission over the RT_MII is triggered by the IEP compare register with a resolution of 1 ns. Typically, a PLC system is engineered to schedule packets with a resolution of 10 ns. Since the RT_MII operates at 25 MHz, the actual transfer occurs with a granularity of 40 ns. IEP timer provides external SYNC and LATCH signals to synchronize the application with communication. The SYNC signal is also used in a system test to measure jitter of the communication cycle in an IRT domain with multiple devices. The IEP timer wraps around with the communication cycle times that are a multiple of 31.25 µs. The wrap around is known as the send clock factor. A 250-µs cycle time, produces a send clock factor (SCF) of 8 is configured.

PROFINET provides IO communication relations (IOCR) by using pairs of CPM and PPM connections. Older PROFINET IRT switch implementations used an absolute forwarder, which required every device to manage RTC3 packet timing with absolute time references. Current implementations of PROFINET IRT switch use relative forwarder in which each device only knows the absolute time of local connection and does a fixed forwarding delay for each RTC3 packet which in not locally consumed. The PROFINET connection is monitored using the data hold timer (DHT) on received CPM packets. Typically, the time-out for CPM packets is set to three and is the only failure event provided from the PROFINET switch to the host. In case of a CPM connection loss, the paired PPM connection must stop. There can be multiple PPMs grouped in an application relation (AR) with one CPM; therefore, all connections of an AR group will stop if the DHT of the CPM expires.

Figure 4 shows additional blocks in yellow for the high performance profile (HPP), which supports IO packet transmission with a cycle time of 31.25 µs. To support a cycle time below the max Ethernet frame size, larger packets are fragmented to fit into the communication period. Dynamic frame packing combines the IO data of multiple devices into one where each device removes and adds local data. Implementation of HPP is planned for next generation devices with ICSS technology.

4 PROFINET IRT Implementation on AM3359ICE

There are various PROFINET IRT switches on the market that typically separate the communication and application into two different devices. There are clear performance, cost, and area advantages of an integrated PROFINET IRT switch with a powerful 1-GHz application processor like the Sitara™ AM335x family of application processors.

Figure 5 shows the implementation of PROFINET IRT on an AM3359ICE board, also called an Industrial Communication Engine (ICE), along with two TLK110 Industrial Ethernet PHYs. The ICE board comes with a software package which includes a bootloader, a real-time operating system (RTOS), a PROFINET device driver, a network stack, PROFINET stack, SNMP stack, and an application example. When starting up, the PRU firmware for the PROFINET IRT is loaded into the ICSS, which goes along with the power, clock, and pin-mux configuration for Industrial Ethernet. The board provides local IOs (eight output LEDs), which are typically used to demonstrate and certify a simple PROFINET application. A 300-MHz CPU speed is sufficient to support a simple IO or sensor application. More complex applications can use higher speed grades of up to 1 GHz. The PRU core speed remains 200 MHz for all speed grades. Depending on the final application interface, a 1.8-V, 3.3-V, or mixed design can be supported by the processor.

The ICE board uses a 3.3-V IO design with only the DDR memory using 1.5 V. The default CPU frequency is 600 MHz. Industrial Ethernet LEDs show status information of PROFINET connection and can be used as an indicator whether IO data exchange is alive.

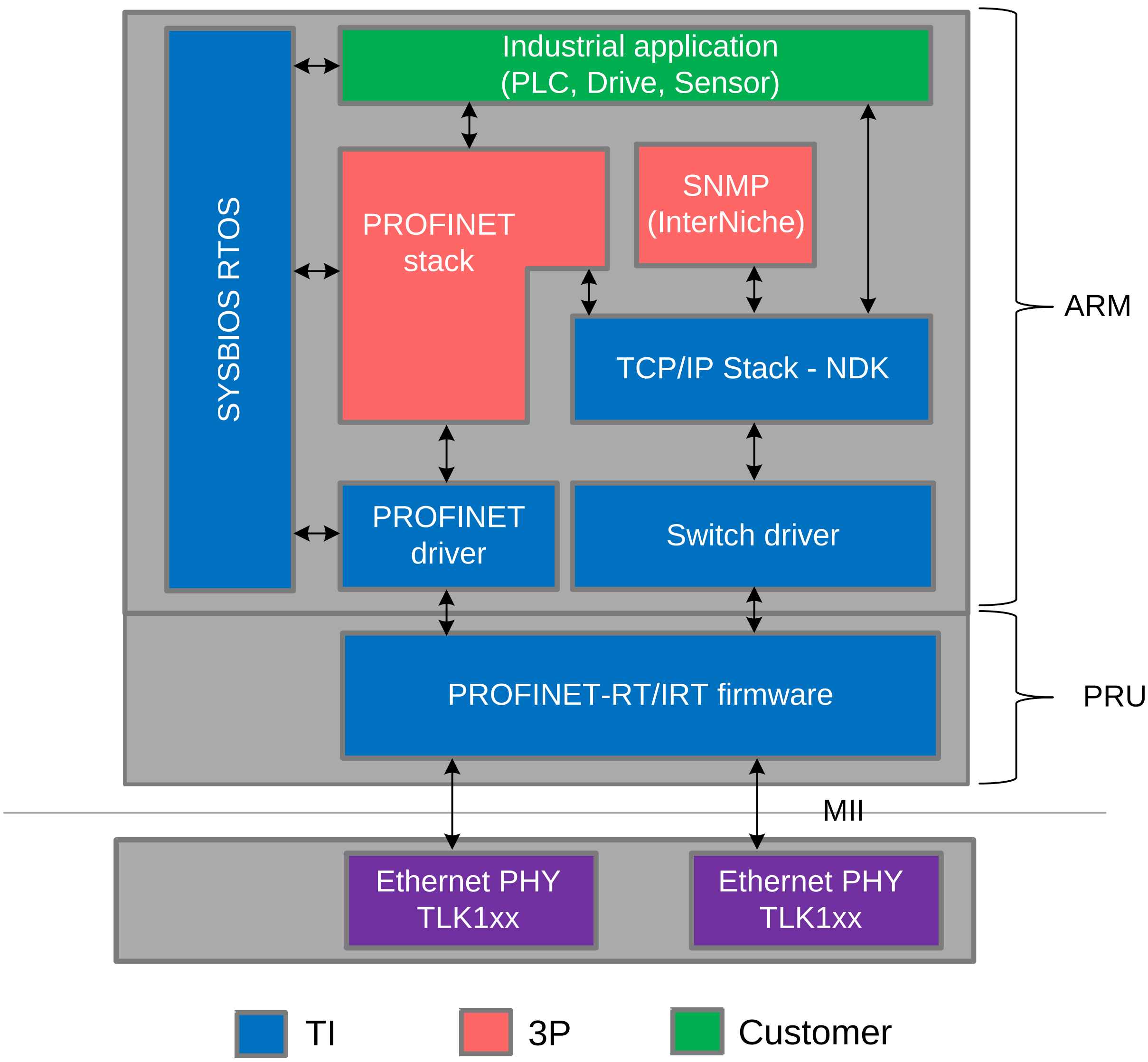

Figure 5. PROFINET IRT System Block Diagram

5 Industrial SDK With PROFINET IRT Device

The complete software package for the PROFINET IRT device solution comes with the Industrial Software Development Kit (ISDK) available on TI's webpage at http://www.ti.com/tool/sysbiossdk-ind-sitara. PROFINET IRT v2.3 device protocol is supported from version 02.01.00.01 and later. Earlier SDK variants support PROFINET RT v2.2, which is replaced by the newer IRT release.

After installing the ISDK on a PC, the following file structure is available:

\ti\sysbios_ind_sdk_2.1.0.1\sdk\	entry point
\ti\sysbios_ind_sdk_2.1.0.1\sdk\board	board support (Ethernet PHY, LEDs, flash, LCD, and so on)
\ti\sysbios_ind_sdk_2.1.0.1\sdk\docs	Industrial SDK (release notes, user guide, getting started)
..\sdk\examples\profinet_salve	code composer project
..\sdk\examples\profinet_salve\GSD	device configuration file in XML format
..\sdk\examples\profinet_salve\snmp	SNMP interface and stack
..\sdk\os_drivers\	OS drivers for ICSS and other peripherals
..\sdk\os_drivers\docs	OS driver API guide
..\sdk\protocols\profinet_slave\Docs	PROFINET API guide, how to connect to PLC guide
..\sdk\protocols\profinet_salve\drivers	PROFINET APIs
..\sdk\protocols\profinet_slave\fimrware	PROFINET interface and firmware objects
..\sdk\protocols\profinet_slave\stack_lib	Molex PROFINET stack library

This example is a PROFINET I/O RT/IRT device (slave) application based on Molex PROFINET stack. It also incorporates Simple Network Management Protocol (SNMP) using InterNiche SNMP stack. SNMP is required for managing devices in the network. This application supports SNMP MIB-2 (system and interfaces), LLDP-MIB, LLDP-EXT3-MIB, and LLDP-PNO-MIB, which are mandated for Conformance Class B. The SNMP stack available in the example is a limited version and shuts down after 1024 SNMP requests.

When activated, the I/O Device is assigned an IP address of 0.0.0.0. The PROFINET controller must configure the desired IP address and device name to the I/O device before an I/O connection can be established with the device. Once the application is up, the PROFINET I/O RT/IRT device will start communicating with a PROFINET PLC, or a PROFINET IO Tester or SPIRTA. The GSD file configures the I/O device in the master side is provided along with the application in GSD folder.

On the ICEv2 board, the LED blinks orange when the application is running. A simple sample I/O application demonstrates how to implement PROFINET. All the 1440 bytes of output data are exposed to the application. Sample I/O application simply uses the first byte of output data and maps it to the digital output LEDs on the board. It also implements a mechanism to read the digital inputs, which the sample application interprets as:

- Setting Jumper on Digital Input 0 generates an alarm. This is an external way to manually generate the alarms from the I/O device.
- Setting Jumper on Digital Input 1 generates a bit shift pattern input.
- Setting Jumper on Digital Input 2 generates a fixed test data input.

The user can write a simple PLC program where the input data of I/O device is transmitted back by PLC as output data. For example, a jumper can be inserted in Digital Input 1 on the I/O device to generate a bit shift pattern, which is then transmitted back by PLC to demonstrate the moving LED light on the digital output LEDs. Details on setting up a PROFINET connection with a PLC is included in sdk/protocols/profinet_slave/docs.

6 Test Data

PROFINET device capabilities are described in the General Station Description (GSD) file, which is provided to PROFINET engineering parameters for system tests and PROFINET test suites during certification tests. The GSD Markup Language (GSDML) provides a number of options to describe the device capabilities. For conformance class C (IRT), there is a separate section with RT_Class3 properties listed in Table 1.

Table 1. Extract of PROFINET IRT Relevant GSD Parameters

TOKEN	PARAMETER	COMMENT
StartupMode	"Advanced", "Legacy"	Can be both
ForwardingMode	"Absolute", "Relative"	Relative on new newer devices
MaxBridgeDelay	Time delay inside the bridge (ns)	
MaxNumberIR_FrameData	The maximum number of RT Class 3 frames, which may be forwarded by this interface	
MaxRangeIR_FrameID	Contains the maximum width of RTC3 FrameIDs (2 to 3840)	Default 1024
MaxRedPeriodLength	500 to 4000 µs	Default 3840 µs
MinFSO	1760 to 5000 ns	Default 5000 ns
MinRTC3_Gap	1120 to 2000 ns	Default 1120 ns
MinYellowTime	6720 to 125000 ns	Default 125000 ns if no HPP
YellowSafetyMargin	0 to 1640 ns	Default 160 ns
MaxFrameStartTime	The minimum FrameSendOffset for green 1600 to 5000 ns	Default 1600 ns

An extract of GSD file used for certification is shown below. It includes relevant timing parameters of the PROFINET IRT switch including the TLK110 PHY delay values listed as MaxPortRxDelay and MaxPortTxDelay.

```
...
SupportedRT_Classes="RT_CLASS_1;RT_CLASS_3"
PTP_BoundarySupported="true"
DCP_BoundarySupported="true"
<RT_Class3Properties
MaxBridgeDelay="2920"
MaxNumberIR_FrameData="1024"
StartupMode="Advanced"
ForwardingMode="Relative"
MaxRedPeriodLength="4000"
MinFSO="4000"
MaxRangeIR_FrameID="1024"/>
<SynchronisationMode
T_PLL_MAX="1000"
SupportedRole="SyncSlave"
SupportedSyncProtocols="PTCP"
MaxLocalJitter="250" />
<ApplicationRelations
NumberOfAR="1"
StartupMode="Advanced">
<TimingProperties
SendClock="8 16 32 64 128"
ReductionRatio="1 2 4 8 16 32 64 128 256 512" />
<RT_Class3TimingProperties
SendClock="8 16 32 64 128"
ReductionRatioPow2="1 2 4 8 16"
ReductionRatioNonPow2="1"/>
<PortSubmoduleItem
ID="IDS_1P1"
SubslotNumber="32769"
MAUTypes="16"
MaxPortRxDelay="184"
MaxPortTxDelay="86"
```

There are four different test categories for the PROFINET IRT device. Before the tests are configured, the GSD file is verified with a GSD checker tool, which does a compliance check. The first and most relevant test to PROFINET IRT is the SPIRTA test. SPIRTA is software to test PROFINET IO devices using RT_Class_3 communication. There is a specific PC hardware setup with the CP1616 network card, which emulates an IRT controller and more complex PROFINET networks. The card measures network timing parameters that are used as a pass/fail criteria of the test. In total, there are 55 tests the device must pass. The AM335x-based solution passes all SPIRTA tests listed in Table 2.

Table 2. SPIRTA Tests and Results

TEST ID	TEST NAME	TEST STATUS
SPIRTA_01	PROFINET_version	PASS
SPIRTA_02	Delay01__Delay01_NoAR	PASS
SPIRTA_03	Delay01__Delay01_NoFU	PASS
SPIRTA_04	Delay01__Delay01_WFU	PASS
SPIRTA_05	Delay02	PASS
SPIRTA_06	Delay03__Delay03_NoAR	PASS
SPIRTA_07	Delay03__Delay03_NoFU	PASS
SPIRTA_08	Delay03__Delay03_WFU	PASS
SPIRTA_09	Syncslave01__Syncslave01_NoAR	PASS
SPIRTA_10	Syncslave01__Syncslave01_NoFU	PASS
SPIRTA_11	Syncslave01__Syncslave01_WFU	PASS
SPIRTA_12	Syncslave02__Syncslave02_NoFU	PASS
SPIRTA_13	Syncslave02__Syncslave02_WFU	PASS
SPIRTA_14	Syncslave03__Syncslave03_NoFU	PASS
SPIRTA_15	Syncslave03__Syncslave03_WFU	PASS
SPIRTA_16	Syncslave03__Syncslave03_NoAR	PASS
SPIRTA_17	Syncslave04__Syncslave04_NoFU	PASS
SPIRTA_18	Syncslave04__Syncslave04_WFU	PASS
SPIRTA_19	Syncslave05	PASS
SPIRTA_20	Syncslave06__Syncslave06_NoFU	PASS
SPIRTA_21	Syncslave06__Syncslave06_WFU	PASS
SPIRTA_22	CMDEV	PASS
SPIRTA_23	CMDEV_Legacy	PASS
SPIRTA_24	CPM	PASS
SPIRTA_25	PPM	PASS
SPIRTA_26	MUXDEMUXScheduler01__MUXDEMUXScheduler01_NoFU	PASS
SPIRTA_27	MUXDEMUXScheduler01__MUXDEMUXScheduler01_WFU	PASS
SPIRTA_28	MUXDEMUXScheduler02__MUXDEMUXScheduler02_NoFU	PASS
SPIRTA_29	MUXDEMUXScheduler02__MUXDEMUXScheduler02_WFU	PASS
SPIRTA_30	MUXDEMUXScheduler03__MUXDEMUXScheduler03_NoFU	PASS
SPIRTA_31	MUXDEMUXScheduler03__MUXDEMUXScheduler03_WFU	PASS
SPIRTA_32	RTC3PSM	PASS
SPIRTA_33	RedRelay01	PASS
SPIRTA_34	RedRelay02	PASS
SPIRTA_35	RedRelay03	PASS
SPIRTA_36	RedRelay04	PASS
SPIRTA_37	MRPD__MRPD01	PASS
SPIRTA_38	MRPD__MRPD02	PASS
SPIRTA_39	MRPD__MRPD03_PerformanceClient	PASS
SPIRTA_40	MRPD__MRPD03_PerformanceManager	PASS
SPIRTA_41	MRPD__MRPD04	PASS

Table 2. SPIRTA Tests and Results (continued)

TEST ID	TEST NAME	TEST STATUS
SPIRTA_42	MRPD__MRPD05	PASS
SPIRTA_43	COD_RPC	PASS
SPIRTA_44	COD_LLDP	PASS
SPIRTA_45	COD_CYCLIC	PASS
SPIRTA_46	COD_PTCP	PASS
SPIRTA_47	DHT	PASS
SPIRTA_48	PTCPTimeoutFactor	PASS
SPIRTA_49	NRTStorageCapacity	PASS
SPIRTA_50	NRTFramePrioritization	PASS
SPIRTA_51	PermanentData	PASS
SPIRTA_52	ReductionRatio	PASS
SPIRTA_53	PerformanceIndicatorCheck01	PASS
SPIRTA_54	PerformanceIndicatorCheck02	PASS
SPIRTA_55	PerformanceIndicatorCheck03	PASS

The second test suite verifies the robustness of the PROFINET IRT switch when measured with different load scenarios and device behavior under load. The NETLOAD test setup consists of a PC that generates interfering packets into a PROFINET connection through an industrial Ethernet switch, a PLC CPU, the device under test, and a PROFINET remote IO that is connected to the DUT. There are two different load scenarios for RTC1 and two different load scenarios for RTC3. Under these load conditions, the device under test is verified to perform a proper communication function and a proper application function. For the "normal" operation, both functions must work without error. For the "faulty case", the PROFINET communication may drop but must recover. The local device application always must continue to operate. Two traffic types are applied as network load with unicast, multicast, and broadcast address. Blind network traffic takes a certain percentage of network bandwidth, which makes it more difficult for the PROFINET device to work. Directed traffic of NRT and RT packets are implemented using the PROFINET EtherType. During a directed traffic load, the PROFINET device must filter certain fields in the packet to decide whether to process this packet in the PROFINET stack and application. Table 3 summarizes the results of 792 NETLOAD tests using the AM3359ICE board with PROFINET IRT firmware.

Table 3. NETLOAD Test Summary

TOOL OR SOFTWARE	VERSION
CCS version	6.1.0.00104
SYSBIOS version	6_41_04_54
NDK version	2_24_02_31
XDC Tools version	3_31_02_38_core
Compiler version	GNU v4.8.4 (Linaro)
Platform	AM335X ICE v2.1, AM437X IDK
Branch	int_isdk_02_01_00_01
Build ID	132126f0f5e2b964824c39b18fe87d7bc4bdbbe5 (29-Jul-2015)
Application	PROFINET IRT Slave Release Mode SD card binary
Date of testing	29-07-2015

Table 4. Total (Normal/Limited/Faulty)

TEST CATEGORY	PASS	FAIL	INC	NRY	NA
IRT CLASS 1	198	0	0	0	0
IRT CLASS 3	198	0	0	0	0
IRT CLASS 1	198	0	0	0	0
IRT CLASS 3	198	0	0	0	0
Grand Total	**792**	**0**	**0**	**0**	**0**

The PROFINET IO Tester is the third test suite required for certification. There are 105 PROFINET IO tests that primarily focus on the protocol compliance. Most of this functional test resides in the partner stack from Molex and are passed using the included GSD file in the Industrial SDK.

The three test suites do not use a larger setup with multiple devices. For the PROFINET IRT to work in a larger setup, many IRT devices are connected in a system level test. Figure 6 shows the time synchronization jitter between the first and last device in a setup with 10 devices tested over 24 hours. The jitter is in the range of ±50 ns.

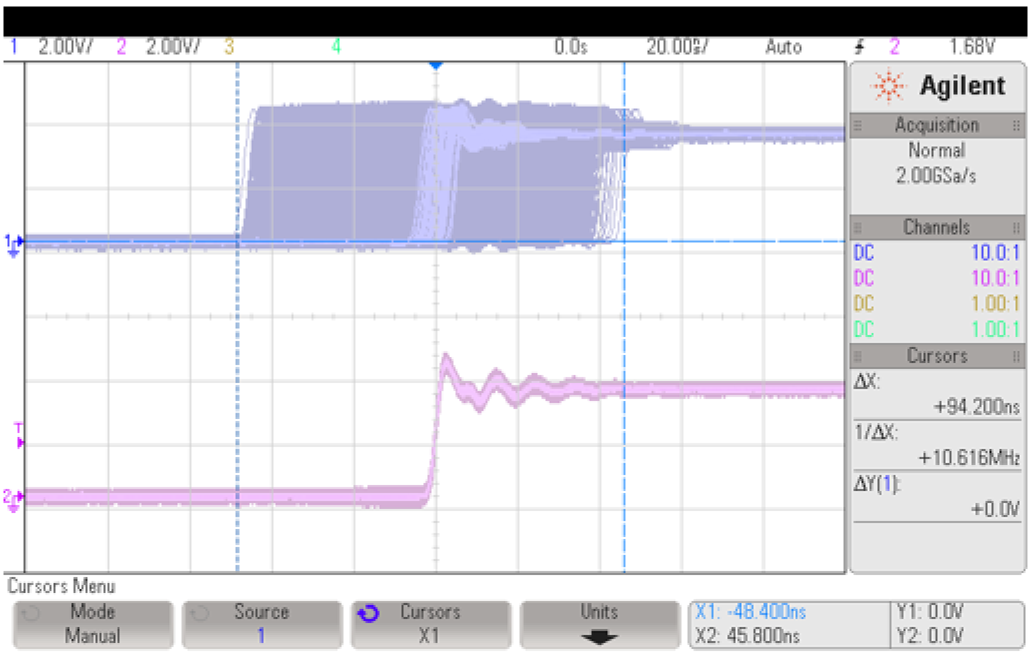

Figure 6. Time Synchronization Jitter in PROFINET IRT Domain

Figure 7 shows the PROFINET IRT Device Certificate for the AM3359ICE board using PROFINET IRT firmware, Molex PROFINET IRT stack, and TLK110 Industrial Ethernet PHYs. This shows the highest conformance class and NETLOAD class of the solution.

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Certificate

PROFIBUS Nutzerorganisation e.V. grants to

Texas Instruments Deutschland GmbH
Haggertystr. 1, 85356 Freising, Germany

the Certificate No: **Z10659** for the PROFINET IO Device:

Model Name:	**AM3359 Profinet Evaluation Kit**
Revision:	**SW/FW: T 1.0.2; HW: 1**
Identnumber:	**0x0127; 0x0310**
GSD:	**GSDML-V2.31-MOLEX_TI-AM335xProfinet_SDK-20150609.xml**
DAP:	**DIM 1: Molex-TI sample device, 0x1010 0000**

This certificate confirms that the product has successfully passed the certification tests with the following scope:

☑ PNIO_Version	V2.32
☑ Conformance Class	C Optional Features: IRT
☑ Netload Class	III
☑ PNIO_Tester_Version	V2.3.5
☑ Tester	SIEMENS AG, Fürth, Germany PN346-1, IRT086-1

This certificate is granted according to the document:
"Framework for testing and certification of PROFIBUS and PROFINET products".
For all products that are placed in circulation by June 19, 2018 the certificate is valid for life.

(Official in Charge)

Board of PROFIBUS Nutzerorganisation e. V.

(Karsten Schneider)

PROFI NET®

(K.-P. Lindner)

Figure 7. PROFINET IRT v2.32 Device Certificate

7 Design Files

7.1 Schematics

To download the schematics, see the design files at TIDEP0029.

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDEP0029.

7.3 Layer Plots

To download the layer plots, see the design files at TIDEP0029.

7.4 Altium Project

To download the Altium project files, see the design files at TIDEP0029.

7.5 Gerber Files

To download the Gerber files, see the design files at TIDEP0029.

7.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDEP0029.

7.7 Software Files

To download the software files, see the design files at TIDEP0029.

8 References

1. PROFIBUS, *PROFINET Technology and Application — System Description* (link)
2. PROFIBUS, *PROFINET v2.3 ED.2 — Profile Specification*
3. PROFIBUS, *PROFINET v2.3 ED.2 — Protocol Specification*
4. PROFIBUS, *PROFINET v2.3 ED.2 — Service Specification*
5. PROFIBUS, *GSDML Specification for PROFINET IO v2.31* (link)
6. PROFIBUS, *PROFINET IO Security Level 1 (Netload) v1.2* (link)
7. PROFIBUS, *Test Specification for PROFINET v2.32* (link)
8. PROFIBUS, *PROFINET IRT Engineering v1.32* (link)

9 Terminology

CPM— Consumer Protocol Machine

DCP— Discovery Configuration Protocol

FDB— Filter Database

ICSS— Industrial Communication Subsystem

IRT— Isochronous Real-time

ISDK— Industrial Software Development Kit

MAC— Media Access Control

MRP— Media Redundancy Protocol

PRU— Programmable Real-time Unit

PPM— Provider Protocol Machine

PRU— Programmable Real-time Unit

QoS— Quality of Service

RTA— Real-time Alarm

RTC1— Real-time Class 1

RTC3— Real-time Class 3

UUID— Universally Unique Identifier

10 About the Author

THOMAS LEYRER is a Systems Architect at Texas Instruments who is responsible for Industrial Communication solutions.

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS