TSN Ethernet and Intelligent Applications for Industry 4.0

Hitoshi Mizunuma & Moder Tseng
Toshiba Electronics Components Taiwan Corporation
Today’s Agenda

01  Background
02  Toshiba’s solution for IIoT
03  Industrial Ethernet
04  Vision sensing
05  Robot hand
06  Wireless connectivity
01

Background

1. IIoT network infrastructure
2. Field bus vs. Industrial Ethernet
3. Why AVB/TSN?
IoT network infrastructure

**Things**
- Wearable
- Smart Home
- Smart shop
- Smart logistics

**Local Network**
- Fog
- Gateway

**The Internet**
- Cloud
- Remote Server
- User access and control
- Business data Analysis

**Back-end service**
IIoT network infrastructure

IIoT uses field bus to satisfy real-time constraints

Industry environment

The Internet

Back-end service

Wireless

Legacy field bus

ICT network

IT network

OT network

Real-time processing

Sensing and manipulation (sec. ~ msec.)

Production Management (Non time-critical)

Remote Server

User access and control

Business data Analysis

IPC

Smartphone Log monitor

Gateway

Cloud

IPCs

PLC from company A

PLC from company B

IPC

IPC

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Q: Where should smart algorithm be installed?

Legacy Factory:
- IPC
- Gateway
- Cloud
- PLC
- Thermometer

Smart Factory:
- IPC
- Gateway
- A.I. on cloud
- Big data
- Prediction model
- PLC
- Motion sensor
- Strain sensor
- Pressure sensor

IIoT network infrastructure

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IIoT network infrastructure

Answer: Locate a new device between IT and OT networks

- Good, because no need to change existing IT/OT network.
- However, field bus bandwidth down to PLC could be a concern in near future.

Today

IT network

- Smartphone Log monitor
- Gateway
- Production Management (Non time-critical)

OT network

- Workflow/recipe control (min. ~ subsec.)
- Sensing and manipulation (sec. ~ msec.)
- PLC

Answer: Locate a new device between IT and OT networks
IIoT network infrastructure

Field bus cable is replaced with Ethernet cable to increase OT network bandwidth -> Industrial Ethernet

Tomorrow

Wireless
Industrial Ethernet
Legacy field bus

Better, because Ethernet interface is widely used and cabling cost is cheap.

However, incompatibility of time sensitiveness over different OT network still exists.

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Field bus and Industrial Ethernet in 2017

Industrial Ethernet: 46% (38)
Annual growth: 22% (20)

- EtherNet/IP: 11%
- PROFINET: 11%
- EtherCAT: 7%
- Modbus-TCP: 4%
- POWERLINK: 4%
- Other Ethernet: 9%

Fieldbus: 48% (58)
Annual growth: 4% (7)

- PROFIBUS DP: 14%
- CAN/CANopen: 5%
- CC-Link: 6%
- Modbus-RTU: 6%
- DeviceNet: 4%

Wireless: 6% (4)
Annual growth: 32% (30)

- Bluetooth: 1%
- WLAN: 4%
- Other Wireless: 1%

Variety of Industrial Ethernet Protocols

Promoter
- Rockwell Automation
- Siemens
- Phoenix Contact
- Mitsubishi
- Beckhoff
- Rexroth Bosch Group
- Schneider Electric (MODICON)

Field bus Technology
- DeviceNet
- PROFINET
- INTERBUS
- CC-Link
- CANopen
- SERCOS I, II
- Modbus

Industrial Ethernet Technology
- EtherCAT
- CC-Link IE
- Ethernet POWERLINK
- SERCOS III
- Modbus-IDA

Sensor bus Technology
- IO-Link
- AVB/TSN

Timeline:
- 1990
- 2000
- 2010
- 2020
IIoT network infrastructure

Ethernet TSN is best, because it resolves network interoperability

- Key concept is to use OSI 2\(^{nd}\) layer to support & guarantee time sensitiveness.
- If your protocol is aware of TSN, you can avoid vendor lock-in and minimize network cost by reusing Ethernet asset.

**The day after tomorrow**

**IT network**
- Smartphone
- Log monitor
- Gateway
- Production Management (Non time-critical)

**OT network**
- PLC
- Workflow/recipe control (min. ~ subsec.)
- Sensing and manipulation (sec. ~ msec.)

**Industrial Ethernet**

<table>
<thead>
<tr>
<th>Industrial Ethernet protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>MAC</td>
</tr>
<tr>
<td>PHY</td>
</tr>
</tbody>
</table>

**Ethernet protocols**

<table>
<thead>
<tr>
<th>Ethernet protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
</tr>
<tr>
<td>TCP</td>
</tr>
<tr>
<td>IP header</td>
</tr>
<tr>
<td>IP encapsulate</td>
</tr>
<tr>
<td>IEEE 802.1 Time Sync</td>
</tr>
<tr>
<td>IEEE 802.3 MACs</td>
</tr>
<tr>
<td>IEEE 802.3 PHYs</td>
</tr>
</tbody>
</table>

**TSN standard by AVNU**
Analogy with automotive

The same story already happens in automotive network at EU.

Before

Drive/powertrain (sec. ~ msec.)

Telematics/ADAS (min. ~ subsec.)

In-car wireless (Non time-critical)

CAN controller

Gateway/Modem

Camera

Monitor

Host

Wearable

tablet

Key fob

Today

Drive/powertrain (sec. ~ msec.)

Telematics/ADAS (min. ~ subsec.)

In-car wireless (Non time-critical)

CAN controller

Gateway/Modem

Camera

Monitor

Speakers

Host

Wearable

tablet

Key fob

Wireless

Ethernet AVB

Legacy (CAN/Analog)

Soft real-time

Hard real-time

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02

Toshiba solutions for IIoT

1. Ethernet AVB/TSN bridging
2. Vision sensing and robot hand
3. Wireless (BLE + SubGHz)
Toshiba solution for IIoT [1]

Ethernet AVB bridge IC “Neutrino” phases into MP for automotive

(* Neutrino is a pet name of TC9560XBG)

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Toshiba solution for IIoT [2]

Neutrino-2 is designed to target TSN bridge for IIoT application

(*) Neutrino-2 is under development
Toshiba solution for IIoT [3]

Robot-hand and vision-sensing

Industry IoT network

Production Management
(Non time-critical)

Workflow/recipe control
(min. ~ subsec.)

Sensing and manipulation
(sec. ~ msec.)

IPC
Smartphone
Log monitor
Gateway

IT network

OT network

AD converter
Main MCU (TMPM369)
Motor controller (TMPM375)
Vector Engine
Pre-driver
MOSFET
Opt. encoder+
line receiver
Magnet encoder
Shunt resistor
BLDC motor

Bend sensor

Image recognition (Visconti)
CoHOG
SfM
Parallel RGB

Dynamic Range Enhancer (TZA300)

Zoom
Focus
ISP

MCU+MCD (TMPM343)

(*) PTZ: Pan/Tilt/Zoom
(*) OIS: Optical Image Stabilizer

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Toshiba solution for IIoT [4]

BLE and Sub-GHz

Industry IoT network

Wireless
Industrial Ethernet
Legacy (CAN/Analog)

Bluetooth LE (TC35678)
UART
LCD screen
TZ2102

Smartphone Log monitor
Gateway

Sub-GHz (TC32306)
GPIO
LCD screen
TZ2102

IPC

Production Management
(Non time-critical)

Workflow/recipe control
(min. ~ subsec.)

IT network

OT network

PLC

Sensing and manipulation
(sec. ~ msec.)

IPC

Smartphone Log monitor
Gateway

Sub-GHz (TC32306)
GPIO
LCD screen
TZ2102

IPC

Production Management
(Non time-critical)

Workflow/recipe control
(min. ~ subsec.)

IT network

OT network

PLC

Sensing and manipulation
(sec. ~ msec.)

IPC

Production Management
(Non time-critical)

Workflow/recipe control
(min. ~ subsec.)

IT network

OT network

PLC
03

Industrial Ethernet (AVB+TSN)

01  Background
02  Toshiba IIoT solution
03  Industrial Ethernet
04  Vision Sensing
05  Robot hand
06  Wireless connectivity
1st GEN Ethernet AVB bridge IC: Neutrino

Neutrino family product line

<table>
<thead>
<tr>
<th></th>
<th>PCIe</th>
<th>HSIC</th>
<th>CAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC9560XBG</td>
<td>○</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>TC9560AXBG</td>
<td>○</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>TC9560BXBG</td>
<td>×</td>
<td>○</td>
<td>×</td>
</tr>
</tbody>
</table>

- **CPU ARM-M3**
- **AECQ-100 Grade 3**
- **Interfaces**
  - PCIe (EP) one lane (Gen 2) [TC9560XBG, TC9560AXBG]
  - USB HSIC (480 Mbps) [TC9560BXBG]
    - Device only
  - Ethernet (AVB support)
    - RGMII, RMII, MII interface
    - IEEE 802.1AS,IEEE 802.1Qav support
    - Supports 2 x AV traffic queues and 1 best effort queue
    - DMA
  - I2S/TDM master
  - CAN-FD option [TC9560AXBG]
    - 2 channels

(*) Neutrino is a pet name of TC9560XBG
Partnership with Qualcomm

- Environment: 2x Qualcomm S820A Platform with Neutrino
- Synchronized video stream from talker to listener
- Android OS environment
04 Vision-sensing

01 Background
02 Toshiba IIoT solution
03 Industrial Ethernet
04 Vision Sensing
05 Robot hand
06 Wireless connectivity
Visconti™ image recognition HW accelerator

Our image recognition IC is called Visconti, which embeds a series of hardware accelerator for image recognition algorithm.

### New features at Visconti4 series

<table>
<thead>
<tr>
<th>Pyramid accelerator (x2)</th>
<th>Color CoHOG Accelerator (x2)</th>
<th>SfM Accelerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Create pyramid images (1-In to 4-Out)</td>
<td>- Enhanced CoHOG Accelerator (Color info. Etc.) + Linear support vector machine</td>
<td>- 3D Reconstruction • Self Motion Estimation</td>
</tr>
</tbody>
</table>

![Diagram](image1)

### Enhanced features from previous series

<table>
<thead>
<tr>
<th>Affine Transformation Accelerator (+2 Total:3)</th>
<th>Matching Accelerator (+1 Total:2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 3ch (RBG)</td>
<td>- 2ch • High speed sub-pixel Estimation</td>
</tr>
</tbody>
</table>

![Diagram](image2)
Image recognition accelerators by Toshiba

Color CoHOG detects pedestrians even at night-time

SfM reconstructs 3D shape of an object using mono-camera
05

Robot hand (MCU+MCD)

01 Background
02 Toshiba IIoT solution
03 Industrial Ethernet
04 Vision Sensing
05 Robot hand
06 Wireless connectivity
Robot Hand  Function overview

- **Operation synchronized with the glove**
  Fitting the glove, and when you hold or open your hand, the robot hand also performs the same operation.

- **Automatic operation for exhibition**
  Automatically the robot hands open, hold and do like behavior of rock-paper-scissors for exhibition.
Robot Hand Demo Overview

Hand structure

- BLDC Motor X5
- U/V/W X5
- Motor MCU TMPM375FSD MG
- RS485
- Main MCU TMPM369FD FG
- Optical Encoder
- Magnetic Encoder
- 2TypeEncoder X5
- Motor Control X5
- Globe Bend sensor x 4 (Analog value)
- Analog input

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Robot Hand system block diagram 1

Main MCU TMPM369FDYG A/D conversion

RS485 LTC485

RS485 communication Line type bus structure

Motor MCU TMPM375FSDMG

Pre-Driver IR2101

MOSFET

BLDC Motor Thumb root

Motor MCU TMPM375FSDMG

Pre-Driver IR2101

MOSFET

BLDC Motor Thumb

Motor MCU TMPM375FSDMG

Pre-Driver IR2101

MOSFET

BLDC Motor Index finger

Motor MCU TMPM375FSDMG

Pre-Driver IR2101

MOSFET

BLDC Motor Middle finger

Motor MCU TMPM375FSDMG

Pre-Driver IR2101

MOSFET

BLDC Motor Ring finger & Little finger

Bend sensor (Analog value) 5ch
Robot Hand system block diagram 2

- **Main MCU**: TMPM369FDFG
- **Pre-Driver IR2101**
- **BLDC motor EC-MAX16 @12V,5W**
- **Optical encoder MR TYPEM512**
- **Magnetic encoder AERT-6600-T16**
- **Line receiver MC3486**
- **Motor MCU**: TMPM375FSDMG
- **Vector Engine**
- **RS485: LTC485**
- **RS485**
- **MOSFET**
- **Gear head GP16C**
- **Shunt resistor**
- **A/D conversion**
- **Bend sensor (analog value)**
- **Serial input (Absolute value)**

**Demo Video1**
**Demo Video2**
Robot Hand  Functions detail

- **Main control contents: TMPM375 motor drive board**
  - RS485 communication with the main board
  - RS485 command decoding
  - BLDC motor control using vector engine
  - 3-shunt method
  - Position control is maintained at any angle
  - Optical encoder input (A / B / Z signal processing)
  - Serial interface between the magnetic encoder

- **Main control contents: TMPM369 main board**
  - RS485 communication with the motor drive board
  - A/D conversion processing of analog signal from the bend sensor on the globe
  - Operation mode decision of hand robot (for normal / exhibition)
  - LED display of operating mode
Selection Map of MCD/MCU Motor Control Solution

- Vector Control : High Efficient, Quiet operation

Feature

Vector Control

- Air-conditioning Compressor
- Refrigerator Compressor
- Washer / Dryer
- Direct Drive

Non-Vector Control

- Air-conditioning Fan

Torque Variance

MCD

- MCD+IPD/FET

SiP

- Air-conditioning Compressor

MCU

- VE MCU+Pre Dr.

SiP

MCD+IPD/FET

Feature

Projector

Scanner

Motor

Robot

Printer

Vending Machine

MFP

■ Vector Control : High Efficient, Quiet operation
What’s Vector Engine?

Vector Engine (VE) is a dedicated co-processor for Field Oriented Control (FOC). VE automatically manipulates PWM and ADC to perform FOC. VE enhances adopting FOC in your system and realizes ecology system!

◆ Configuration of VE

➢ ADC result manipulation
➢ Phase conversion
➢ Coordinate transformation
➢ SIN/COS computation
➢ PI calculation
➢ Phase current calculation
➢ Trigger generation for ADC

Green & ECO!

Configuration of VE:

- ADC result manipulation
- Phase conversion
- Coordinate transformation
- SIN/COS computation
- PI calculation
- Phase current calculation
- Trigger generation for ADC
Motor Control MCU Roadmap

Motor control MCU for industry
Corresponds from Low end to High end

**VECTOR CONTROL**

**TX03/04R Series (Automotive)**
- Cortex®-M3@80MHz
  - TMPM370/2/3/4/6
- Cortex®-M3@40MHz
  - TMPM375FS
- Cortex®-M3@40 to 144MHz
  - TMPM358
  - TMPM351
- Cortex®-R4F@160MHz
  - TMPM07x
- Cortex®-R4F@240MHz
  - **TMPM37xFY**

**TX04 series**
- Cortex®-M3@80MHz
  - **TMPM37xFY**
- Cortex®-M3@40 to 144MHz
  - TMPM358
  - TMPM351
- Cortex®-M4F@120MHz
  - *TMPM475
  - *TMPM470
- Cortex®-M4F@200MHz
  - **TMPM47x**

**TX03 series**
- Cortex®-M0@40MHz
  - **TMPM470/2/3/4/6**
- Vector Engine Plus (VE+)
  - Superior performance
- Vector Engine Plus (VE+)
  - Advanced Encoder* (A-ENC)

**TX00 series**
- Cortex®-M0@40MHz
  - *TMPM07x
- Cortex®-M0@40MHz
  - **TMPM07x**

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Motor Driver IC Features

Substantial product line-up fit for various kind of needs.
- DC Brushed Motor Driver
- Stepping Motor Driver
- DC Brush-less Motor Driver

Substantial detection functions of abnormal state support for safety system design.
- Power On Reset (POR)
- Over Current Protection (ISD)
- Thermal Shut Down (TSD)

Low power consumption supports for ecological high-efficient product design.

Low power consumption is realized by reduction of circuit current, output saturation voltage and output DMOS on-resistance.
Motor Driver IC Technologies

High reliability based on latest original technology & over 30 years production

Over 30 Years Activity

◆ Long Business History since 1980
  * Rolled out with launching into consumer product market and expanded to OA, Industrial, HA product market.
  * TSB covers MCD for BLDC, brushed and stepping motors
  ➔ Around 1000 customers are using our MCD now!

Power technology

◆ BiCD0.13μm Process
  * DMOS process required for power devices
  ➔ Improve power efficiency by 0.13μm

◆ Power PKG Line-up
  * HSOP, HTSSOP, QFN, HZIP, etc

◆ Advanced error detection Circuit
  * High reliability ISD(Over current shut down), TSD (Thermal shut down) and POR(Power on reset).

Original System Technology

◆ Drive System
  ➔ Cooperation with TSB motor Lab
  * Sine-wave current control, vector control (For low noise motor drive)
  * Sensorless control (Reduce external components)

◆ Combination Technology
  * PMMCD (Power management MCD)
  * DC/DC converters
  * Multi motor drive channels

◆ MCD+MCU Solution
  ➔ The edge is MCU-included solution

◆ MCD+IPD Solution
  ➔ The edge is IPD-included solution

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Wireless connectivity (BLE+SubGHz)
TC32306FTG(Sub-GHz) + TC35678FSG(BLE) system

Our advantage is to re-use Cortex-M0 of BLE IC to control Sub-GHz IC, reducing two chipset footprint to contribute form factor minimization.

Vehicle side

- TC32306FTG
- Sub-GHz range ~600m

Gateway

- BLE range ~10m

Smartphone

- BLE:TC35678FSG
- 2.4GHz

IPC

- External MCU
- CPU Cortex-M0
- BLE control
- Control Block
- Control
- RF Block
- 920MHz

Vehicle side

- TC32306FTG
- Sub-GHz IC
- RED

Our advantage is to re-use Cortex-M0 of BLE IC to control Sub-GHz IC, reducing two chipset footprint to contribute form factor minimization.
### SubGHz spectrum and Toshiba target

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Purpose</th>
<th>Electrical field strength</th>
<th>SPEED (nominal)</th>
<th>Communication distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>~322</td>
<td>RKE, Garage opener, etc.</td>
<td>&gt;500uV/m at 3m distance</td>
<td>—</td>
<td>~50m</td>
</tr>
<tr>
<td>315</td>
<td>RKE, TPMS</td>
<td>25uW(EIRP), 250uW(EIRP)</td>
<td>75~19.2Kbps</td>
<td>700m~1km</td>
</tr>
<tr>
<td>400</td>
<td>Industrial monitoring application</td>
<td>1mW, 10mW</td>
<td>4800bps</td>
<td>100m~3km</td>
</tr>
<tr>
<td>1200</td>
<td></td>
<td>10mW</td>
<td>14.3kbps</td>
<td>300m~1.5km</td>
</tr>
<tr>
<td>920~928</td>
<td>Smart meter, HEMS, etc.</td>
<td>1mW, 10mW, 20mW</td>
<td>20~400kbps</td>
<td>~600m</td>
</tr>
<tr>
<td>920</td>
<td>Short range wireless system (PAN), Active Tag</td>
<td>250mW</td>
<td>20~400kbps</td>
<td>~1.8km</td>
</tr>
<tr>
<td>2400~2497</td>
<td>W-LAN, BT, ZigBee, etc.</td>
<td>3mW/1MHz, 10mW/1MHz</td>
<td>600Mbps</td>
<td>50-250m</td>
</tr>
</tbody>
</table>

**Communication range is extendable up to 1.8km at the expense of power consumption increase in 920MHz band.**
Industrial Grade BLE ver. 5.0 controller

Bluetooth® Core spec.
Ver. 5.0 compliant, 1M/2Mbps support

Ultra Low Power consumption
Peak current: 6.0mA@TX 0dBm, 1Mbps
11mA@TX +8dBm, 1Mbps
Sleep current < 1.2uA (Advertise)
Deep Sleep current <100nA

RF Performance
TX Output power: +8dBm MAX
RX Sensitivity: -94.5dBm

High Power Output x8

Interface
UART (Host I/F) 2chs (selectable for test purpose)
SPI 2ch, I²C 2ch
12bit ADC, PWM 4chs, Interrupt input

On-chip DC-DC converter (1.8-3.6V input)
On-chip SiOSC (32kHz)

64kB RAM User Area
128kB Flash User Area (TC35680)

Small package
QFN40 5x5mm, 0.4mm pitch(TC35680/681)
WCSP 0.35mm pitch(TC35681)

Operation Temperature Range
-40 to +125 degree C (TC35681)

ES: Dec. 2017, MP: 3Q. 2018

TC35681

Ultra Low Power consumption
Peak current: 6.0mA@TX 0dBm, 1Mbps
11mA@TX +8dBm, 1Mbps
Sleep current < 1.2uA (Advertise)
Deep Sleep current <100nA

RF Performance
TX Output power: +8dBm MAX
RX Sensitivity: -94.5dBm

High Power Output x8

Interface
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Small package
QFN40 5x5mm, 0.4mm pitch(TC35680/681)
WCSP 0.35mm pitch(TC35681)

Operation Temperature Range
-40 to +125 degree C (TC35681)

Wider Temp.
Our strategy is to support both consumer-grade and industrial-grade BLE products at the same time with the same priority. Toshiba is the sole IC supplier supporting temperature range up to 125°C.

<table>
<thead>
<tr>
<th></th>
<th>Toshiba BLE G3</th>
<th>Nordic nRF52840</th>
<th>TI CC2640R2F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receipt peak current</td>
<td>4.5mA</td>
<td>5.4mA</td>
<td>6.1mA</td>
</tr>
<tr>
<td>Transmission peak current</td>
<td>6.0mA @0dBm</td>
<td>6.4mA @0dBm</td>
<td>6.1mA @0dBm</td>
</tr>
<tr>
<td></td>
<td>+8dBm @ 11.0mA</td>
<td>+8dBm @ 13.6mA</td>
<td>+5dBm @ 9.1mA</td>
</tr>
<tr>
<td>Maximum output [dBm]</td>
<td>8</td>
<td>8</td>
<td>5 (Differential)</td>
</tr>
<tr>
<td>Rx Sensitivity [dBm]</td>
<td>-91.5 (2Mbps)</td>
<td>-92.0 (2Mbps, Ideal Tx)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-94.5 (1Mbps)</td>
<td>-96.0 (1Mbps, Ideal Tx)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-99.0 (500kbps)</td>
<td>-99.0 (500kbps)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-105.0 (125kbps)</td>
<td>-103.0 (125kbps)</td>
<td></td>
</tr>
<tr>
<td>Link budget</td>
<td>113dB</td>
<td>111dB</td>
<td>108dB</td>
</tr>
<tr>
<td>BT standard ver.</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Number of external component</td>
<td>7</td>
<td>20</td>
<td>27</td>
</tr>
<tr>
<td>Operational temperature</td>
<td>-40 to <strong>125°C</strong></td>
<td>-40 to 85°C</td>
<td>-40 to 85°C</td>
</tr>
</tbody>
</table>
This reference system supports SubGHz RFIC TC32306FTG and BLE IC TC35678FSG for testing a bridge functionality between BLE and Sub-GHz.

**DEMO Function:**
- GPIO/I2C control at 920MHz band from PC console.
- GPIO/I2C control at 920MHz band from android smartphone.