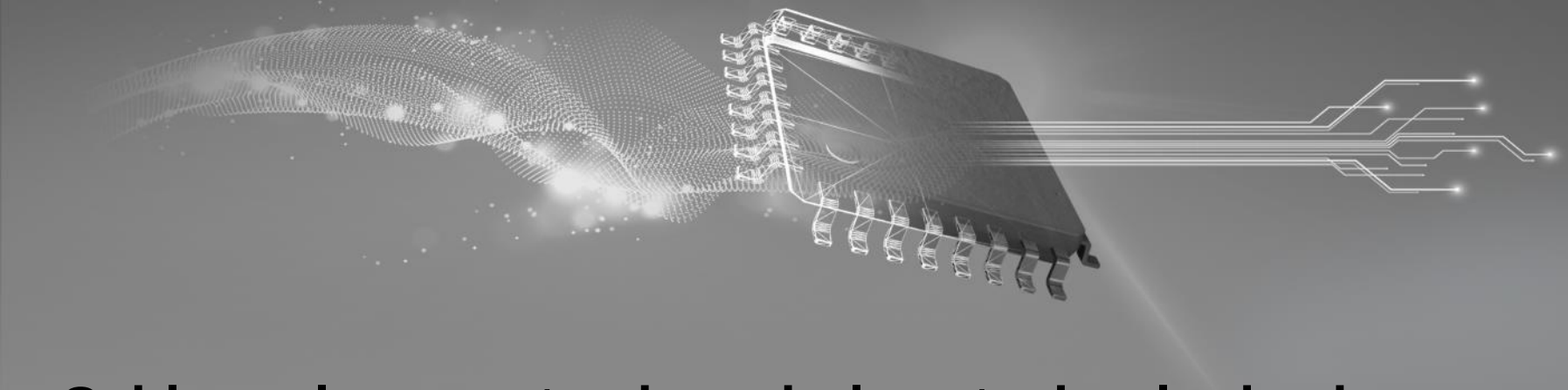
TI TECH DAYS



# Cable replacement using wireless technologies in automotive

David Lara

Donovan Porter

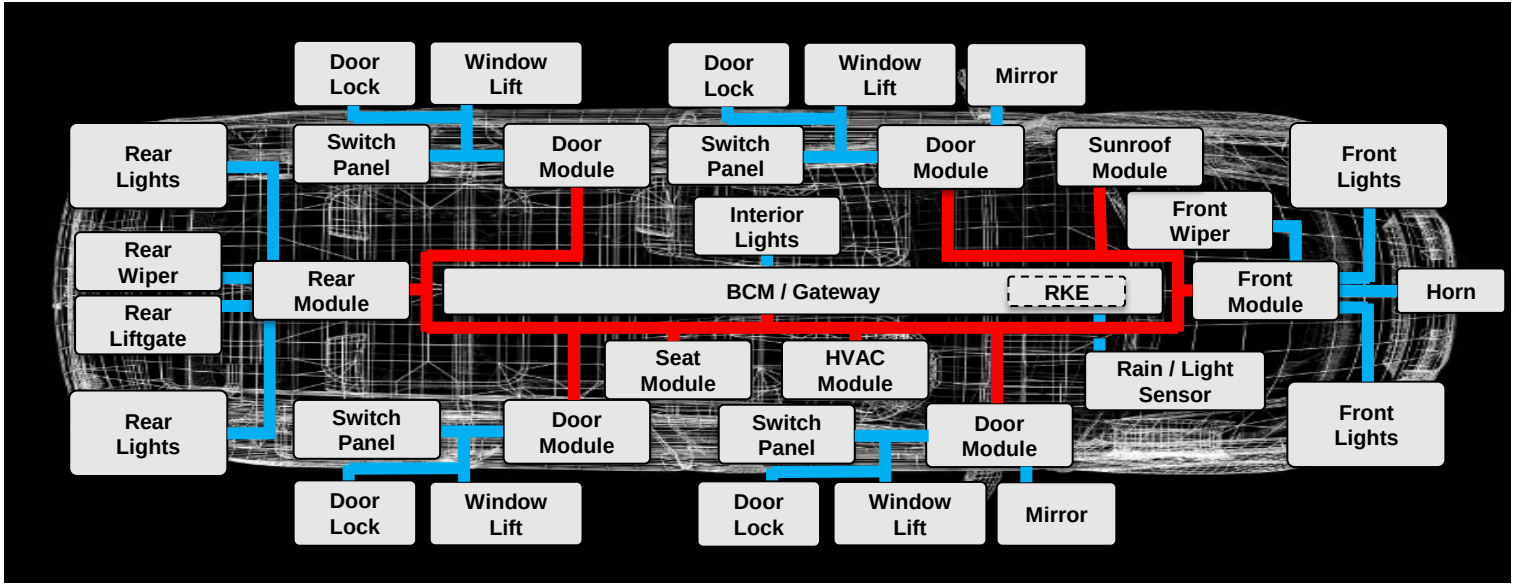
Texas Instruments

# Agenda

- Cable replacement introduction
- Cable replacement use cases
  - *Bluetooth*® Low Energy auto-addressing
    - What is wired auto-addressing?
      - Example of wired auto-addressing
    - Wireless auto-addressing
      - How does it work, implementation and results
  - Wireless Battery Management System
    - What is Wireless BMS (wBMS)?
      - How does it work, implementation and results
- Summary
- Q&A

# To wire or not to wire

- There are multiple wired networks inside of the vehicle
- Some of these networks serve specific needs and have different requirements
  - Priority, speed, security, reliability, etc…



# To wire or not to wire

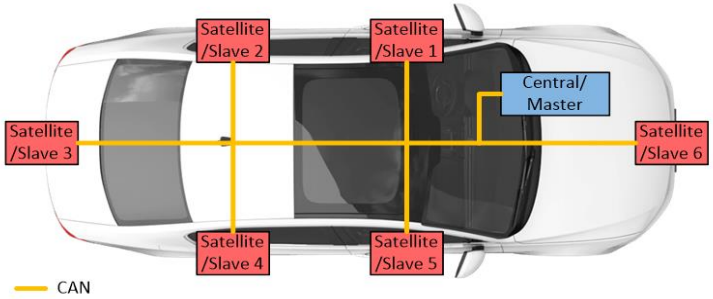
- What we can be sure, is that wiring increases overall vehicle weight
  - The cabling inside of car could go from 3 to 4 miles long
  - In most cases replacing or fixing is costly and time consuming

- Wired networks are tried and not going anywhere soon; but wireless are the next evolution
  - Wired protocols that this could potentially replace
    - LIN, UART, isoSPI, isolated CAN-bus

# Wireless *Bluetooth*® Low Energy auto-addressing

# Introduction

- Automobile manufacturers have been adding Bluetooth® *Low Energy* capability for numerous applications.
- Passive entry passive start (PEPS) is an example which employs a key fob that can send a signal to a smart key module to trigger the mechanism to unlock the automobile door.
- When used in conjunction with Bluetooth® *Low Energy*, the smart key module system includes a central module and several satellite modules distributed throughout the body of the car.
- A typical system might have between six and twelve satellite modules in addition to a central module.
- A master or central module communicates with the satellite or slave modules using a communication interface.

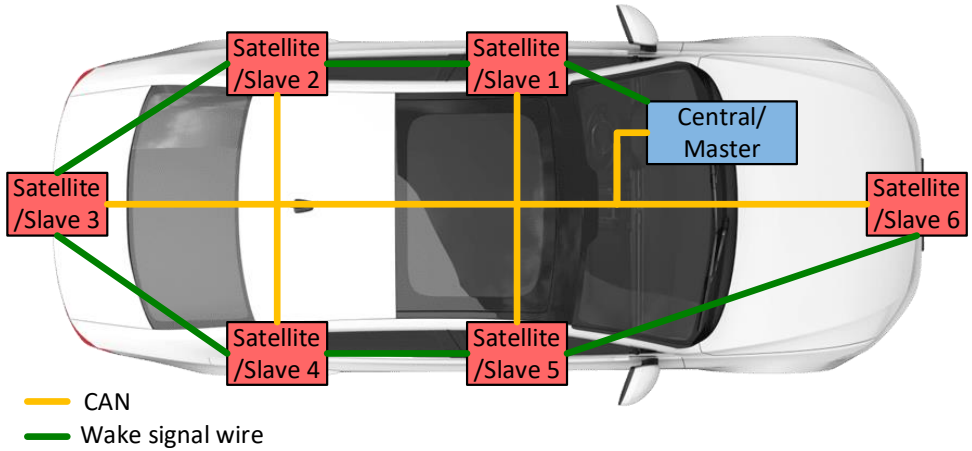


# Bluetooth® Low Energy auto-addressing in Car Access

- **Problem:**
  - Vehicle manufacturers require a way for Bluetooth satellite modules to automatically receive a CAN address from the central/master module to simplify assembly of satellite nodes in a car. The CAN address pertains to the modules location around the vehicle (driver door, bumper, etc.).
- **Current solution to the problem:**
  - A dedicated LIN or single wire communication daisy chain network is used to address satellite modules. This daisy chain interface is used only for addressing purposes.
- **BLE auto-addressing solution**
  - The wireless solution removes the need for a dedicated communication bus or any form of wired connection to auto-address the satellite modules. Instead, the modules location can be determined using Bluetooth localization methods and a CAN address can be provided by the central/master module

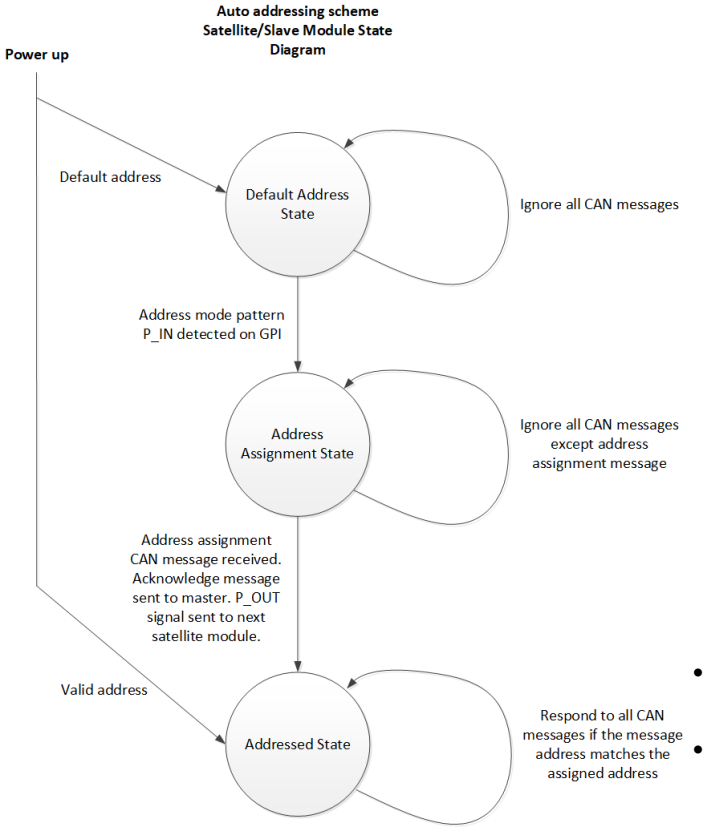
# Single wire auto-addressing

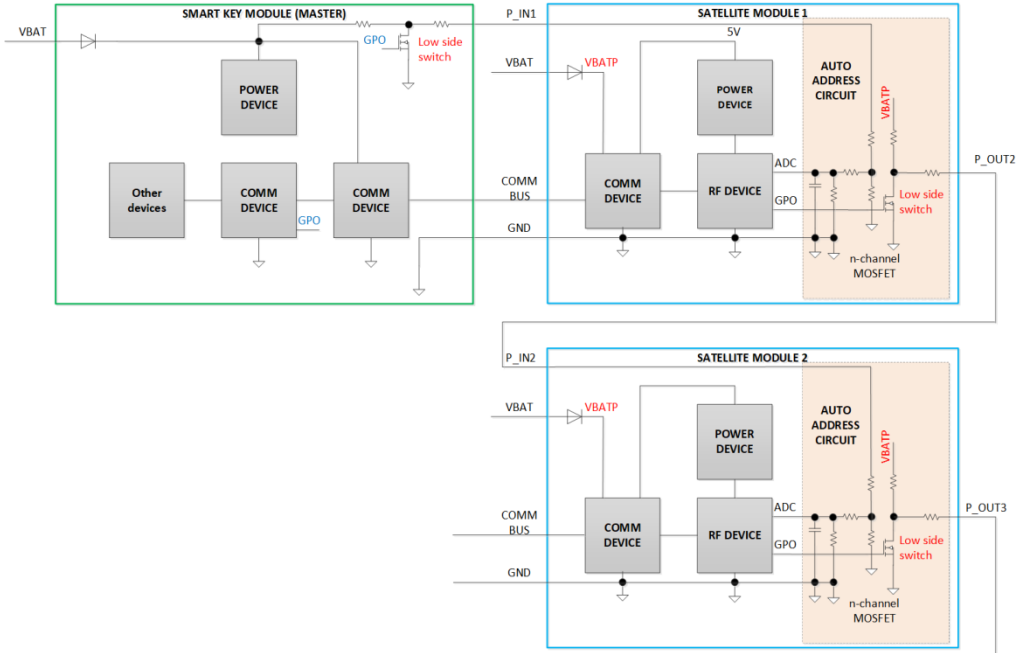
- The auto-addressing is a scheme developed by TI to provide CAN addresses to the slave nodes




- After auto-addressing has finished the slave  nodes will perform their normal functionality.

# Single wire auto-addressing, how does it work?




- Cost effective daisy chained 12V signal for auto-address “wake” to alert slaves when to listen to the CAN bus.
- Auto-addressing process for individually waking satellite modules so they can receive their address via CAN
  - Good for production as well as module replacement

# TIDA-020032 Bluetooth LE + CAN Satellite Module
# Automotive PEPS/Phone as a Key Bluetooth® Low Energy Satellite Module

## Features

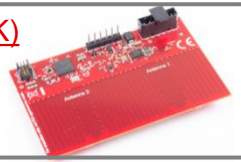
- Wide input voltage operating range (5.8V – 30V)
- TCAN4550-Q1 can disable entire system, requiring only 25uA (typ) in sleep state.
- CAN-FD communications
- Capable of calculating Bluetooth® Low Energy 5.1 Angle of Arrival for BLE localization
- Single-wire CAN auto-addressing

## Target Applications

1. Phone as a key (PaaK) Bluetooth Low Energy Satellite Modules
2. Passive Entry Passive Start (PEPS) BLE Satellite Modules

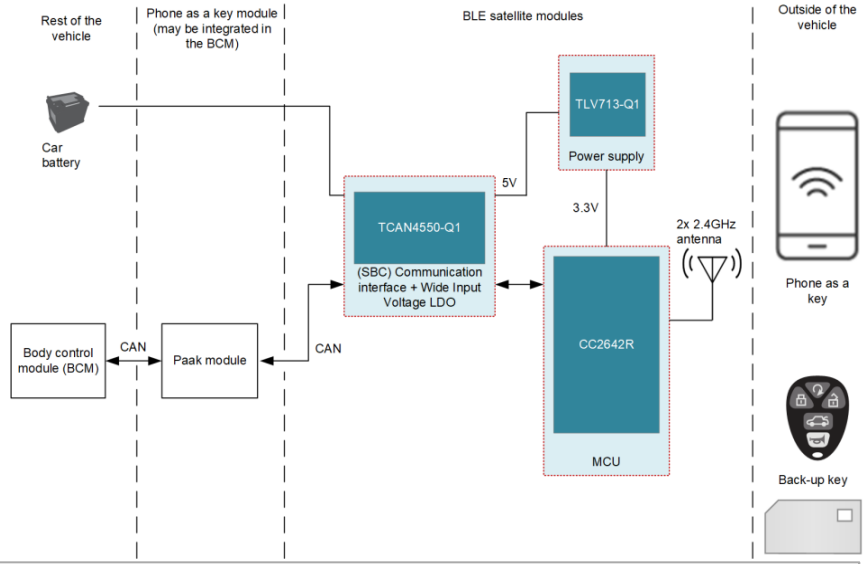
## Tools & Resources

- SimpleLink™ software development kit (SDK)
- CC2642R EVM
- TI Bluetooth Low Energy RTLS



## Benefits

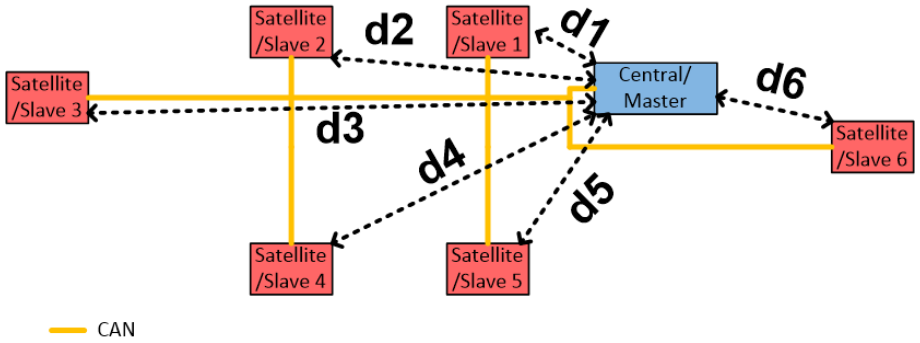
- Can provide multiple Bluetooth Low Energy real time localization measurements (RSSI, BLE5.1 AoA)
- CAN-FD communications allows IQ data to be sent to the central (master) module for AoA calculation with minimal delay
- Wide input operating range and low power sleep mode for optimized operation off an automtive battery



# Wireless auto-addressing

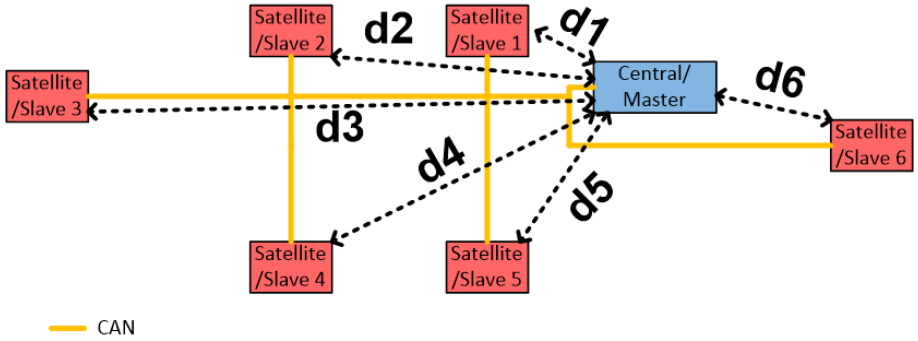
- *Currently a **wired communication** interface is **used to address all the satellite nodes** and it will **not be used again during the life of the vehicle**?*

- Using Bluetooth® localization techniques, Bluetooth® satellite modules can be given a CAN address during manufacturing and after a module is replaced.
  - The satellite modules can be addressed in the order of the closest module to the farthest module based off their distance measurements from a central (master) module.



# Auto-addressing using Bluetooth® *Low Energy*

- Distances ***dn*** represents the measured distance (from Bluetooth® RSSI and/or some other Bluetooth® localization technique)
  - *Ideally d1 < d6 < d5 < d2 < d4 < d3*




- Testing is required as the actual distance can vary from the measured distance due to the RF operation in the particular location of the vehicle.
- As long as each satellite modules measured distance is repeatedly similar and there is no overlap between measured distances from multiple modules, the central can properly address them without knowing their exact location around the car because the order of the closest measured distances for each module will always be the same.

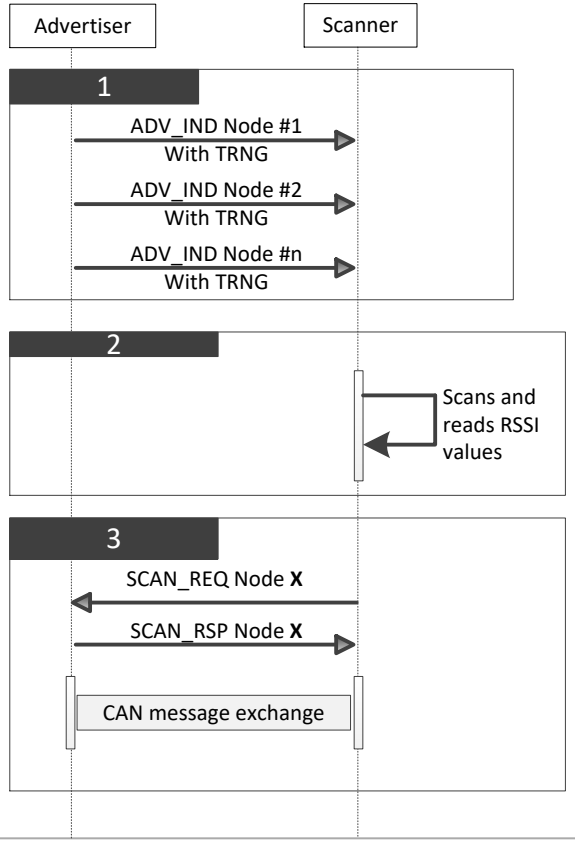
# Auto-addressing implementation

1. “Advertisers” are advertising using “**True Random Number Generated** ”
   - Avoid node duplication

2. “Scanner” scans and reads RSSI values from the “Advertisers”
   - Uses RSSI averages to determine the “Advertiser” closest to him
   - Scans multiple times

3. “Scanner” sends a SCAN request to the closest RSSI device. Then it transmits the auto-address CAN message and waits for the “Advertiser” acknowledge
   - “Advertiser” uses the SCAN_REQ to enable the auto address through CAN and when it receives the auto-address CAN message it sends the acknowledge and STOPS advertising

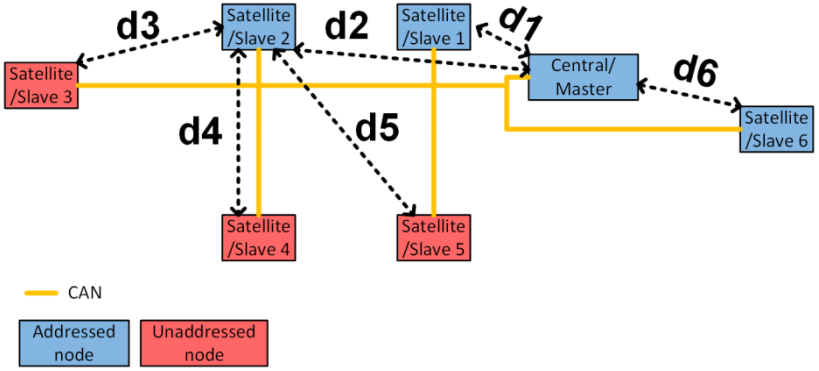
4. These repeats until there are no more “Advertisers”



# Auto-addressing, using role change

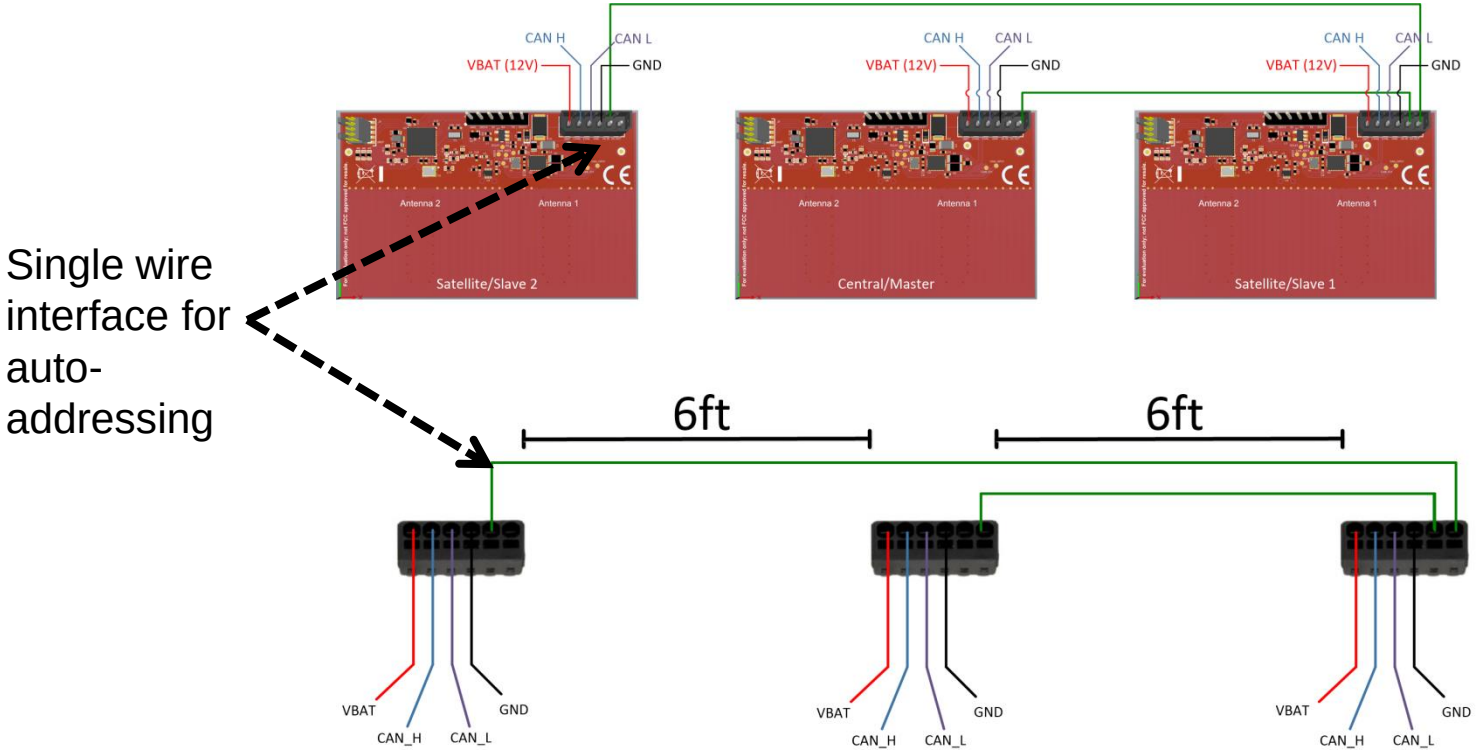
In the case where the master module distance measurement for some modules is not distinguishable (i.e. multiple modules measure the same or similar distances).

- A previously addressed module can be used to locate the other un-addressed modules, in other words the satellite modules will be switching GAP roles, from advertiser to scanner
- This can be done using multiple satellite modules as well
- In this example, the central is able to localize satellites 1, 2 and 6 but not 3, 4, and 5
- Satellite module 2 is then used to measure the distances for 3, 4, and 5
  - As long as the distance measurements are consistent and there is no overlap on distance measurements between modules, satellite modules can be properly addressed and will always be addressed in the same order



# Wireless auto-addressing test setup

- 3 x TIDA-020032 BLE+CAN Satellite Module



# Auto-addressing comparison

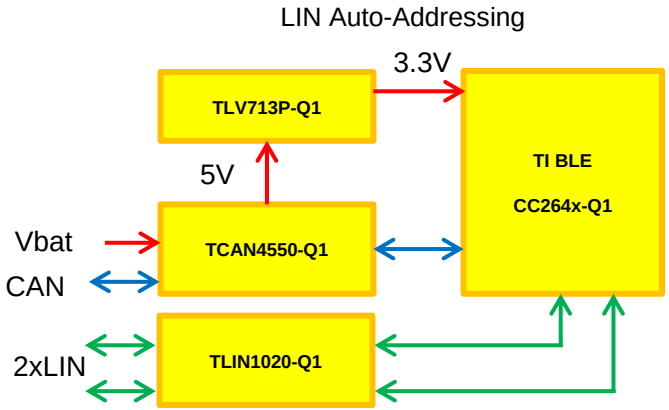
| | **BLE** auto-addressing (2 Nodes) | **Single wire** auto-addressing (2 Nodes) | **LIN** auto-addressing (9 Nodes) |
|---|---|---|---|
| Delay (msec) | 2000 | 400 | 3000 |
| Reliability (x20 tests) | 100% (open space) | 100% | 100% |
| Cost | $ | $$ | $$$ |

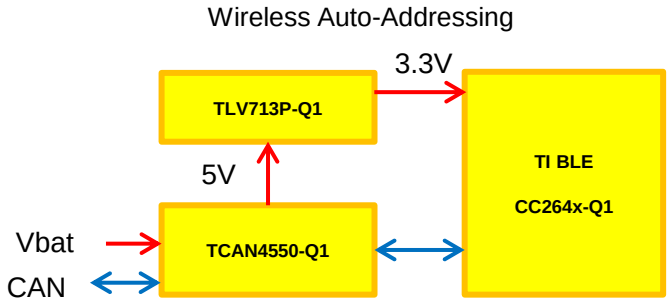
- *Bluetooth*® Low Energy auto-addressing parameters
  - Master
    - SCAN duration = 1 second
    - SCAN window = 250ms
    - SCAN interval = 250ms
  - Slave
    - Advertisement parameters = 100ms

  → Average ~10 RSSI samples x node x second

# Summary

- Wireless auto-addressing ultimately saves cost compared to current solutions
- By removing the requirement for LIN PHYs and any additional circuitry required in alternate solutions, the bill of material (BOM) costs are reduced
- Further testing is required as the actual distance can very from the measured distance due to the RF operation in the particular location of the vehicle (non-line-of-sight challenges). BLE parameters could be improved for a better and faster response (don't forget the role change)




Using wireless auto-addressing, TI's solution becomes much more cost effective

# Wireless Battery Management (wBMS)

# Introduction to BMS

- Lithium battery cells are continuously getting more affordable and energy dense, and can drive hybrid electric vehicles (HEVs) and electric vehicles (EVs) longer.
- With these advancements, automotive design engineers can now turn their attention to further enhancing efficiency by reducing the size and weight of the battery management system (BMS).
  - For background on battery management systems, see "HEV/EV battery management systems explained simply."
- The traditional wired BMS architecture connects battery packs using wire harnessing in a daisy-chain configuration, which is cumbersome to manufacture, often requires maintenance, and is difficult to service.
- To overcome these challenges, an evolution to wireless BMS shows potential, with wireless chipsets working in conjunction with battery monitors to communicate and pass voltage and temperature data from each cell to the main microcontroller in the system.

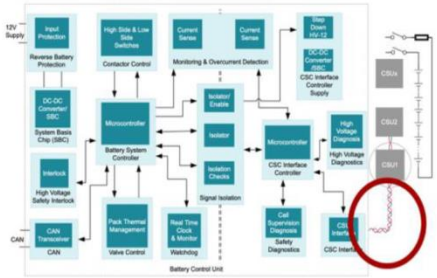
# What is wireless BMS (wBMS)

- **WBMS aims to provide a wireless connection between the between the Battery Management System and the Battery Packs, thereby replacing traditional wired (daisy chain) connections**

- **WBMS has the potential to provide significant breakthroughs:**
  - Improved reliability with the elimination of wiring harness and connectors
  - Lower system cost and weight
  - Reduced wiring complexity for large multi-cell battery stacks
  - Flexible (and therefore improved) placement of battery modules in an HEV/EV
  - Time synchronized measurements across each battery individual node

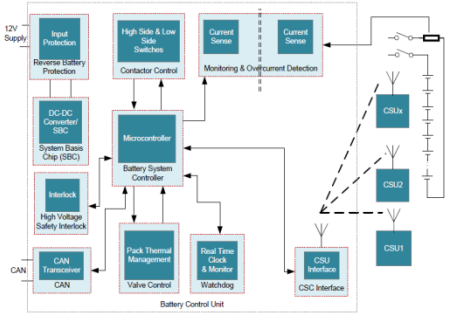
- **However, WBMS must address and resolve:**
  - Safety
  - Quality
  - Reliability
  - Availability
  - Security

## Wired BMS




- Daisy Chain communication used today
- One of the main issues is the wire harnessing and the complexity, cost and manufacturing time required. Manual production and installation needed!
- Connector, cable & isolation (cap choke, transformer) ~0.80$ per connection (OEM information)
- Additional components for isolation

## Wireless BMS

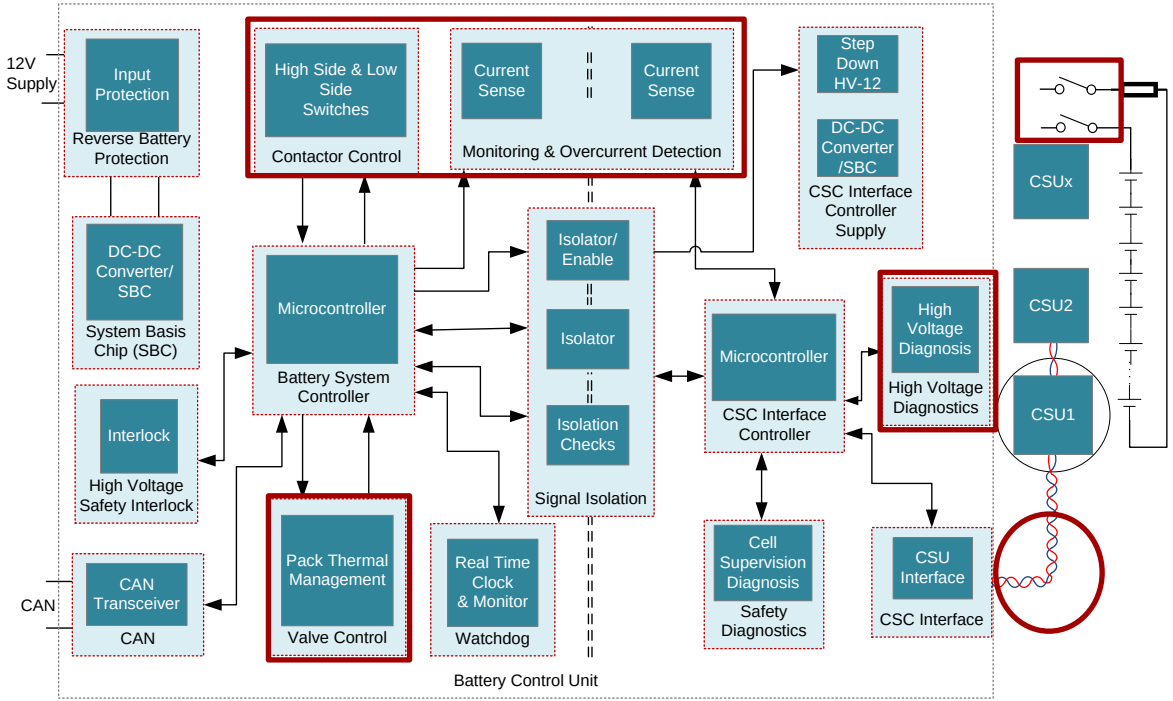



- Nodes communicate in wirelessly
  - Failure of one node does not cause failure of complete communication chain
- Simpler HV/LV isolation concept
  - No need of galvanic isolation BCU/CSU

# Wireless Battery Management System (wBMS)

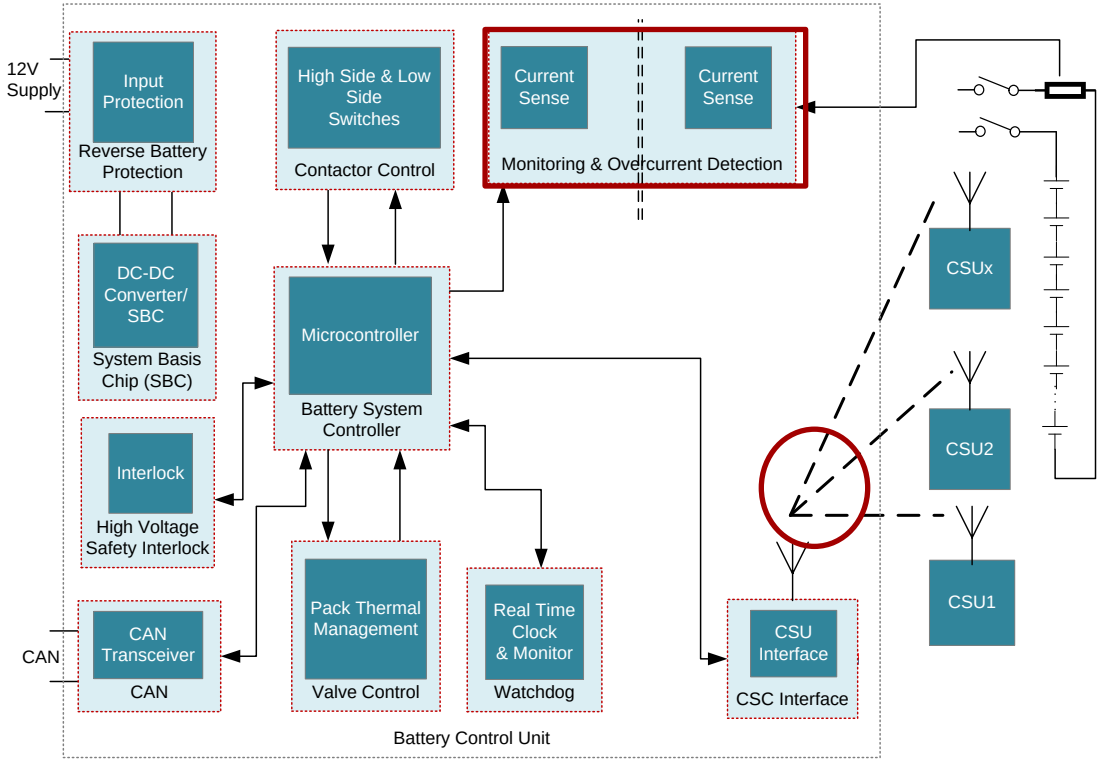
- **Problem:**
  - Warranties cost due to cable failures and high cost to replace a battery cell
    - #1 failure reason in automotive is the wiring harness and connectors (according to OEM/Tier1)
  - More than 3 miles of wiring adding weight
- **Current solution to the problem:**
  - Daisy Chain communication used today
  - Currently, data is passed via wired protocols:
    - isolated CAN-bus, differential UART, isoSPI
- **wBMS solution:**
  - Replacing cables while keeping in mind Safety, Quality, Reliability, Availability and Security.

# Wired battery management system




- Daisy Chain communication used today
- #1 failure reason in automotive is the wiring harness and connectors (according to OEM/Tier1)
  - Warranty claims derived from reliability issues
  - Cumbersome and not-reusable
  - More than 3 miles of wiring adding weight
- Battery Control Unit (BCU) is in direct control of the Battery Disconnect Switch and the Cooling System

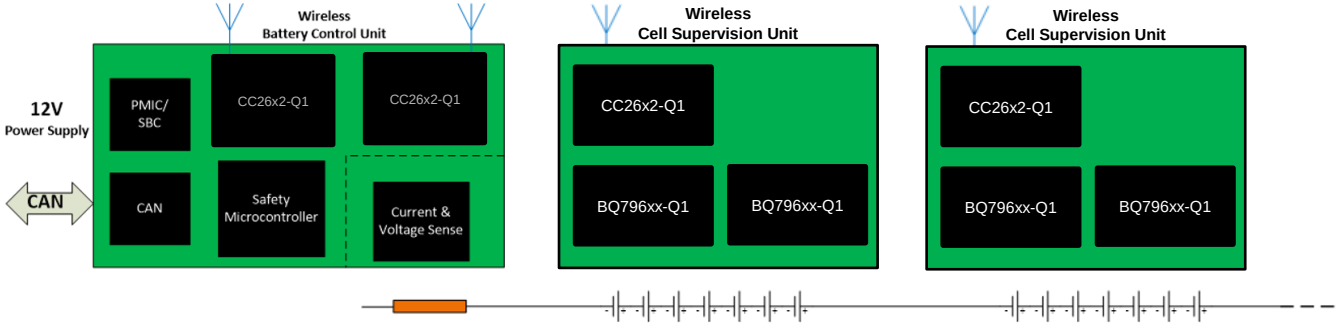
# Wireless battery management system




Benefits:

- Increase reliability by removing harnesses and wiring
- Scalable and re-usable design
- Easier to mount, serve and repair
- Lighter
- Nodes communicate in wireless star network topology
  - Failure of one node does not cause failure of complete communication chain
  - High throughput , low latency, robust
  - Supports up to 100 nodes connected
  - Fulfill ASIL-D error failure rates in harsh RF environments
  - Communication encrypted
- Simpler HV/LV isolation concept
  - No need of galvanic isolation BCU/CSU

# WBMS - Cable Replacement Use Case




Safe state:
Disconnect battery
Cool down battery

Battery Control Unit

- Battery disconnect
- Thermal control

- Safety critical
- Gray Channel
- Timestamp needed

Cell Supervision Unit

- Cell voltage

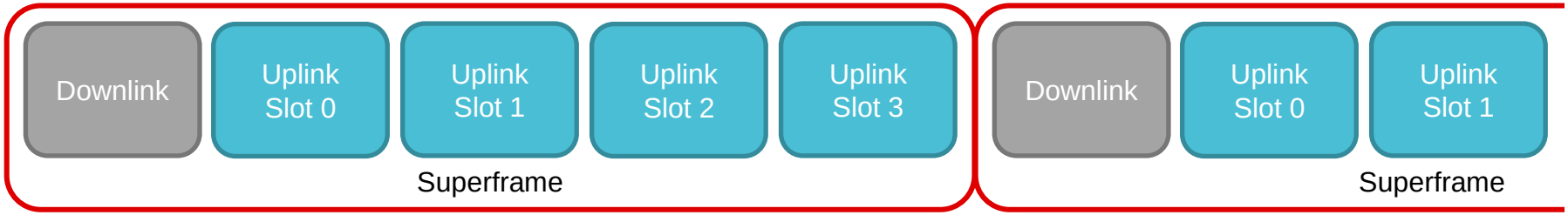

- Cell temperature

Safety risk:
Cell UV/OV
String/Cell OC
Thermal runaway

# TI protocol for wBMS

- High throughput, low latency, robust – optimized for the wBMS use-case
- 4x-5x more throughput than IEEE 802.15.4e configurations
- Guaranteed data transmission from each node every 100ms
- Star beacon network
- Supports up to 128 nodes connected
- Data-rates: 2Mbps
- Handle additional overhead needed to fulfill ASIL-D error failure rates in harsh RF environments
- Support for 2.4GHz
- Communication encrypted using AES-128 with Message Integrity Checks
- Support for over the air software update
- Scalable network topology for future needs

# Communication Protocol Overview

# TI WBMS reference design and demo

## Design Features

- Wireless BMS evaluation board featuring **BQ7961x-Q1** FS Compliant and SimpleLink™ **CC26x2R-Q1** wireless MCU
- High throughput, low latency, robust 2.4 GHz frequency hopping wireless protocol Guaranteed data transmission from each node every 100ms

## Design Benefits

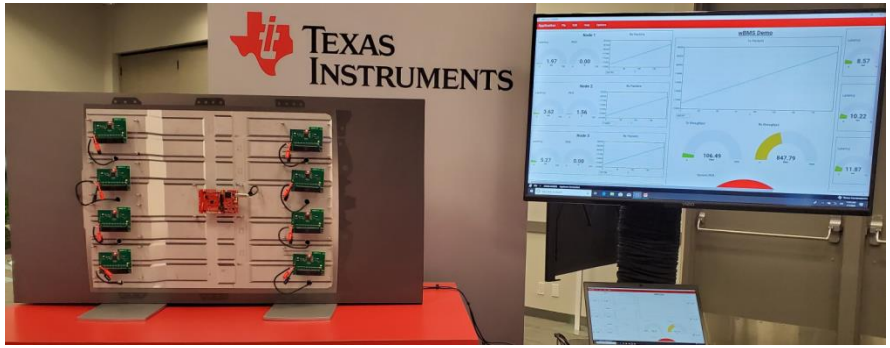
- High throughput, low latency wireless protocol optimized for the wireless BMS use case
- ISO26262 compliant component (BQ79616-Q1) together with Quality Managed CC26x2R-Q1
- The TI WBMS protocol provides measures for all defined failure modes and handles additional overhead needed to assist system integrators to meet their safety goals in harsh RF environments.

## Tools & Resources


- **WBMS rev B Hardware**

- Hardware Design Files available now
- WBMS blog and Video1 Video2

## 2020 Demo



# TI WBMS protocol – Performance Summary

| | |
|---|---|
| **Topology** | Star network<br>Up to 100 nodes per 1 master |
| **Reliability** | Network PER $10^{-7}$ measured in BMS enclosure & noisy environments<br>97dB link budget: 5dB TX & -92dB |
| **Safety** | TUV certified concept based on gray channel principle<br>Systematic Compliance: SW FMEA and ASPICE Level 2<br>CC2662R-Q1 QM device with Safety Manual, FMEDA & FS FIT rate |
| **Data Integrity Mechanisms** | Timestamp, CRC, ACK, Unique ID, Sequence Number<br>Multiple retransmissions per FTTI (100ms) |
| **Throughput** | 1.2Mbps (250B payload) |
| **Latency** | 16ms network (1M:8S), 55ms network (1M:32S) w/ 250B payload |
| **Network Formation** | 300 mSec |
| **Power Consumption** | Main node 294uW, Devices 200uW |
| **Security** | Shared Network Key: Pre-shared key to start & Key refreshment<br>Packets are Authenticated & Encrypted (AES-128) |

# Comparing aspects of wired and wireless BMS

| Considerations | Wired BMS | Wireless BMS |
|---|---|---|
| **Weight** | Wiring increases overall vehicle weight. | A wireless system decreases vehicle weight. |
| **Design flexibility and serviceability** | Less flexibility with a larger footprint overall; more difficult to service.<br>Larger overall footprint; less flexible system design due to cumbersome wires, difficult to service. | Smaller footprint enables more flexibility with a simpler design and placement within the vehicle. Easier to service. |
| **Measurement** | Time-synchronized measurements of voltage and current can be a difficult design challenge. | Wireless systems naturally enable time-synchronized measurements and provide the ability to add more synchronized sensing capabilities. |
| **Reliability** | Wiring harnesses tend to break over time; they are difficult to repair and require rewiring of battery packs. | No wires to maintain; design has to overcome harsh automotive radio-frequency environments and non-line-of-sight challenges. |
| **Security** | Contained and fully secure system communication. | Possible to breach poorly designed systems that lack security protocols. |

# Summary

- If you're exploring the idea of switching to a wireless BMS architecture, here are three key questions to consider:

1. **Is it reliable?**
   - Although wireless communication is already replacing cables in various applications, one critical point to consider is the reliability of the wireless link and network. You can quantify reliability using packet error rates and the probability of successfully sending a message between a transmitter and a receiver. This probability should be 99.999%, with a packet error rate of $10^{-7}$.
2. **Is the wireless BMS safe for passengers, mechanics and property?**
   - A wireless BMS should accurately monitor conditions and respond quickly, reliably and safely if a hazardous event is detected to mitigate danger or destruction. Ideally, the system should meet requirements up to Automotive Safety Integrity Level D, which is the highest functional safety goal defined by the International Organization for Standardization 26262 road vehicle standard.
3. **Is it secure?**
   - Will a wireless BMS work if someone attempts to tamper with the vehicle's battery system? Look for systems that provide encrypted messages, using security enablers such as cryptographic accelerators with key exchange and refreshment mechanisms, message integrity checks and debugging security.

# Thanks for listening…

TEXAS INSTRUMENTS

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