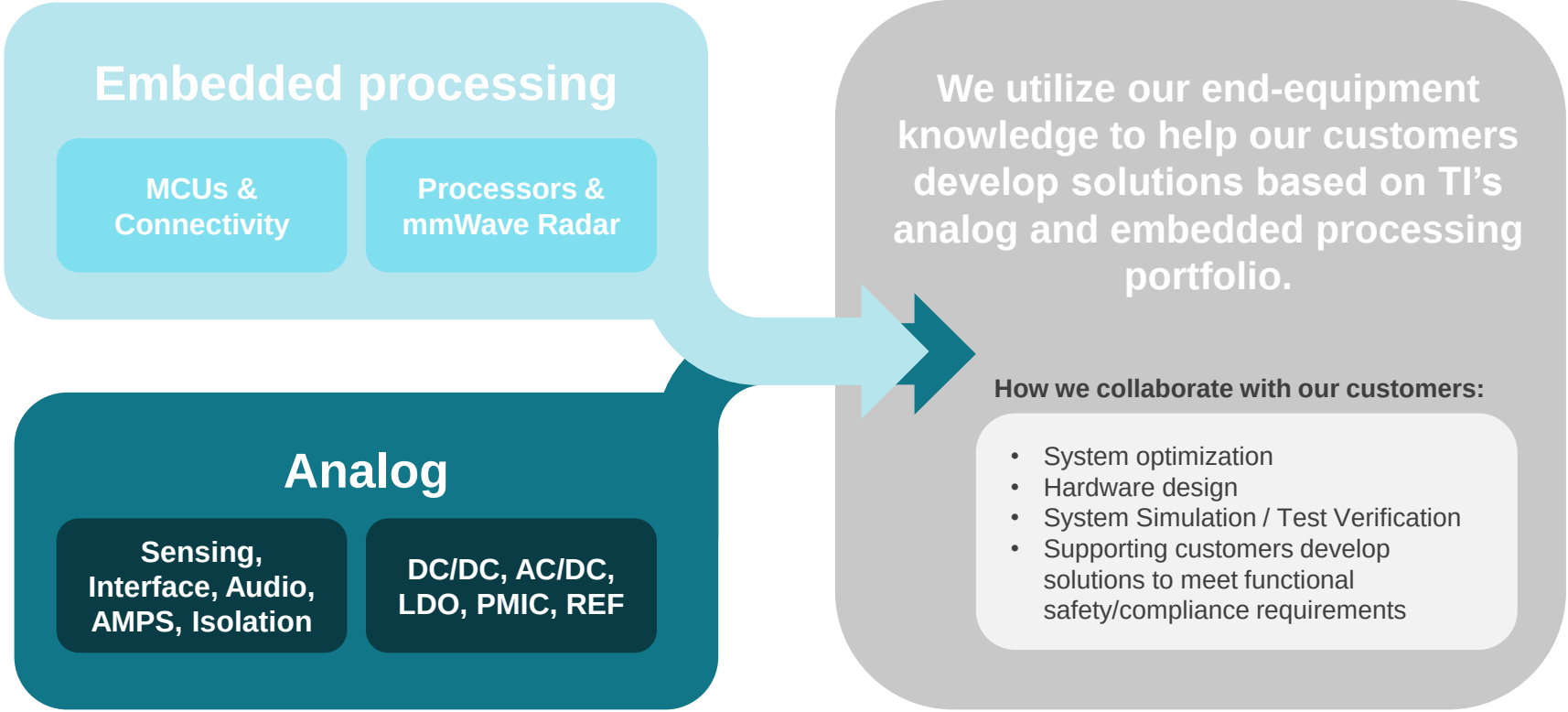
Building Automation - HVAC

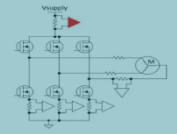
SEM helps customers develop solutions

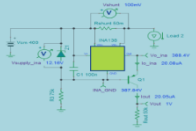


Systems Engineering & Marketing | Where we are

Design collaborations with customers

Architecture definition / concept	New technology evaluation	Architectural analysis	Design optimization for cost, features
Design	Circuit design	Simulations	Competitive analysis
Hardware development	Schematics	Layout	Design review
Prototype verification	Functional testing	Troubleshooting	Pre-compliance testing





TI Power Design Services

A Global Design and Support workforce

A team of **28** Engineers located across **3** continents

What We Do:

Design power supplies for strategic customers in order to make TI products easy to use.

Services Offered:

- *Custom Schematic, Layout, and Board Builds*
- *Design Reviews (Customer Schematics, PCBs)*
- *App note, design article, and reference design suggestions*
- *Quick-turn board level prototypes and full test reports*

How to Engage:

- *Reach out to your assigned TI FAE with details on your opportunity*
- *Search over 2500 PDS designs on TIDesigns beginning with "PMP"*
- *Search ti.com/psds for our seminar white papers and presentations*

Subject Matter Experts:

- *AC/DC, PoE, High Current, USB Type C, Battery Chargers, and more.*
- *Wide range of experience from µWs to kWs*

Texas Instruments

Enabling the future of buildings

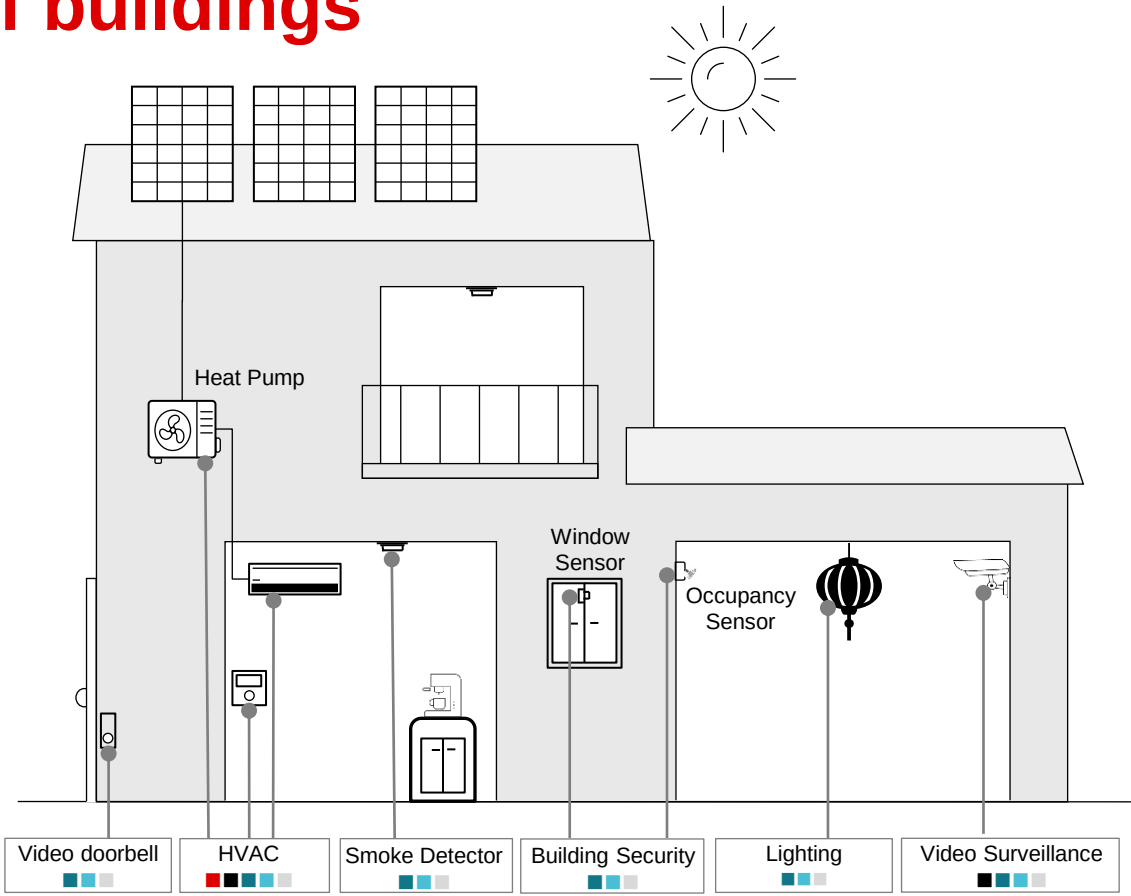
High-voltage power conversion
High efficiency PFC to meet stringent APF regulations in HVAC system

Motor Control
High efficiency, low noise drives for quieter and more efficient appliances

Sensing
Smart sensors to control building HVAC, lighting, access and occupancy

Connectivity
Monitor and control household electronic devices and appliances to increase safety, security and efficiency

Artificial Intelligence
Objects classification, voice/noises recognition, predictive maintenance, energy management



HVAC Trends

HVAC in Building Automation: Trends and Updates

Trends and Applications

2023 Minimum Efficiencies			
System Type	Old Minimum	New Minimum with M Ratings	New Minimum with M1 Ratings
Split System HP	14.0 SEER	15.0 SEER	14.3 SEER2
	8.2 HSPF	8.8 HSPF	7.5 HSPF2
SPP AC and Gas Electric (EER applies to SW only)	14.0 SEER	14.0 SEER	13.4 SEER2
	11.0 EER	11.0 EER	10.6 EER2
SPP HP and Dual-Fuel HP	14.0 SEER	14.0 SEER	13.4 SEER2
	8.0 HSPF	8.0 HSPF	6.7 HSPF2

Increased HVAC system efficiency


Furnace


Furnace Controls

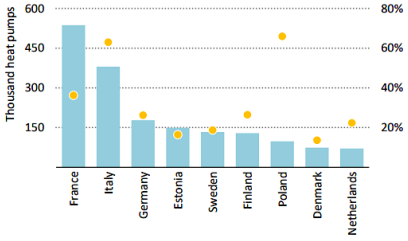

Expansion Device


Zoning Controls


U.S. A2L refrigerant adoption


Furnace Controls


A2L Sensor



Heat pumps to replace gas heating in E.U.


Indoor Unit/Controller


Expansion Device


Air to Water HP Zone Controls

Devices

Reference Designs


TIDM-02010:
Dual motor control (1.5kW, 200W) with digital interleaved PFC


TIDA-010273:
250W 3-Phase motor control for fan and pumps. (C2000/M0 + GAN IPM)


TIDA-010257:
10KW Vienna PFC


TIDA-010085:
24-VAC multi-channel solid state for low power HVAC control


TIDA-010950:
Damper/EEV control with position sensing and 15W power reg.


WINSE-3P-ZRT512C-R454B-TI
A2L refrigerants leak detection

Technical Content

- A2L Refrigerant Standard Overview and TI Mitigation Control Board Designs for Designers
- HVAC controller architecture selection guide
- Heat Pump and System Controller Webinar Series
- MSPM0 – ADC Attach on AM62x using SPI
- Make System Design Easy With MSPM0 Precision Analog
- Application Brief: PLC Analog Input Front-End Architectures

MPU/MCU

- **AM623**: 1400MHz Quad 64-Bit Arm Cortex-A53 and 400MHz single Arm Cortex-M4F with AI accelerator
- **MSPM0G**: 80MHz Arm 32-bit Cortex-M0 MCU

Motor control MCUs

- **C2000** (InstaSPIN-FOC with FAST and eSMO observer, 1/3-shunt current sensing, IEC60730 library)

Gate drivers

- **UCC27710/2** 620V half bridge driver
- **UCC23513** single-channel opto-compatible isolated gate driver
- **DRV7308** 600V, 3-Phase IPM for BLDC

EEV & Damper Control

- **DRV8428**: Bipolar stepper motor control
- **DRV8316C**: BLDC motor control

Ethernet 10/100M PHY

- **DP83826IRHBR**: Balance of performance/price
- **DP83TD545**: T1S with MAC interface

Analog Input Front-End

- **ADS1220**: 16-bit, 2-kSPS, four-channel, low-power, delta-sigma ADC with PGA, VREF, SPI and two IDACs

Current Sensing

- **TMCS1123:** ±1300V reinforced isolation, 80ARMS 250kHz Hall-effect current sensor

Connectivity

- **CC3551E:** Wireless MCU with dual-band (2.4 and 5 GHz) Wi-Fi 6 and Bluetooth® Low Energy 5.4
- **CC1352:** Arm Cortex-M4F multiprotocol Sub-1 GHz & 2.4 GHz wireless MCU with 352kB Flash

Vienna PFC

TIDA-010257: 10kW Vienna PFC

Q4,2024 publish

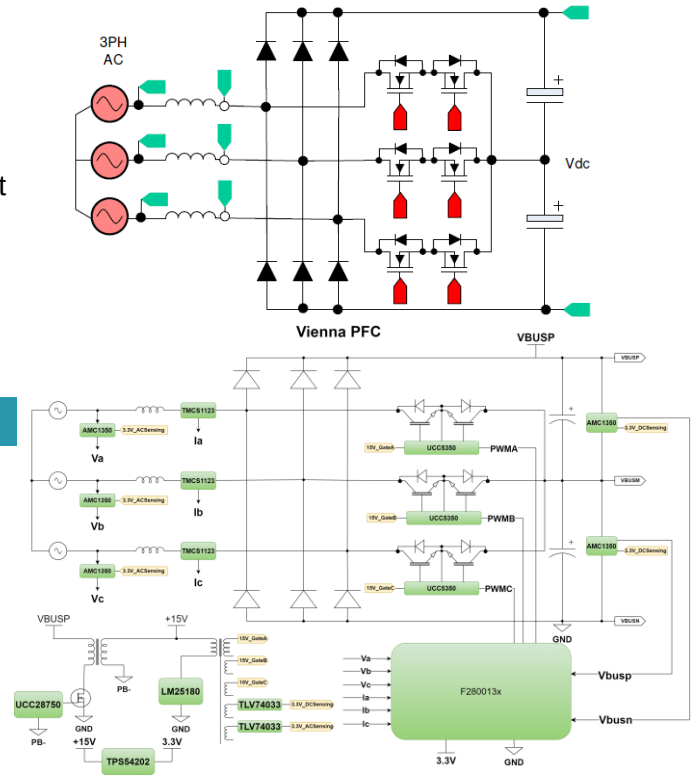
Design challenge/problem statement

- Cost of passive PFC choke is getting high as raw material price increasing
- Passive PFC can't provide very high power factor.
- Size of passive PFC choke is bigger.
- The higher the power, the higher the cost of passive PFC, BOM cost for 4kW Vienna PFC is lower than passive PFC.
- Harmonic current limits will be compulsory requirements for new GB17625.1-2022, effective in Jul, 2024.

Features

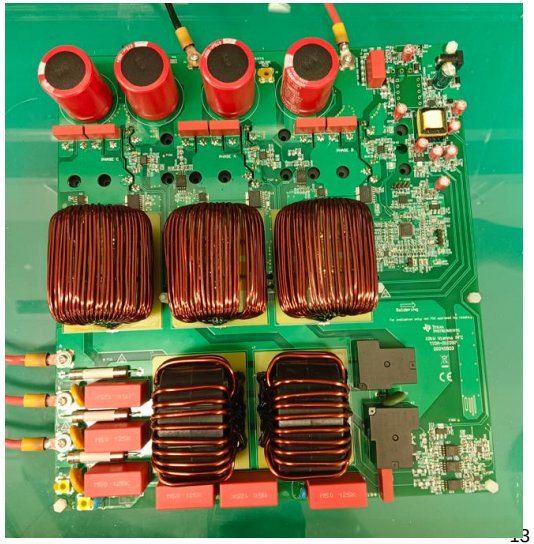
- 50kHz PWM switching
- Less than 2% Total Harmonic Distortion at full load and low line.
- 98% peak efficiency.
- 10kW at 400VL-L 50Hz, output 700VDC nominal.

Block diagram/schematic



What differentiates this subsystem solution

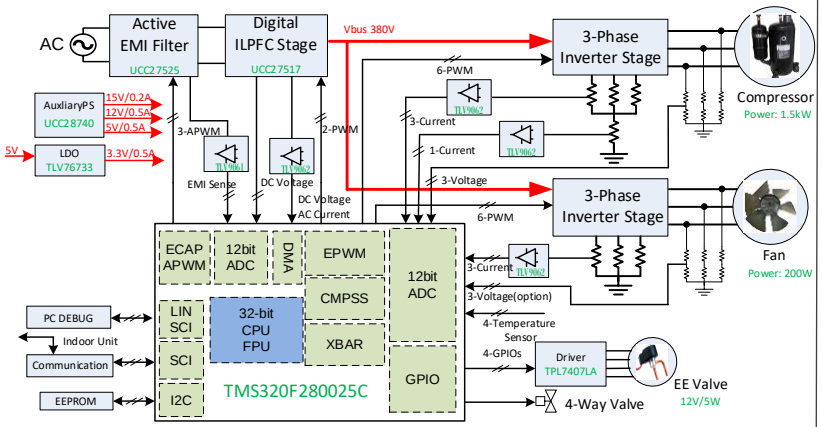
- 3 phases 3 level Vienna topology enable low voltage power devices
- Full digital control with C2000 DSP, while still have capacity to drive two motors.
- High efficiency
- High power factor
- Low cost
- Low Total Harmonic Distortion.



Motor Driver

HVAC Inverter Board Reference Sheet (Internal only)

Subsystem Block Diagram



Technical Content

- Heat Pump and System Controller Webinar Series
- **App note (1Q24 RTM)** 35W motor control for ventilation fan (M0 + MCF8315)

Reference Designs

TIDM-02010: Dual motor control (1.5kW, 200W) with digital interleaved PFC

TIDA-010265 : 750W 3-Phase motor control for compressor

TIDA-010250
1-kW brushless DC motor inverter for compressor (M0 + UCC27712)

TIDA-010273 250W 3-Phase motor control fan and pumps (C2000/M0 + GAN IPM)

Devices

Analog Input Front-End
- **ADS124S08**:16-bit, 4-kSPS, 12-ch delta-sigma ADC with PGA and voltage reference
- **ADS1220**: 16-bit, 2-kSPS, four-channel, low-power, delta-sigma ADC with PGA, VREF, SPI and two IDACs
- **ADS1015**: 12-bit, 3.3-kSPS, 4-channel, delta-sigma ADC with PGA, oscillator, VREF, comparator and I2C

Motor control MCUs
- **C2000** (InstaSPIN-FOC with FAST and eSMO observer, 1/3-shunt current sensing, IEC60730 library)
- **MSPM0** (Sensor-less FOC with eSMO observer for PMSM, 3-shunt current sensing, sensor-trap for BLDC)

Gate drivers
- **DRV8328/9** 60V 3-phase BLDC Gate Driver
- **LM2105** 107-V half-bridge gate driver
- **UCC27710/2** 620V half bridge driver
- **UCC23513** single-channel opto-compatible isolated gate driver
- **DRV7308** (RTM 4Q24) 600V, 3-Phase Integrated Power Module for BLDC/PMSM

Fixed function gate drivers
- **MCF831x**, 40-V sensor-less FOC control three-phase BLDC motor driver

Discovery Questions

Basic
- What is the power level
- Is this a multiple motor inverter (compressor + fan)
- Is expansion valve control on the inverter board
- Are there any board size constraints
- What communication is used for the inverter board
- Isolation requirements (power, comms, signal)

Intermediate
- What PFC architecture is being used
- Is a pre-charge circuit needed for the power input
- What motor control algorithm is used for the fan/compressor
- What fault conditions are monitored on the inverter board
- Is there a target efficiency requirement
- What control signals interface to this board

Advanced
- For current sensing, is it using 1, 2, or 3 shunt
- What is the switching frequency for the inverter(s)
- What motor type is being used (brushed, BLDC, etc.)

TIDM-02010 – Dual Motor Control with Digital PFC Reference Design

Solution Features

- Wide input voltage: 85/165VAC~265VAC
- Variable out voltage: 350V~380VDC
- Input power: nominal 1.5kW, maximum 2.0kW
- Digital interleaved boost stage PFC with 72kHz switching frequency
- Sensorless-FOC PMSM for compressor supporting parameter identification, 6kHz switching frequency
- Sensorless-FOC PMSM for fan supporting flying start, 18kHz switching frequency
- Power factor: >0.98 @ full load, 220VAC
- Power efficiency: >93% @ >50% load, 220VAC
- THD: <5% @ >50% load, 220VAC

Target Applications

- Air conditioner outdoor unit
- Residential water heater & heating system
- Mini-split Condensing Units
- Rooftop Package (Monoblock) Units

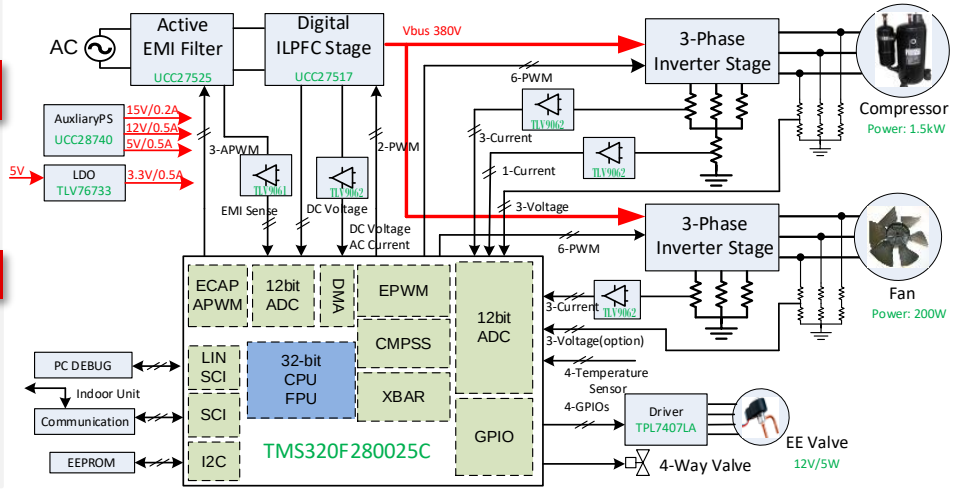
Tools & Resources

- TID Design Guide
- Demonstration User's Guide
- Design Files: Schematic, BOM, Gerbers, Software in MCSDK

- Device Datasheets:
  - TMS320F280025C
    → F280039C, F2800137
  - UCC27517
  - TLV9062
  - UCC28740

Benefits

- Proven, highly integrated single MCU dual motor and digital PFC control design based on real HVAC systems
- Innovative algorithms for highest efficiency, lowest /highest speed, lowest vibration/acoustics, best start-up, widest adaptability
- Modular software and hardware design can be easily adapted to similar compressor and blower control applications and across broad C2000 portfolio of real-time controllers



TIDA-010265 – Single Motor Inverter for Appliance with GUI

Features

- Wide input voltage: 85/165VAC~265VAC
- Input power: nominal 0.75kW (continuous), maximum 1.0kW
- Inverter efficiency: >93% @ >50% load, 220VAC
- Sensorless-FOC PMSM with FAST or eSMO, 5k~20kHz switching frequency
- InstaSPIN-FOC based Motor parameter identification and Rs online calibration
- Support speed closed-loop for washer or fridge, torque control and constant power control for blower or pump applications.
- Support flying start for washer, fan and blower applications
- Support automatic deep field weakening for washing machine at high speed
- Enables vibration compensation control for compressor applications
- Support 1-shunt, 2-shunt or 3-shunt current sensing
- Faults protection include over current, over load, stall, under/over voltage……
- UART based GUI for configuration, debugging and tuning the motor control parameters, monitor and log the motor running status
- UL1998/IEC60730 integration

Target Applications

- Air conditioner indoor unit fan
- Residential water heater & heating system
- Refrigerator & freezer compressor
- Washer machine motor drive
- Pump and HVAC blower or fan

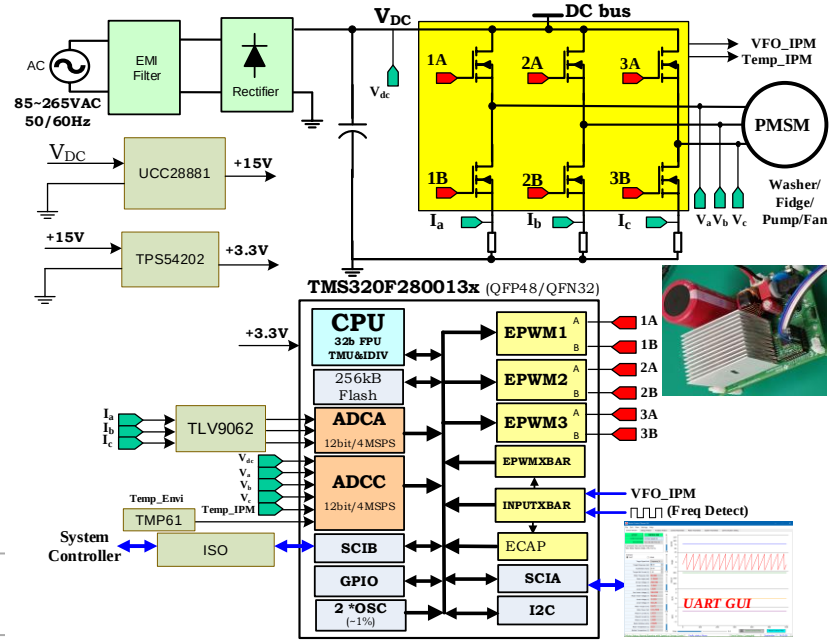
Tools & Resources

- TID Design Guide
- UART based GUI
- Demonstration User's Guide
- Design Files: Schematic, BOM, Gerbers, Software in MCSDK

- Device Datasheets:
  - TMS320F2800137(QFP48)
  - TLV9062
  - UCC28881DR
  - TPS54202DDCR

Benefits

- Proven, highly integrated single motor inverter design
- Innovative algorithms for highest efficiency, lowest /highest speed, lowest vibration/acoustics, best start-up, widest adaptability
- Modular software can be easily adapted to similar high voltage motor control applications and across broad C2000 portfolio of real-time controllers
- Powerful GUI based UART for monitor and debug the motor on a real application in high noise environment



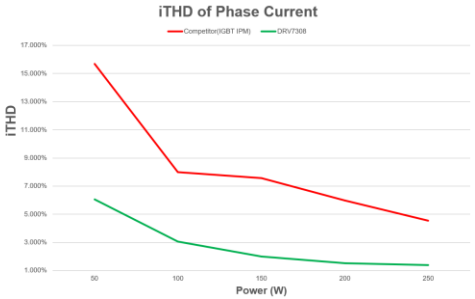
TIDA-010273: 250W Motor inverter with GaN IPM with GUI

Design challenge/problem statement

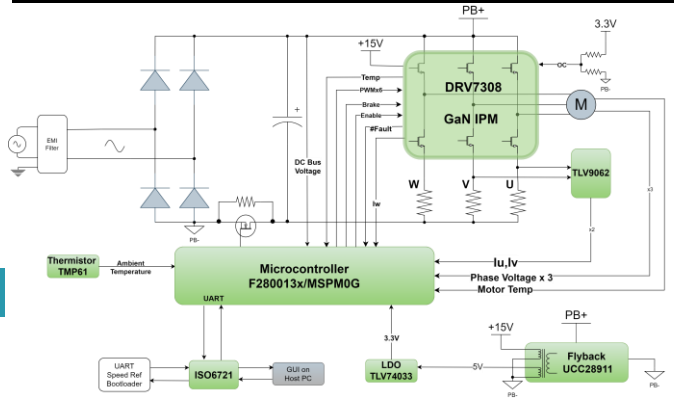
- Low Efficiency of IPM(~97% at low carrier frequency)
- Low switching frequency(6-8kHz)
- High iTHD for low switching frequency.
- Big board size due to big heat sinks
- High leakage current for IGBT IPM (<1mA), high standby power.
- Big size board and double side components needed for discrete IGBT solution.

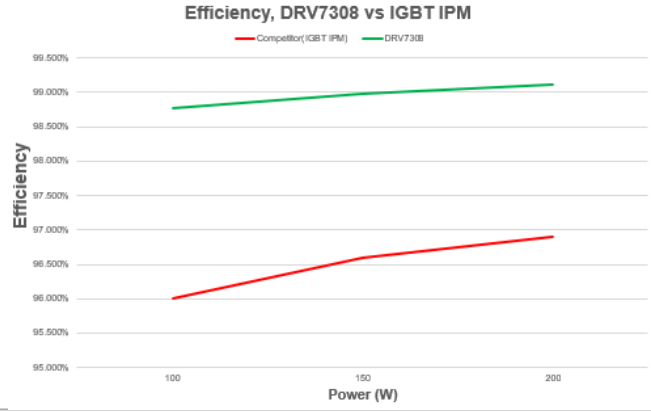
Features

- 220VAC/250W motor inverter
- UART based GUI
- Small profile and compact design
- High efficiency, Low iTHD



Block diagram/schematic





What differentiates this subsystem solution

- High efficiency (>=99%).
- High switching frequency (16k-20kHz) with still high efficiency.
- Low iTHD due to high switching frequency
- Tiny board size 80*55mm, to deliver 250W without heatsink.
- Low leakage current(<100uA) for low standby power
- Less external components to support single side components to save manufacturing cost.
- Support both C2000 and MSPM0 microcontroller.
- Low standby power 0.12W tipical

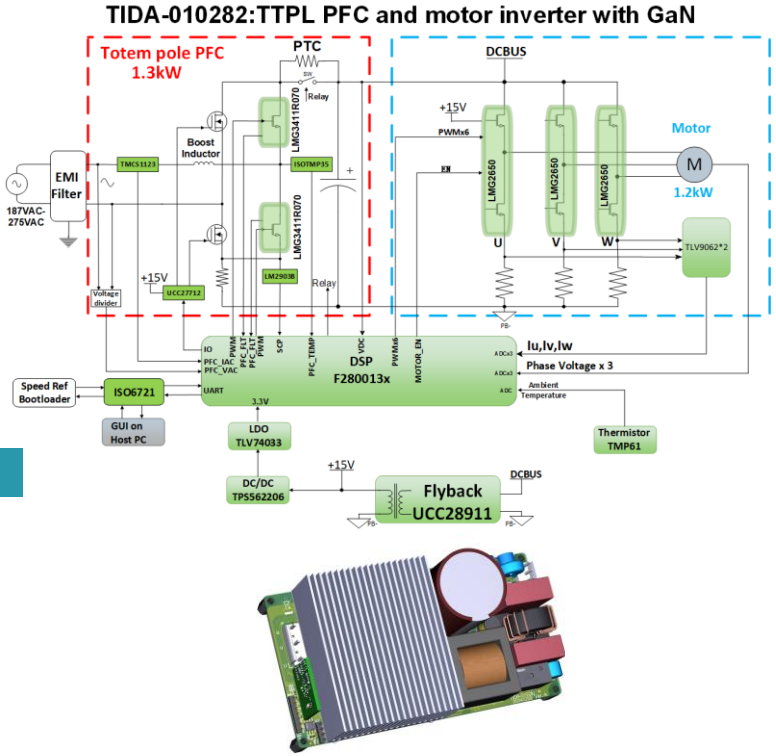
TIDA-010282: 1.3kW All-GaN Platform for TTPL PFC and Motor Inverter

Q2,2025 release

Design challenge/problem statement

- Low efficiency of traditional PFC(~97%)
- Low efficiency of IGBT IPM(~97%)
- System efficiency **94%**, power loss up to **78W** for 1.3kW system
- High iTHD for low switching frequency and long dead time
- Big size and heavy heat sinks
- Mixed Through-hole and SMT power devices, lead to a complex assembly process.

Block diagram/schematic



What differentiates this subsystem solution

- High efficiency GaN TTPL PFC(~99%)
- High efficiency of GaN motor inverter(~99%)
- System efficiency **98%**, power loss is only **26W**.
- Low iTHD by high switching frequency and small dead time
- Only SMT power devices, easy to be assembled
- On board bias supply
- PFC switching frequency up to 100kHz
- Small heat sink size: 60*75*30mm
- Compact board size: 140*75mm

Features

- 220VAC/1.3kW motor platform with All-GaNs for PFC and motor inverter
- Compact size
- High efficiency (4% inc), low iTHD

Applications

- Washer/Dryer
- Cooker Hood
- HVAC
- Air Conditioner
- Motor Driver

HVAC Damper and EEV Control with Position Sensing

TIDA-010950

Solution Features

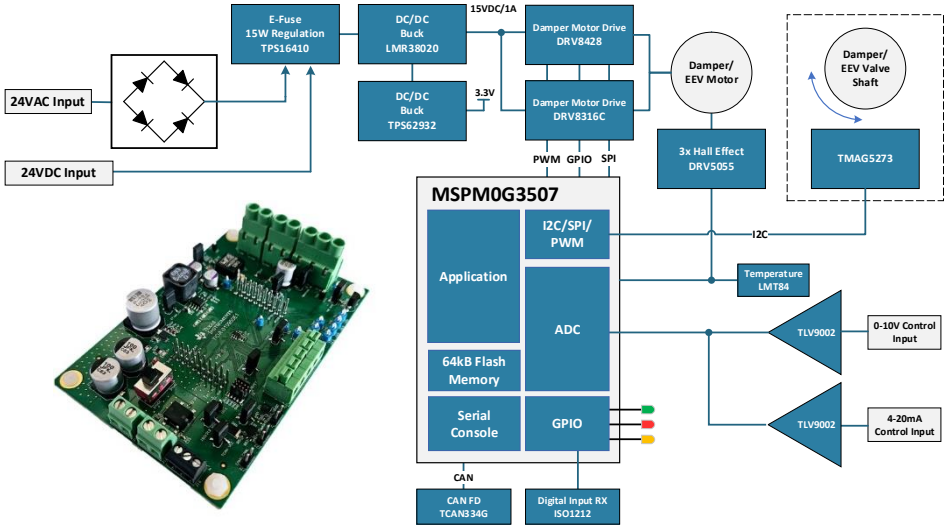
- IEC 60335-1 Compliant <15W power limiting enabled
- Cost optimized control of BLDC motors and electronic expansion valves in a single board
- Operates from 24VAC or 24VDC power supply
- CAN-FD communication interface
- Isolated digital input for open/close of dampers
- Damper position sensing leveraging TMAG5273 linear output 3D Hall-effect sensor.
- 0-10V and 4-20mA damper/EEV position control inputs
- Integrated BLDC current sensing
- Integrated voltage-adjustable buck regulator (3.3 V/5 V, 200-mA) and LDO (3.3 V / 30 mA)

Devices

- TPS16410
- LMR38020
- TPS62932
- DRV8428
- DRV8316C
- TMAG5273
- LMT84
- MSPM0G3507
- ISO1212
- TCAN344G

Solution Benefits

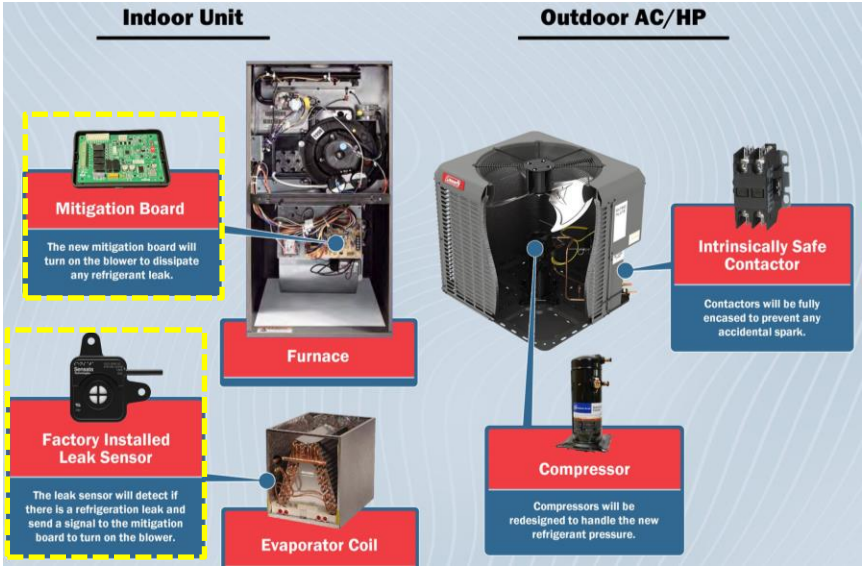
- Low-cost design
- Small solution size
- Power regulation for IEC 60335-1 applications
- Accurate detection of damper/stepper motor rotational position
- Boosterpack form-factor for high flexibility in MCU/MPU platform evaluation possibilities



A2L Refrigerant Sensing

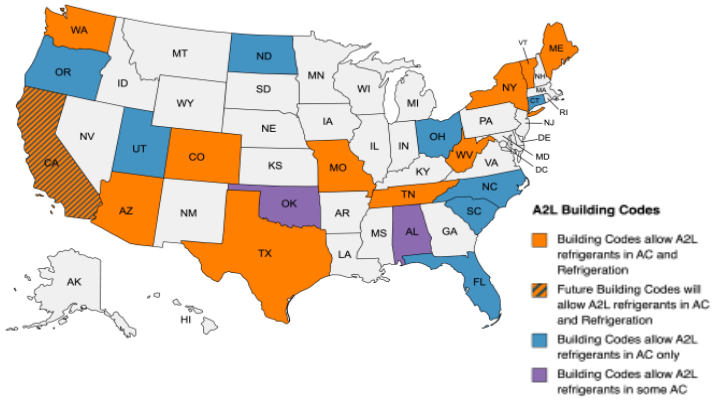
HVAC Trend: A2L Refrigerant Adoption in U.S.

- Conventional refrigerants have high GWP but are non-flammable (A1).
- Adoption of new refrigerants with lower GWP means gas sensing and mitigation hardware is required for every A2L compatible indoor air handler.
- As of 2019, more than 68 million HVAC systems worldwide use A2L refrigerants



Category	Refrigerant	GWP	Flammability	TFA yield
Conventional HFC	R-410a	2 088	Non-flammable (A1)	0%
	R-134a	1 430		7-20%
Hydrocarbon (HC)	R-290 (Propane)	≤3	Higher flammability (A3)	
	R-1270 (Propene)			0%
	R-600 (Butane)			
	R-691 (Pentane)			
Lower-GWP HFC	R-32	675	Lower flammability (A2L)	0%
HFC/HFO blend	R-454B	490	Lower flammability (A2L)	30%
HFO	R-1234yf	4	Lower flammability (A2L)	100%
	R-1234ze	<1		<10%
CO_2	R-744 (Carbon dioxide)	1	Non-flammable (A1)	0%

*U.S. is now starting to see shift towards A2L refrigerant adoption



A2L Refrigerant Leak Detection with NDIR Sensing

Features

- Target Gas: R454B; R32, R290 (customizable).
- NDIR Sensing technology provide high accuracy and resolution.
- Dual simultaneous sampling ADC for reference and target gas (12 bit SAR)
- Reference thermopile for reliability and accuracy
- RS-485 communication interface to communicate with mitigation systems
- 5~24V wide voltage range power input
- Winsen's NDIR Sensor and Chamber

Applications

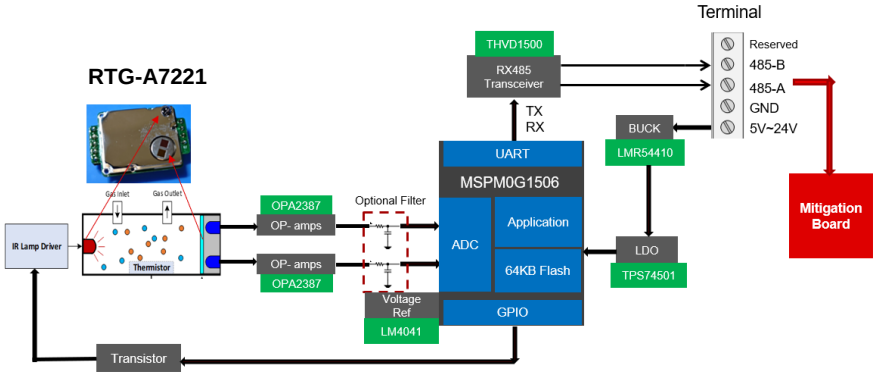
- HVAC
- Air conditioner
- Industrial Safety & Process control

Key devices

- **MSPM0G1506**
- **OPA2387**
- **THVD1500**
- **LMR54410**
- **TPS74501**
- **LM4041**
- **Winsen: RTG-A7221**

Benefits

- Cost-optimized NDIR sensing design
- Output method: RS485(default),UART/PWM(customizable)
- Lifespan: > 15 years
- Accurate gas detection (2.5%LFL)
- High resolution (0.1% LFL)
- Fast response time (<10s)



Thermostat

- Radar
- Solid-State Relay(SSR)
- HMI

Low-power mmWave radar + PIR + Wireless Reference Design

Solve following customer challenge:

- <1mW avg power of 10 meters people motion detection, wireless communication design

Features

- Low power consumption: <1mW of total avg power, <700uW when radar and wireless is in deep sleep mode.
- 3Hz of radar chirp for 10 meters people motion detection.
- Radome PPR support and RF test result
- PIR sensor supported (By external base board)
- Zigbee or BLE5.3 supported (By external base board)
- Wifi 2.4GHz supported (By external base board)
- Sub1_GHz supported (By external base board)
- Costless 2 Layers PCB layout for module design

Applications

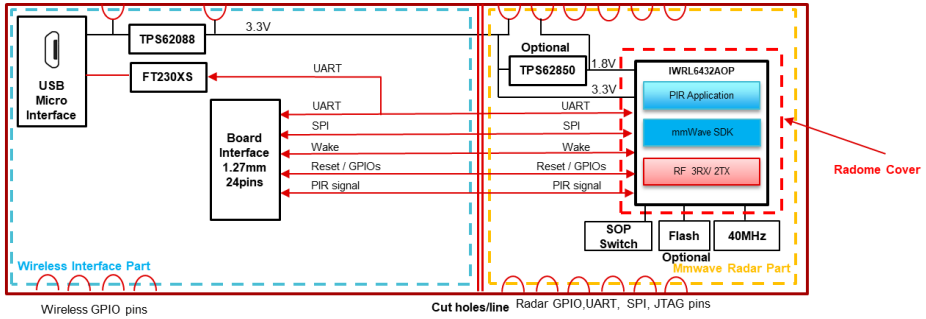
- IP camera, video doorbell, Occupancy detector

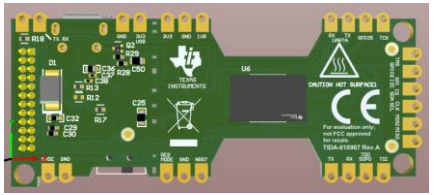
Devices

- **IWRL6432AOP, IWRL6422AOP**

Benefits

- PIR + mmwave radar design for low power consumption
- Radome PPR demonstration and performance tests
- Simple Layout design for customer project reuse and tests





TPSI88xxx

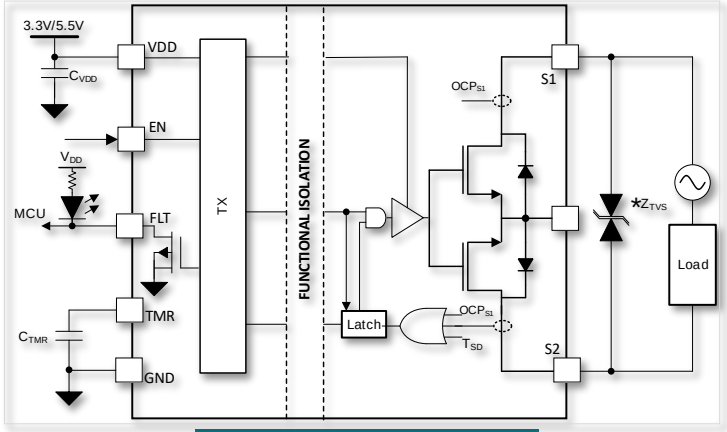
In Development

80V, 30/80/160mΩ, Smart Solid-State Relay with Functional Isolation and Over-Current Protection

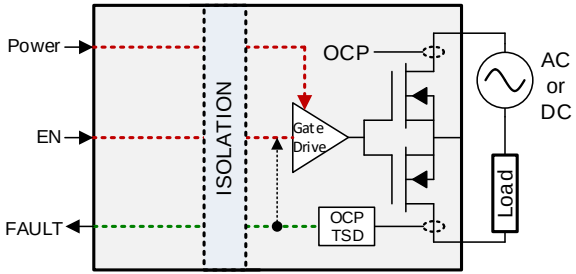
Features & Benefits

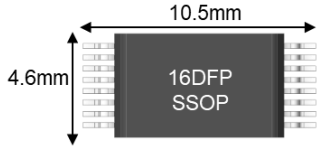
- **Integrated, smart switches to replace relays / photoMOS**
  - No isolated secondary supply required
  - Over-current protection (various thresholds) and thermal shutdown
  - Zero-cross detection (TPSI8880Zx) reduces inrush current during switching
  - Latched/Auto-retry fault reporting on primary side eliminates need for additional isolators for diagnostics
  - Input supply range and logic control: 3.0-5.5V
- **Reliable switches with back-back FETs for reverse current blocking**
  - FET standoff voltage: ±80V (87V Absmax for transients)
  - **R_{ON}: 30/80/160mΩ @ 25°C**
  - **Load current: 1A-3.5A DC**
  - Low Leakage current: < 1µA @ 105°C
  - Supports DC or AC load switching
  - Low latency (<250us Enable/Disable Delay) compared to relays and optos allows for better system control
- **Robust Isolation improves system lifetime**
  - Highest reliability compared to traditional mechanical relay and optical SSR
  - Isolation working voltage: ±200Vrms Functional
- **Compact, space saving solution**
  - Package: SSOP-16 (10.5mm x 4.6mm)
  - Ambient temperature range: -40 to 125ºC

BLOCK DIAGRAM



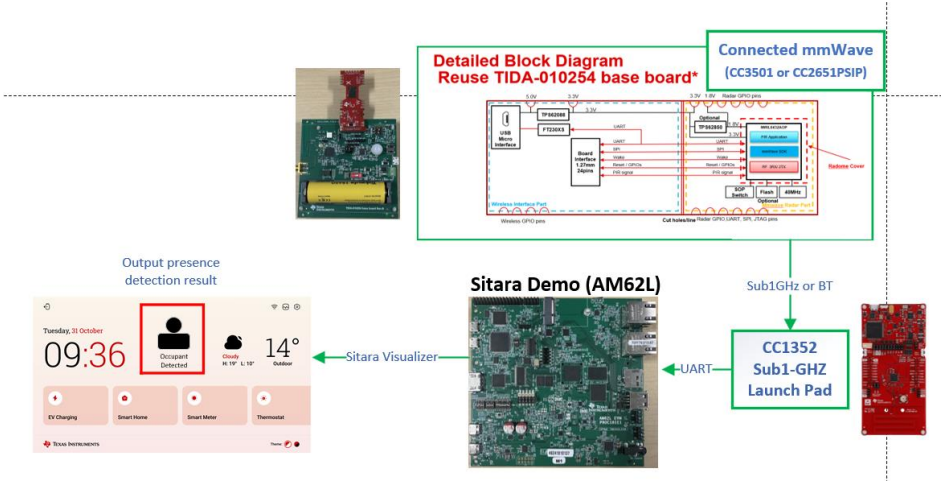
Integrated over-current protection

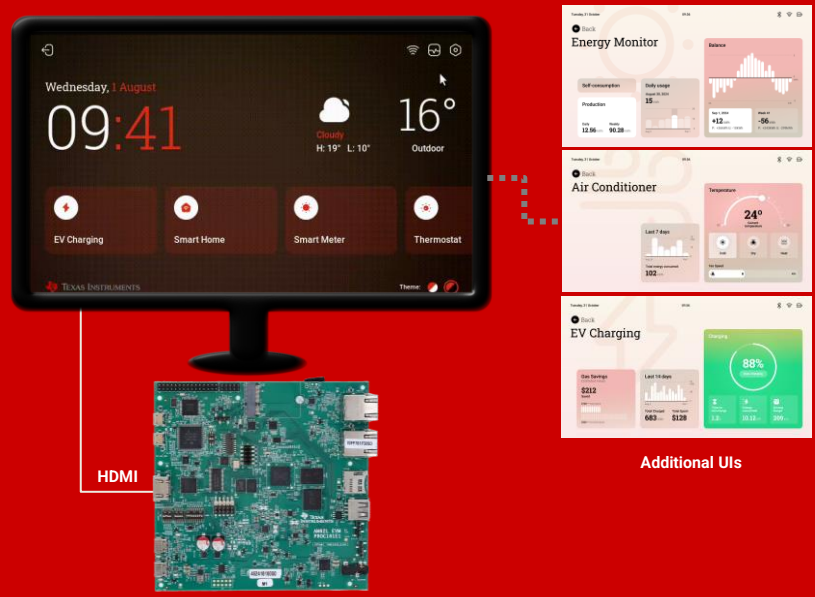




Multi-protocol Building Automation – HMI Control

- The **AM62L Arm® -based processor**: A low-cost, power-efficient system-on-chip (SoC) with TPS6214 Power Management balancing performance, energy efficiency, and small size
- **Dual Cortex® A53** – Utilize CPU to render fluid Smart Automation graphics
- Utilize **Linux® & Processor SDK** for scalability of & long-term focus for Building Automation



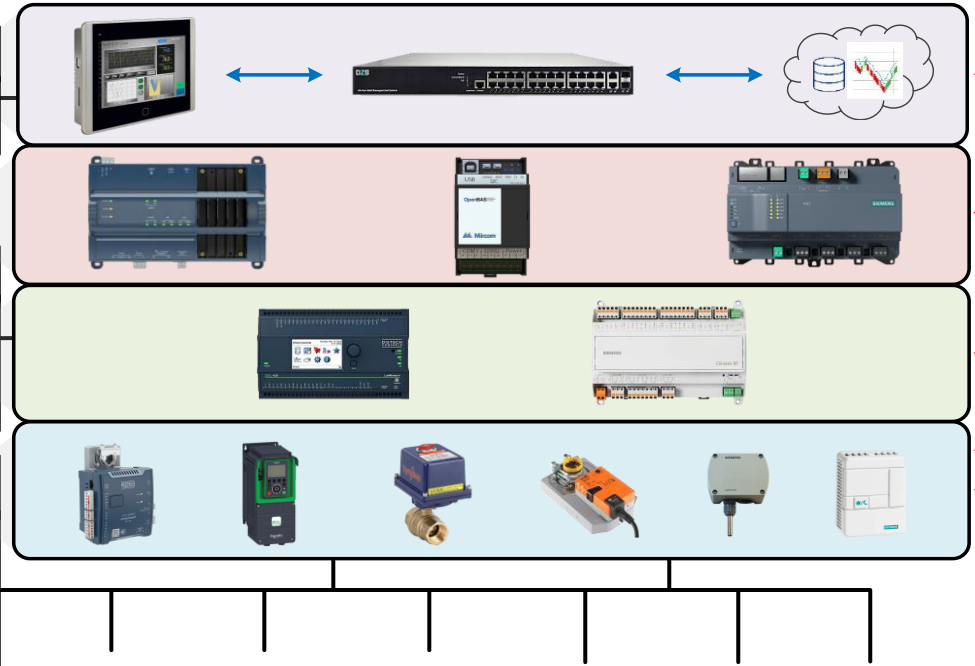


Showcases the capabilities of the AM62L Arm-based processor. Connected to a display, a light weight 2D home automation GUI is shown and rendered on the CPU for easy access & control to smart home devices. Remotely connect to end nodes using Matter, Thread, Zigbee & Sub-1 GHz TI 15.4-Stack.

HVAC Controller

- Communication Hierarchy
- Processing Architecture
- UIO

HVAC System Controller: Communication Hierarchy



Management Level
- Ethernet
- BACNet

Integration Level

Integration Level
- BACNet (IP/MSTP)
- Proprietary

HVAC Unit/Field Controller Level

Sensor & Actuator Level
- 0-10V/4-20mA
- LonWorks
- RS-485/Modbus
- BACNet
- KNX
- Proprietary

← Ethernet Switch, SCADA Workstation, HMI Panel

Top tier functional block in industrial buildings. Mostly Ethernet/BACNet based communication with lower-level controllers.

Mainly communication aggregation points for all lower level controls. Not typically controlling equipment directly.

Aggregation point of unit control modules, sensor data, field control device status

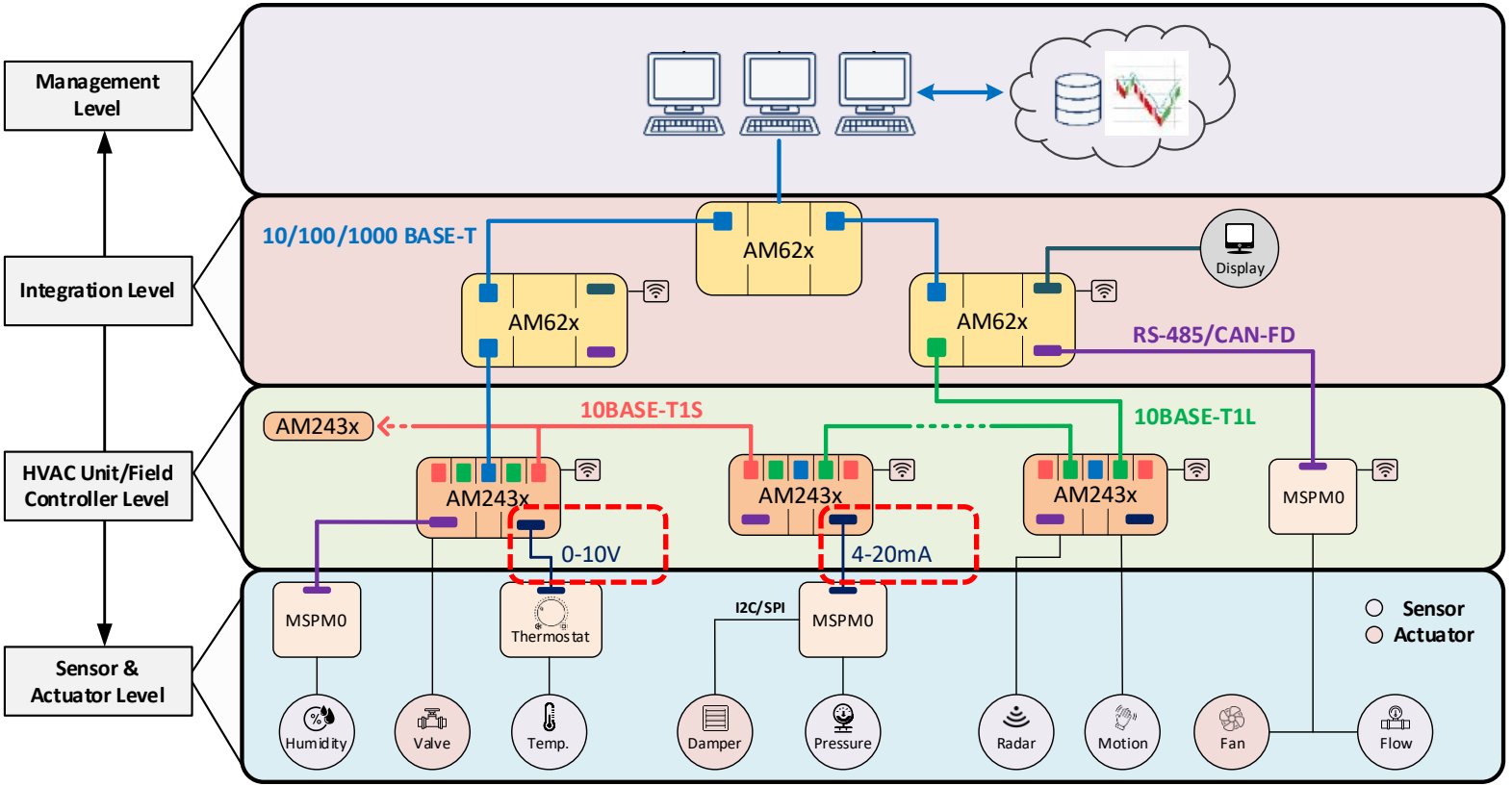
Unit and zone controls- typically controls a complete HVAC indoor/outdoor or a boiler/chiller for a defined space.

Unit controllers, sensor data collection, field level device control

Lowest Level controls and sensors- does a majority of the BAS system functions

← Actuators, VFDs, Sensors

HVAC System Controller: Processing Architecture



UIO

	Most Flexible UIO (4 Ch)		Most Flexible UIO (1 Ch)	Low Cost UIO (4 Ch)
	Samples Now		Samples by End of 25	
Building Automation (High End) RTM*: 4Q 26	**AFE67104** 13-bit DAC 16-bit ADC / ch (slower) No PGA / Single Range 48V Protection ± 12.5V, ± 25mA Out ± 12.5V Input			**AFE67304** 13-bit DAC 16-bit ADC / ch (slower) No PGA / Single Range 0-12.5V, 0-25mA Out 0-12.5V Input
Factory Automation RTM*: 3Q 26	**AFE87104** 16-bit DAC (8lsb INL) 20-bit ADC / ch PGA 48V Protection ± 12.5V, ± 25mA Out ± 48V (1 MΩ), ± 12.5V (HiZ), RTD, TC Input Adaptive Power Digital Input Digital Output w ext Drv	**DAC87104** 16-bit DAC (8lsb INL) 12-bit ADC / ch 48V Protection ± 12.5V, ± 25mA Out Adaptive Power	**AFE87101** 16-bit DAC (8lsb INL) 20-bit ADC PGA 48V Protection ± 12.5V, ± 25mA Out ± 48V (1 MΩ), ± 12.5V (HiZ), RTD, TC Input Adaptive Power Digital Input Digital Output w ext Drv	
Process Automation RTM*: 1Q 26	**AFE771H4** 14-bit DAC (1LSB INL) 20-bit ADC / ch PGA 48V Protection ± 12.5V, ± 25mA Out ± 48V (1 MΩ), ± 12.5V (HiZ), RTD, TC Input Adaptive Power **HART / ch** Digital Input Digital Output w ext Drv		**AFE771H1** 14-bit DAC (1LSB INL) 20-bit ADC PGA 48V Protection ± 12.5V, ± 25mA Out ± 48V (1 MΩ), ± 12.5V (HiZ), RTD, TC Input Adaptive Power **HART / ch** Digital Input Digital Output w ext Drv	

** All RTM dates subject to change. Also looking into APL (Advanced Product Launch)*

AFE67104

12-Bit DAC, Quad-Channel, Software-Configurable Analog Input and Output AFE

SAMPLING 2Q25

Features

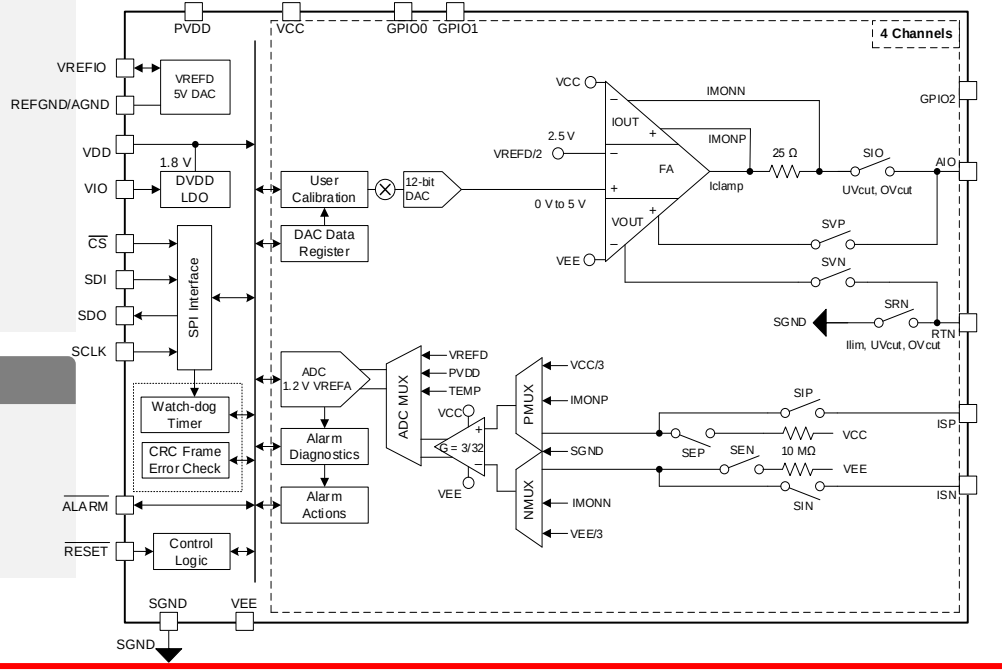
- Current output: ±25 mA
- Voltage output: ±12.5 V
- 13-bit monotonic DAC
- Current input (w/ external R_{SENSE}): ±12.8 V
- Voltage input: ±12.8 V
- Zero-drift, instrumentation amplifier
- 16-bit delta-sigma ADC
- Low-latency digital filter with 50 Hz and 60 Hz notches
- ±48 V tolerance on all analog I/O pins
- Wide Operating Temperature: -40°C to 125°C
- 9mm x 9mm 64-pin RGC (QFN) package

Applications

- Building Automation
- PLC
- Robotics Control

Benefits

- Have all Software in 1 central MCU
- SW programmable diagnostics and fault management



HVAC Others