Technical White Paper

TI Solutions to Increase Efficiency of Air Conditioner and HVAC

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ABSTRACT

Annual Performance Factor (APF) and Seasonal Energy efficiency Ratio (SEER), are key ratings to evaluate energy efficiency of air conditioners and heating, ventilation, and air conditioning (HVAC), their requirements keep increasing. This technical white paper introduces TI solutions, such as Power Factor Correction (PFC), Auxiliary Power Supply, Digital Signal Processor (DSP), Compressor Motor Drive, Fan Motor Drive, Temperature and Humidity Sensors, as well as Millimeter-wave Radar, to help Air Conditioner and HVAC to meet those increasing requirements.

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1 Introduction

Aligns with the sustainable development needs of modern society and consumers' heightened awareness of energy-saving and environmentally friendly products, numerous countries and regions have implemented a series of policy measures, including financial support, preferential tax policies, and mandatory energy efficiency standards, to incentivize enterprises and individuals to adopt air conditioners with higher APF and SEER ratings.

As a leading semiconductor provider, Texas Instruments (TI) continues increasing attention to energy efficiency and environmental protection, leveraging advanced semiconductors to assist air conditioner manufacturers in enhancing energy efficiency standards at the system level.

Figure 1-1 illustrates a typical air conditioning system, including an indoor unit and an outdoor unit. The primary subsystems includes PFC, Auxiliary Power Supply, DSP, Compressor Motor Drive, Fan Motor Drive, Temperature and Humidity Sensors, as well as Millimeter-wave Radar. This document explores TI's solutions for each of these subsystems.

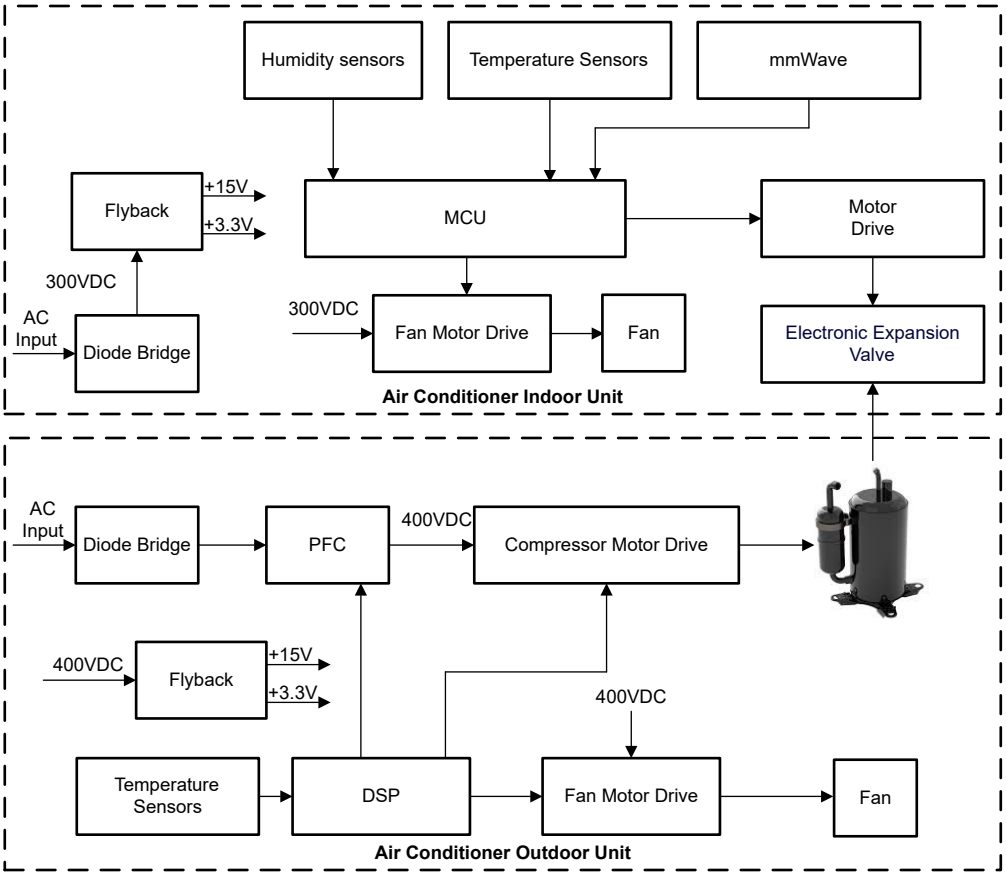

Figure 1-1. Air Conditioning Outdoor Unit

2 Power Factor Correction (PFC)

The current mainstream PFC employs a bridge-based solution, utilizing IGBT or MOSFET as the switching device. This approach results in significant losses in the input bridge rectifier and power switches, leading to an overall efficiency of only around 96-97%. Additionally, due to limited switching frequency, the size of boost inductor is big, consequently increasing the overall volume and weight of the PFC.

TI has introduced a Totem-Pole PFC solution based on the third-generation semiconductor GaN. This Totem-Pole PFC replaces the traditional diode bridge with active switches and utilizes GaN instead of MOSFETs, thereby enhancing efficiency with a peak efficiency exceeding 99%.

Due to the improved efficiency and faster switching frequency, the Totem-Pole PFC is well-suited for high-power-density applications. It can further reduce the size of the boost inductor, ultimately enhancing power density.

TIDA-010203 and TIDA-010236 are two digital Totem-Pole PFC reference designs based on GaN and C2000, achieving peak efficiencies of 99.1% and 98.6%, respectively.

3 Flyback Auxiliary Power Supply

Taking a common household air conditioner as an example, its standby power consumption typically ranges between 1-5W. Calculated over a 24-hour period, the daily standby power consumption falls within 0.024 to 0.12 kWh. Although this figure may seem insignificant, accumulated over time, the total energy consumed becomes substantial. Therefore, users should strive to minimize standby power consumption when using air conditioners.

Texas Instruments boasts a comprehensive portfolio of auxiliary power supply products, among which UCC28730 stands out as a notable mention. UCC28730 is a switching power supply chip with zero standby power consumption, supporting standby power below 5mW, thereby meeting energy-saving and environmental protection requirements. By leveraging Primary Side Regulation (PSR), it eliminates the need for optocouplers, simplifying circuit design and reducing costs. Furthermore, it features wake-up signal detection, enabling rapid response to large load steps and enhancing system responsiveness. The PMP31248 reference design showcases these capabilities of UCC28730.

4 Motor Controller Based on C2000 DSP and FAST Observer

The C2000 series of microcontrollers, designed by Texas Instruments specifically for real-time control applications, is a C28x-based 32-bit microcontroller. This series of MCUs features a high-performance core and application-optimized peripherals, making them ideally suited for advanced processing applications such as motor control, digital power, position sensing, and automotive radar. They boast a high-performance core, abundant integrated peripherals, and enhanced security features.

The Flux, Angle, Speed, and Torque (FAST) Observer, another offering from Texas Instruments, is a motor control observer designed for sensorless field-oriented motor control. Embedded within, it enables designers to identify, debug, and fully control any type of three-phase, variable-speed, sensorless, synchronous, or asynchronous motor control system. The FAST Observer accurately estimates the motor's flux, angle, speed, and torque without physical sensors, enabling sensorless control. Through advanced algorithms and models, the FAST Observer provides high-precision motor state estimation, enhancing control accuracy.

TIDM-02010 is a dual motor control with digital interleaved PFC reference design for HVAC and air Conditioner, which demonstrates the capability of a single DSP chip to simultaneously control an interleaved PFC and dual motors. The following diagram, based on the TIDM-02010 design, compares the efficiency and speed error between the FAST Observer and the eSMO Observer. It can be observed that the FAST Observer offers an efficiency improvement of over 5% compared to eSMO, with an even more significant 10% efficiency gain at low speeds, which is particularly crucial for air conditioners as they operate at low speeds for the majority of their operational time.

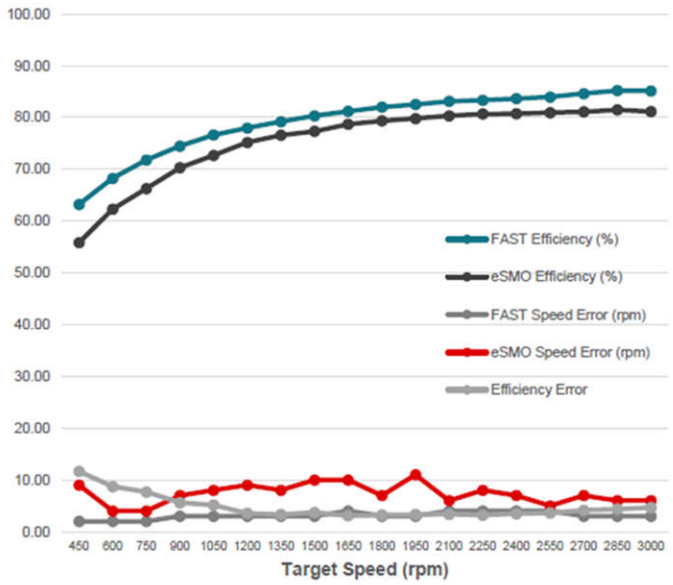

Figure 4-1. Motor Drive Efficiency Comparison: Fast vs eSMO

5 GaN IPM DRV7308 for High-Efficiency Fan Drive

The DRV7308 integrates six high-performance Gallium Nitride (GaN) Intelligent Power Modules (IPMs), achieving an efficiency of over 99%. Compared to traditional IGBTs and MOSFETs, it reduces power loss by 50%. This performance advantage not only significantly enhances the energy efficiency of motor drive systems but also drastically minimizes energy loss. The chip's unique 12mm x 12mm package design makes the DRV7308 an industry-leading ultra-compact, high-efficiency IPM for motor drive applications ranging from 150W to 250W. Due to its high efficiency, the DRV7308 eliminates the need for external heat sinks. Compared to similar IPM solutions, the size of the motor drive inverter printed circuit board (PCB) can be reduced by 55%, assisting engineers in developing more efficient and compact air-conditioning fan drives.

The TIDA-010273 is a 250W motor inverter reference design, which shows the capabilities of DRV7308.

6 Electronic Expansion Valve (EEV)

The Electronic Expansion Valve (EEV) is a device that utilizes electrical signals to control the flow of refrigerant. By adjusting the refrigerant flow, it enables precise control of the refrigeration system, thereby maintaining system pressure, achieving variable temperature heat exchange, and ensuring stable operation and efficient cooling of the air-conditioning system.

The DRV8847 is an integrated low-voltage dual H-bridge driver specifically designed to drive electronic expansion valves. It supports a wide input supply voltage range from 2.7V to 18V and boasts high output current capabilities: at an ambient temperature of 25°C, a single H-bridge can drive a load of 1A RMS, and in parallel mode, it can drive loads up to 2A RMS (under proper heat dissipation conditions). This allows the DRV8847 to drive motors or loads with higher power requirements. Effortless integration with controllers via a simple PWM interface facilitates precise motor control. A low-power sleep mode is also provided, consuming only 1.7µA of supply current in sleep mode at VVM=12V and TA=25°C, contributing to reduced energy consumption during no-load conditions. Built-in protection features ensure reliable motor operation and provide fault status indications, making it convenient for users to promptly detect and address faults.

7 DSP With Edge AI Feature

The application of Artificial Intelligence (AI) in the air-conditioning industry is becoming increasingly widespread, encompassing functions such as remote control, intelligent learning, and scenario adaptation. In terms of energy conservation and carbon reduction, AI plays a pivotal role in several aspects. It enables predictive maintenance, which significantly extends the lifespan of air conditioners and minimizes energy waste caused by malfunctions. Additionally, AI algorithms can optimize operational parameters by analyzing historical data, enhancing the energy efficiency ratio (EER) of air conditioners and reducing electricity bills for users. Furthermore, through real-time monitoring and prediction of system status, AI automatically adjusts the operational parameters of cooling towers, cooling pumps, chillers, and other equipment, minimizing energy consumption across the entire system. According to relevant data, the application of AI technology can achieve energy savings of 15-25% in central air-conditioning systems.

TMS320F28P550SJ processor, though widely used in real-time control applications, particularly in industrial automation, power electronics, and automotive electronics, can also play a significant role in certain AI-related scenarios, especially in embedded systems and edge computing, through its robust processing capabilities and specialized features. It can participate in AI applications in the following ways:

- **Embedded AI Inference**

  In embedded systems requiring extreme real-time performance, such as sensor fusion in autonomous vehicles or real-time path planning for industrial robots, the TMS320F28P550SJ can execute lightweight AI inference tasks. These might involve simplified versions of trained models, enabling quick decision-making at the edge.

  Leveraging its built-in Control Law Accelerator (CLA) and potentially Neural Network Processing Unit (NNPU), the TMS320F28P550SJ can accelerate certain types of neural network computations.

- **Data Preprocessing and Postprocessing**

  Within the data pipeline of AI systems, the TMS320F28P550SJ can manage data acquisition, preprocessing, and postprocessing. For instance, in machine vision applications, it can process raw image data from cameras, performing tasks like image filtering, edge detection, and other preprocessing steps before forwarding the refined data to more potent AI processors for deeper analysis.
- **Real-Time Control and System Integration**

  Real-time control is an indispensable element in many AI applications. The TMS320F28P550SJ collaborates with AI processors to execute real-time control tasks, such as motor control and motion control. Additionally, it translates the decision outcomes from AI processors into specific control commands, ensuring precise manipulation of the physical environment.

8 Temperature Sensor

Accurate and rapid responding temperature measurement can help air-conditioning systems achieve higher energy efficiency. TI's TMP61, a positive temperature coefficient (PTC) linear thermistor, offers high linearity and consistent sensitivity across the entire temperature range. Unlike metal and metal oxide-based NTCs, the TMP61 PTC is made of silicon, resulting in a linear relationship between resistance and temperature, as well as faster response times. In air-conditioning systems, the use of a single model of TMP61 silicon-based PTC temperature sensors can facilitate temperature detection at different locations with high resolution, while simultaneously simplifying material management. For more information on TMP61, see *The Benefits of TMP61 Linear Thermistors in Air Conditioner System*.

9 mmWave Radar

mmWave radar has the capability to accurately perceive the presence and status of people within a room, enabling intelligent adjustment of the air conditioning's cooling/heating capacity and air volume. This intelligent adjustment method not only enhances the comfort of the air-conditioning system but also effectively reduces energy consumption, achieving the goal of energy-saving and consumption reduction.

It is worth mentioning that mmWave radar senses targets by emitting and receiving electromagnetic waves, eliminating the need for image or sound information. As a result, there is no risk of privacy leakage. In the current context where users are placing increasing importance on privacy protection, this advantage of mmWave radar undoubtedly provides strong support for its application in smart home products such as air conditioners.

The IWRL6432 mmWave Sensor device is an integrated single chip mmWave sensor based on FMCW radar technology. The device is capable of operation in the 57GHz to 63.9GHz band and is partitioned into mainly four power domains: RF/Analog Sub-System, Front-End Controller sub-System (FECSS), Application Sub-System (APPSS) and Hardware Accelerator (HWA). IWRL6432 is specifically designed to have separate control for each of the above-mentioned power domains to control the states (power ON or OFF) based on use case requirements. The device also features the capability to exercise various low-power states like sleep and deep sleep, where low-power sleep mode is achieved by clock gating and by turning off the internal IP blocks of the device. The device also provides the option of keeping some contents of the device, like Application image or RF profile retained in such scenarios. For details about IWRL6432, see *Bringing Intelligence and Efficiency to Smart Home Appliances with TI mmWave Radar Sensors*.

10 References

- TIDA-010203,4-kW single-phase totem pole PFC reference design with C2000 and GaN
- TIDA-010236,4-kW GaN Totem-Pole PFC Reference Design for Appliances
- PMP31248, 230V AC input 12V primary side regulated flyback reference design
- DRV7308,650V, 205mΩ 3-phase integrated GaN intelligent power module (IPM)
- TIDA-010273,250W motor inverter reference design
- DRV8847,18-V, 2-A dual H-bridge motor driver
- TMS320F28P550,C2000™ 32-bit MCU, 1x C28x + 1x CLA, 150-MHz, 1.1-MB flash, 5x ADCs, CLB, AES and NNPU
- TMP61,1%, 10-kΩ linear thermistor in 0402, 0603/0805 and through hole packages
- IWRL6432, Single-chip low-power 57-GHz to 64-GHz industrial mmWave radar sensor
- Bringing Intelligence and Efficiency to Smart Home Appliances with TI mmWave Radar Sensors
- The Benefits of TMP61 Linear Thermistors in Air Conditioner System

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