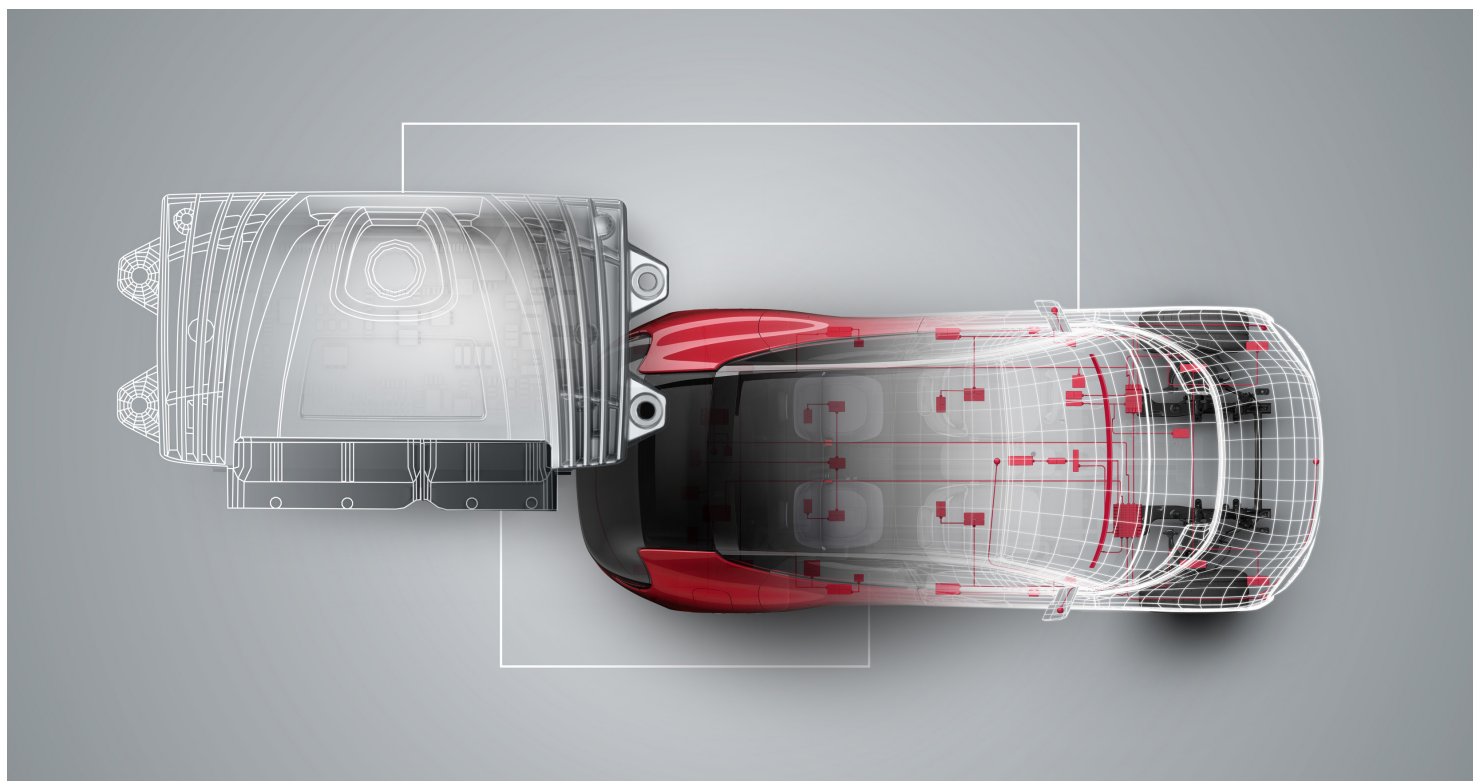




Refrigerant Control Software for Automotive Air Conditioners Developed in Virtual ECU Environments

Software made as SW-C on Trial Basis in View of Controller Integration

Sanden Corp. (Sanden), a manufacturer of compressors for automotive air conditioners and Integrated Thermal Management System (ITMS), has developed control software for a Compact Refrigerant Unit (CRU), a component of ITMS, in virtual ECU environments on a trial basis with Vector's vVIRTUAltargt. This is an attempt to provide control software as an AUTOSAR SW-C in view of ECU integration anticipated in the future.

Integrated Thermal Management System Developed for EVs

Sanden based in Isesaki, Gunma Prefecture is an automotive parts manufacturer that handles compressors for automotive air conditioners and automotive air conditioning systems. In addition to mechanical compressors and electric compressors for Electric Vehicles (EVs), it also supplies parts such as HVAC units, heat exchangers, electric coolant heaters, pipes for air conditioning, as well as heat pump systems and air conditioning systems for off-highway vehicles including construction and agricultural machinery to global OEMs.

Furthermore, Sanden has recently been working on the development of Integrated Thermal Management System (ITMS), which recovers heat from batteries, motors and inverters for EVs, as EVs cannot use exhaust heat from engines (Figure 2).

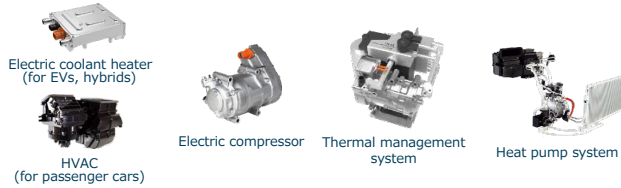
As a case study, this article introduces control software for a Compact Refrigerant Unit (CRU), a component of ITMS.



Figure 1. Sanden's main products. Sanden has the world's second largest share in compressors for automotive air conditioners (according to a survey by Sanden) ^[*1]

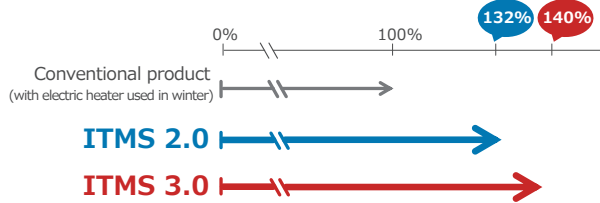
ITMS hardware x software

Sanden has ITMS components, both EC (core part) and software



Technological advantage

Realized higher electric cost efficiency than competitors (extension of driving distance)



Note: This is one example of the driving range improvement effect; the effect varies depending on the driving conditions and other factors.

Figure 2. Sanden's ITMS (Integrated Thermal Management System) enables total thermal management by recovering heat from EV batteries and motors. ITMS 2.0, in which refrigerant is fed into the air conditioning unit, and ITMS 3.0, in which refrigerant is not fed into the air conditioning unit, are under development^[2]

"The CRU's role is to control the electric compressor speed (rpm) and the opening of the expansion valve by sensing the temperature and pressure of the refrigerant to reach the target water temperature as instructed by the higher-ranked software," said Mr. Kenzo Oba of T-1 Section, ITMS Development Unit, R&D Center, Sanden in explaining the function.

Refrigerant Control Software Developed as SW-C in Preparation for ECU Integration

As a preemptive attempt, Sanden has developed control software for a CRU, a component of ITMS, as an AUTOSAR Classic (AUTOSAR) SW-C.

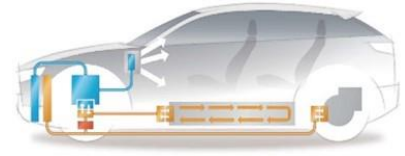
"We have been receiving a growing number of inquiries from OEMs whether CRU control software can be supplied as a

Flexible response to the PFAS regulations

With two methods, direct and indirect ones, systems that use propane gas as refrigerant can also be realized safely

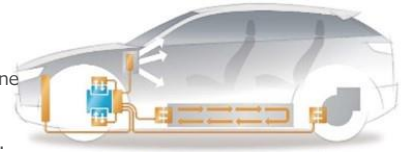
ITMS2.0

ITMS2.0 uses the **direct method**, in which refrigerant is fed directly into the air conditioning unit, realizing excellent responsiveness.



ITMS3.0

ITMS3.0 uses the **indirect method** that enables a significant reduction of refrigerant used in the propane gas refrigerant system in compliance with the **PFAS environmental regulations**.



SW-C as they want to consolidate ITMS functions into a domain controller or zone controller," said Mr. Oba. "We have decided to take up a new challenge as we also wanted to establish a scheme and accumulate the know-how ahead of the era of ECU integration."

The simplest approach to developing and testing an AUTOSAR SW-C would be to prepare an ECU with AUTOSAR but it requires considerable efforts for the development of an ECU platform and porting of AUTOSAR-compliant OS, which would be too much work for the preliminary assessment Mr. Oba was aiming for.

"We were aware that it would require certain amounts of efforts but initially thinking of developing a SW-C by using actual AUTOSAR," said Mr. Oba. "For this reason, we asked Vector Japan, a provider of MICROSAR, or AUTOSAR-compliant OS, about the license, etc., and were suggested to use vVIRTUALtarget, a tool that allows development in a virtual environment without a real ECU or MICROSAR, and decided to take that approach."

vVIRTUALtarget Realizes Level 1 to Level 3 vECUs

Virtual ECUs, generally written as vECUs or V-ECUs, are used to simulate the behavior of ECUs and automotive OS by using software and have the advantage of proceeding with development and testing without waiting for the completion of a platform or OS.

Virtual ECUs vary greatly in their composition and purpose, depending on the extent of virtualization. Five levels defined by

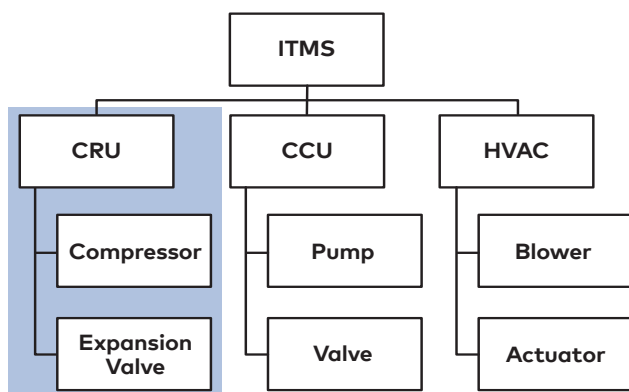


Figure 3. An image diagram of ITMS. In addition to a CRU (Compact Refrigerant Unit) cited as an example, ITMS consists of subsystems such as a CCU (Compact Coolant Unit) and HVAC (Heating, Ventilating and Air Conditioning)

Level	Overview
Level 0	It is used in SW-C control algorithm testing. It consists of a controller model or only C code generated from the controller model. It is defined but hardly treated as a vECU.
Level 1	This vECU is used in SW-C production code testing. It is possible to execute SW-C code at a specific timing by emulating RTE or some OS functions. It has no communication function and the SW-C communication part is at the signal level.
Level 2	It is used in SW-C production code testing, the same as Level 1. In Level 2, it is possible to evaluate a SW-C via network communication because BSW is emulated.
Level 3	This vECU is used in BSW testing (excluding the hardware reliant part such as MCAL) and network testing between vECUs in addition to SW-C production code testing.
Level 4	This vECU is for all BSW testing including MCAL and complex drivers in addition to SW-C testing. A hardware simulator that simulates a microprocessor at the command set level is necessary.

Table 1. Five levels of virtual ECUs defined by prostep ivip

prostep ivip, an industry group based in Darmstadt, Germany that is proceeding with the standardization of digitalization and data use in product development and production (Table 1), are used in a unified manner for the AUTOSAR environment in the industry^[*3]. Generally, Level 2 is suitable for the SW-C development and testing Sanden was working on. To develop an AUTOSAR BSW, etc., it is necessary to build a Level 3 or Level 4 vECU. Vector's vVIRTUALtarget is a solution that realizes Level 1 to Level 3 virtual environments (Figure 5). The advantage is that it allows the user to go ahead with checking the operation of the SW-C without waiting for the completion of ECU hardware or the integration of AUTOSAR and is compatible with AUTOSAR Classic.

Level 1 vECU Built to Test Refrigerant Control Software

First, Mr. Oba started building a Level 1 environment (Figure 6). "While getting familiar with how to use vVIRTUALtarget, we set the goals of checking the input and output of CRU control software, i.e., SW-C, and checking the procedure of generating an ARXML (AUTOSAR XML) file, which describes SW-C interface and data type, etc.," said Mr. Oba. First, from the CRU control model described with MathWorks' MATLAB®/Simulink®, C code and an ARXML file for AUTOSAR

were generated with MathWorks' tool called AUTOSAR Block. They were then given to vVIRTUALtarget to create a dynamic link library (.DLL), which became the SUT (System Under Test), and the .DLL was executed on CANoe and that is how it was done. "When updating the control model and outputting C code and ARXML again with the AUTOSAR Blockset, the past information remained in ARXML in some cases due to the AUTOSAR Blockset's behavior and it took time to figure out why," said Mr. Oba. "But the virtual ECU environment and testing including vVIRTUALtarget went smoothly." Note that in this environment, a higher-ranked ITMS controller did not exist and therefore appropriate messages were defined and set instead of target water temperatures, etc., which would have been sent as instructions.

Simplified HILS also Connected after Smooth Transition to Level 2 vECU

Next, Mr. Oba's team undertook the virtualization in Level 2 (Figure 7). Because vVIRTUALtarget supports ComM, a BSW communication module, it is possible to switch CAN and LIN communication requests from a SW-C. Note that in ITMS, the low-cost LIN is used to connect the electric compressor, expansion valve, and sensors.

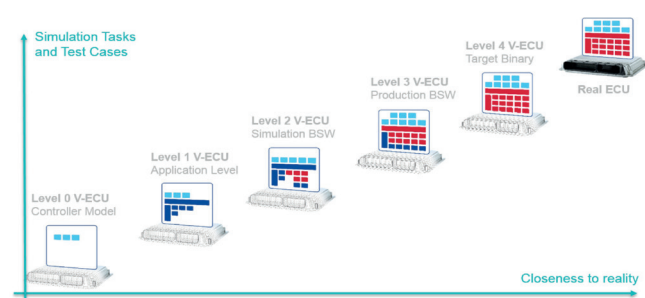


Figure 4. vECU levels defined by prostep ivip. Light blue stands for SW-C, blue for AUTOSAR's simulation area, and red for AUTOSAR's real code^[*3]

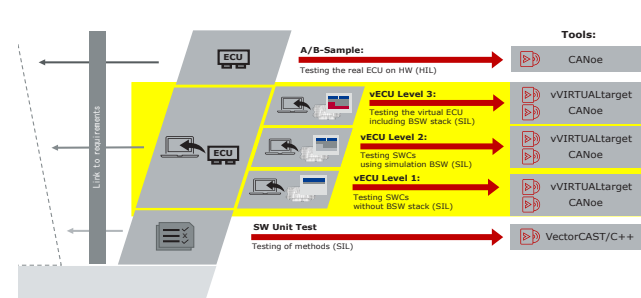


Figure 5. vVIRTUALtarget's target area (area marked in yellow). Level 1 to Level 3 vECU environments can be built

vECU Level 1: vVIRTUALtarget (BSW Emulation)

- It is possible to build a Level 1 vECU with vVIRTUALtarget's BSW Emulation
- It is possible to test a SW-C at the early development stage
- Emulating RTE and OS with vVIRTUALtarget Runtime enables Runnable to execute at a specific timing
 - Cycle execution, event execution
- Software interface created by vVIRTUALtarget:
 - Access to SW Port
 - Open Port: Distributed Object / System Variable for measurement and stimulation
 - Closed Port: Distributed Object / System Variable for measurement
- Example of building flow
 - Prepare ARXML (ARXML including SW-C information such as SW-C Description)
 - After reading ARXML with vVIRTUALtarget and doing the settings, automatically generate a code in line with Runnable
 - After implementing a generated empty function, build a vECU
 - It is also possible to use a code generated with MATLAB/Simulink
 - Load the vECU on CANoe - Communication Setup

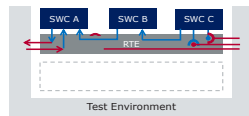


Figure 6. An image diagram of a Level 1 vECU using vVIRTUALtarget. Because it has no communication functions such as CAN and LIN, it is necessary to exchange messages on RTE. vVIRTUALtarget is compatible with several SW-Cs as showed in the Figure

A point to note is that vVIRTUALtarget alone is not compatible with Level 2 and therefore CANoe's Interaction Layer (IL) is needed to be used together. The CANoe IL is a simulation function that sends a message in accordance with communication specifications defined in a database such as ARXML, and it is possible to define network nodes, messages, signals, the transmission type that shows transmission timing, transmission cycle, as well as transmission and reception node responses.

"We have built an environment while referring to vVIRTUALtarget and CANoe Interaction Layer-related documents provided by Vector, and because we already built a Level 1 environment, moving on to Level 2 went smoothly," said Mr. Oba. "As for communication, by writing schedule, etc. in LIN's LDF (LIN description file), we have confirmed that LIN communication can be made from the CRU control software without a problem."

As the last step, testing was conducted by connecting with a third party's simplified HILS owned by Sanden (Figure 8). The electric compressor, expansion valve, pressure sensor, temperature sensor, as well as refrigerant were modeled in HIL. Note that the refrigerant has phases such as liquid and vapor, and because a phase change occurs due to the temperature or pressure, it is difficult to express in a general plant model and therefore Sanden's proprietary model developed in-house is being used. HILS and CANoe are connected via Vector's VN1611 interface.

"We have realized an environment that allows us to conduct testing efficiently such as completing the modification and rebuilding of control software in about 10 minutes," said Mr. Oba.

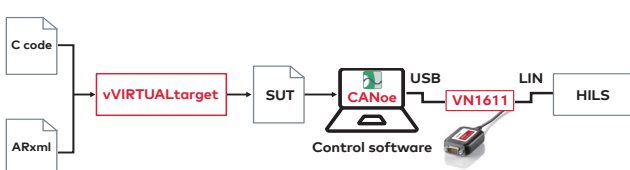
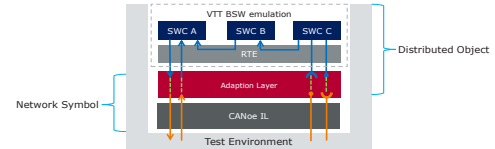


Figure 8. The composition of the environment where the third party's HILS owned by Sanden is incorporated. The Vector VN1611 is CAN/CAN FD/LIN interface hardware

vECU Level 2: vECU Level 1 + CANoe Interaction Layer (IL)



- The roles of Adaption Layer
 - Exchange data between Distributed Object and Network Symbol
 - Coordinate emulated BSW Service and BSW Module (e.g. CanM - Nm)
- Implement with a programming language (CAPL, C#)
 - If the request is small, it is possible to implement with Symbol Mapping alone
 - It is possible to shift from Level 1 to Level 2 seamlessly
- Example of building flow
 - Prepare ARXML (ARXML including SW-C such as ECU Extract and communication design)
 - Build a Level 1 vECU, load it on CANoe
 - Assign IL to a virtual node with CANoe - Simulation Setup
 - Implement Adaption Layer
 - Set Adaption Layer at the virtual node

Figure 7. An image diagram of a Level 2 vECU using vVIRTUALtarget. It is built by using vVIRTUALtarget's BSW emulation function and CANoe Interaction Layer. Network communication such as CAN and LIN is possible from SW-Cs

Acquiring Technology for the Era of Controller Integration

In summary, Mr. Oba said that the following effect was produced through virtual ECU environment building and SW-C testing with vVIRTUALtarget. "In preparation for the era of zone and domain controller integration, we have acquired how to develop CRU control software as a SW-C and testing schemes and build virtual ECU environments by using vVIRTUALtarget," he said. "I believe if such requests come from OEMs in the future, we will be able to handle them smoothly." In the Software-Defined Vehicle (SDV) era, the ECU composition is starting to change greatly and suppliers are expected to meet growing demands for development based on AUTOSAR or provision of a SW-C alone. Vector continues to support building of virtual ECU environments for AUTOSAR through vVIRTUALtarget.

^{[*1][*2]} Source: Sanden Corp.'s Medium-Term Management Plan (SHIFT2028) dated Feb. 26, 2024, https://www.sanden.co.jp/ir/document/pdf/brief/briefing36_12_4b.pdf

^[*3] Source: prostep ivip's white paper Virtual Electronic Control Units, V1.0, dated March 2020, https://www.ps-ent-2023.de/fileadmin/prod-download/WhitePaper_V-ECU_2020_05_04-EN.pdf

Sources :

Figures 1, 2, 3, 8: Sanden Corp.
Figure 4, Table 1: prostep ivip
Cover page, Figures 5, 6, 7: Vector Japan Co., Ltd.

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