2023

WHITE PAPER: HIGH-VOLTAGE CONTROLLER CHIPS FOR NEW ENERGY VEHICLES IN CHINA

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HIGH-VOLTAGE CONTROLLER CHIPS FOR NEW ENERGY VEHICLES IN CHINA

WeChat Account of
NE Times New Energy

WeChat Account of
NE Times Smart Car

CONTENTS

PART

01

Chapter 1

Development Trends in China's New Energy Passenger Vehicle (NEPV) Market

1.1 China's NEPV Market Sees Rapid Growth

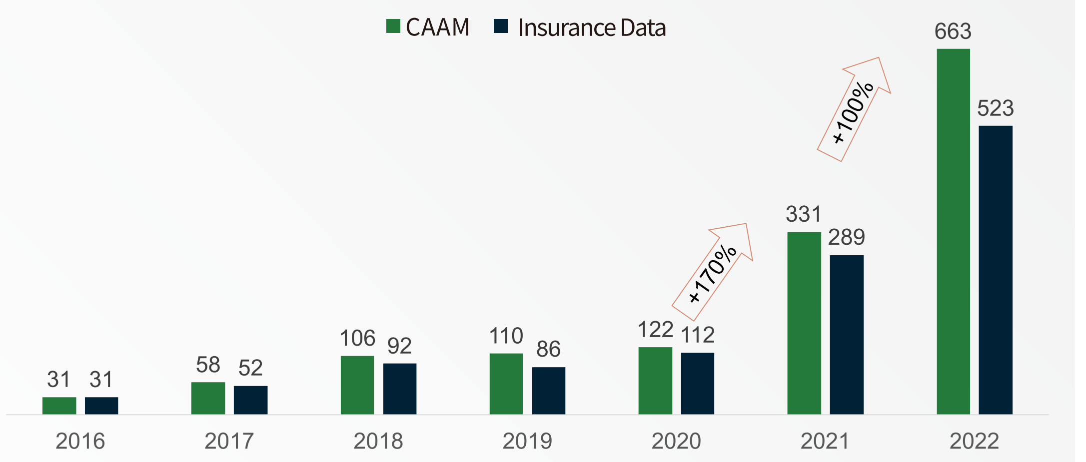
Electrification is currently reshaping China's automotive industry. The wave of electrification and smart technology presents the Chinese industry with monumental changes that it has not faced since its early days of development.

Our research shows that early market development was primarily driven by policy. As technologies related to motors, power batteries and electronic control systems improved and with the blessing of intelligent network connection configurations, there was a vast improvement in the cost performance of New Energy Vehicle (NEV) products. The dual development of "range + recharge experience" went even further in giving wings to this growth. At the same time, a shift was occurring in the degree to which consumers accepted NEVs.

Facilitated by the above factors, there has been a marked progress in the development of Chinese NEPVs since 2020, as they gradually entered a development model driven by the dual forces of "policy + market".

In 2021, epidemic prevention and control entered normalization, and the order of enterprise research and development and production quickly resumed. In addition to various new technologies reducing costs and increasing efficiency, the research and production progress of new energy and energy-saving vehicle models accelerated. The production of new energy passenger vehicles quickly increased to 3.09 million units (including in credit assessment numbers), an increase of 8.4 times compared to 2016. According to the latest statistical data from the China Association of Automobile Manufacturers (CAAM), in 2022, China's new energy vehicles continued to experience explosive growth, with production and sales reaching 6.629 million and 6.463 million units respectively, a year-on-year increase of 100.2% and 96.8%, maintaining the world's first place for 8 consecutive years, accounting for 63% of the global share of new energy vehicles.

Figure 1: China's NEPV Market Cumulative Sales (Unit: 10,000 units)



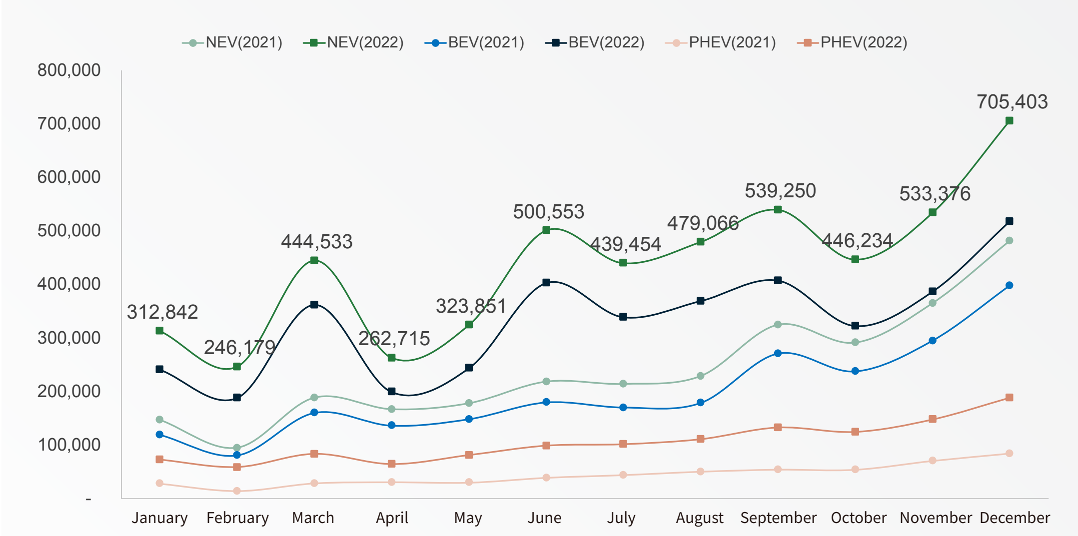
Source: CAAM data, data of compulsory traffic insurance purchased at the terminal, analysis compiled by the NE Times Research Institute

1.2 Fuel Vehicles Sales Fall, NEV Sales Soar

According to statistical data from compulsory traffic insurance purchased for passenger vehicles, in 2022, total sales for China passenger vehicles was 19.93 million units, representing a slight decline from 2021 and down 2.27% YOY, but overall remaining stable. In terms of vehicle engine type, sales in fuel vehicles fell, while sales in NEVs and EEVs were strong. Of those, internal combustion engine vehicle (ICEV) sales were down 19.5% YOY to 13.167 million units. Whereas, NEV sales were up 80.9% YOY to 5.233 million units, with market penetration climbing from 14.2% in 2021 to 26.3% in 2022.

Of various types of NEVs, battery electric vehicle (BEV) sales were up 67.8% YOY to 3.974 million units and plug-in hybrid electric vehicle (PHEV) sales were up 140.1% YOY to 1.26 million units. BEV monthly sales still accounted for 2.5-4 times those of PHEV sales, but PHEV YOY growth was higher.

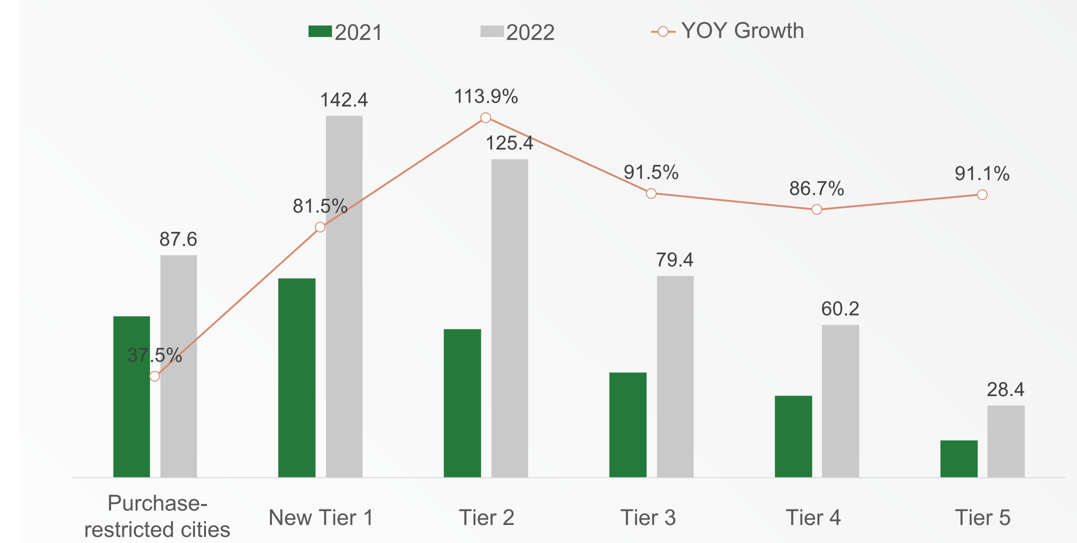
Figure 2: China's NEPV Market Monthly Sales (unit)



Source: Data from compulsory traffic insurance purchased at the terminal, complied by the NE Times Research Institute

The Chinese market is growing fast primarily because the market penetration rate is growing in different tier cities and different price ranges. The changes in NEV market distribution in 2022 compared to 2021 were primarily reflected in third-to-fifth-tier cities, with a significant increase in product sales of 100,000-150,000. Sales in cities with purchase restrictions grew by just 38% in 2022, while other tier cities saw growth of over 80%, of which, growth in second-tier cities reached 114%, demonstrating the shift from policy-driven sales to market driven sales. In terms of market penetration rates, the NEV penetration rate of new cars in purchase-restricted cities reached 41%, while penetration rates in other tier cities grew from 5-8% to 16-30%.

Figure 3: China's NEPV Market Sales Distribution by City Tier (Unit: 10,000 units)

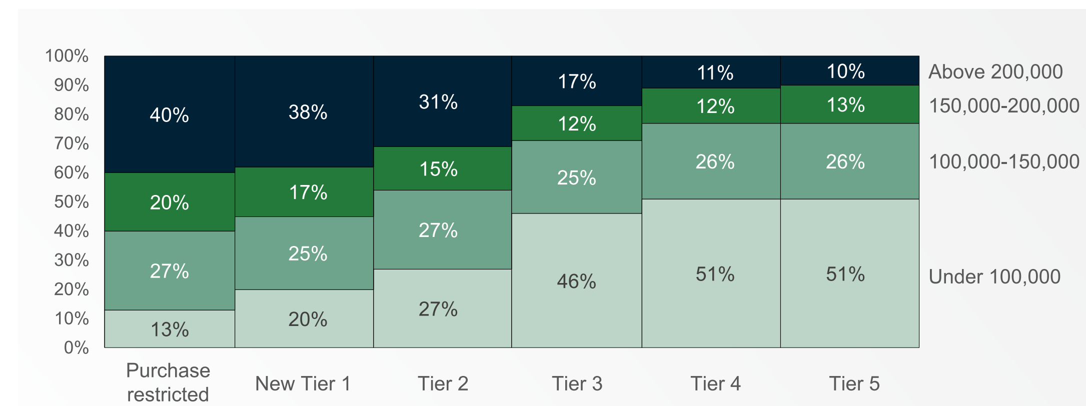


Source: Data from compulsory traffic insurance purchased at the terminal, complied by the NE Times Research Institute

In terms of the growth over different price ranges, the 100-200 thousand range market saw rapid growth of up to over 270% and is currently the main growth engine in the market.

The rapid growth of the 100,000 to 200,000 segmented market has made up for the existing market gap and is the main reason for market growth. Unlike the market segmentation structure where there was a significant vacancy of 100,000 to 200,000 yuan in 2021, the proportion of the 100,000 to 200,000 yuan market in cities at different levels in 2022 was at least 37%. Products with a price of over 200,000 yuan were mainly sold in second tier or above cities, while those with a price of less than 100,000 yuan were more concentrated in cities of third tier or below.

Figure 4: 2022 Chinese NEPV Price Distribution



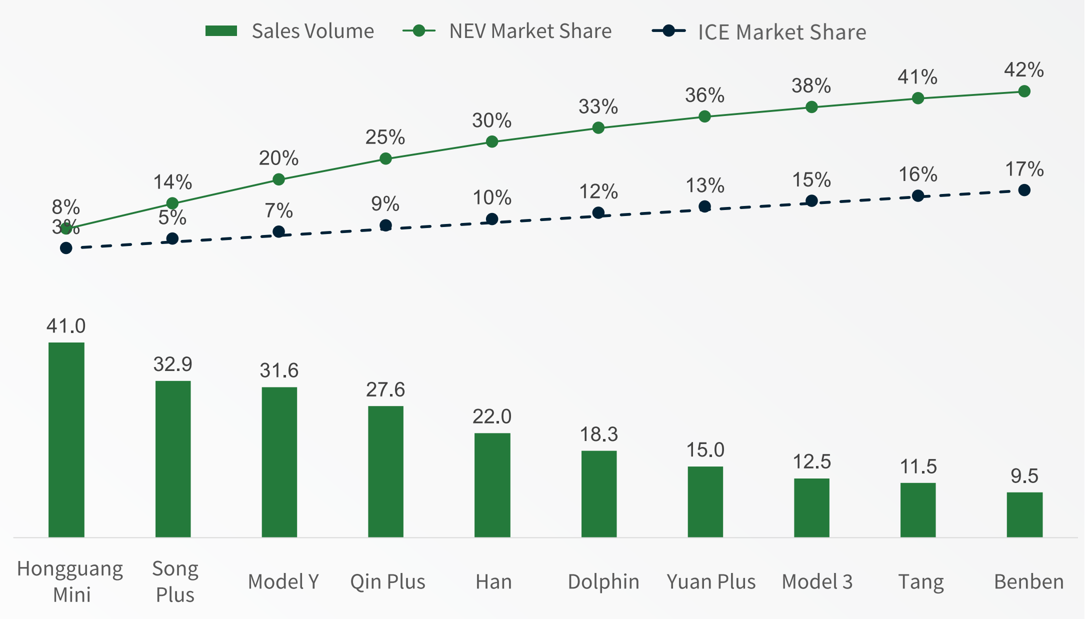
Source: Data from compulsory traffic insurance purchased at the terminal, complied by the NE Times Research Institute

In terms of penetration rates, there was a move away from the "dumbbell" structure of 2021 with significant increases in penetration in all market segments. In terms of class, in the BEV market, A-class annual growth rate reached 94.2%, with 1.303 million units sold, overtaking the A00-class market to become the biggest market segment. There was a clear slowdown in A00-class growth, with 22.9% YOY growth and 1.014 million units sold. The B-class market saw 61.4% YOY growth with 847,000 units sold. Due to its low starting base, the A0-class and C-class markets enjoyed the fastest annual growth with YOY growth of 133.2% and 145.1% respectively, and sales of 476,000 and 314,000.

In the PHEV market, A-class sales grew fastest, with YOY growth of 183% and 694,000 units sold. C-class and B-class performed relatively equally, with YOY growth of 80% and 105.1% respectively and 296,000 and 228,000 units sold.

Main manufacturers and vehicle models: The majority of top 20 car manufacturers maintained growth, with BYD enjoying over 200% growth for a 30% market share. The explosive effect of the new energy market is obvious, with the top 10 models accounting for more than 40%, while the corresponding share of top 20 models in the fuel vehicle market accounted for just 28%.

Figure 5: China's Mainstream NEPV Market Sales Performance in 2022



Source: Data from compulsory traffic insurance purchased at the terminal, compiled by the NE Times Research Institute

Driven by a multitude of factors, the Chinese market grew rapidly in 2022, with wholesale and retail reference already surpassing the 5 million scale. At present, China's new energy market leads the European and US markets in various metrics such as scale, penetration rate and growth.

1.3 Driving Factors behind High-speed Development

The influence of various driving factors affecting the supply and consumer side in the development process of NEVs has not remained unchanged; they have been constantly adapting to adjustments and responding flexibly to feedback from the end market.

The key driving factor for the supply side policy is the dual point policy for new energy vehicles. Since 2018, significant revisions and additions have been made, resulting in an increasing proportion of points. The standard model scores for new energy passenger vehicles have continued to decrease, and the number of points that can be earned by a single vehicle has decreased. This is because new energy vehicles have significantly improved their cost-effectiveness and accelerated penetration due to the technological integration of key components. They have already transitioned from a purely policy driven market to a market driven by both market and policy.

Road privileges, purchase tax deductions, subsidy policies and other short-term policy factors are coming to an end. Long-term factors, such as the increasing maturity of NEV product performance and the constant reduction of TCO (total cost of ownership), will become the new deciding factor determining the degree to which consumers accept NEVs in the future.

Degrading of road privileges: With access to "green channels", NEVs enjoy a major advantage in cities that have purchasing and driving restrictions. For example, consumers have proven to be unprecedentedly enthusiastic about NEVs in cities that have purchasing and driving restrictions like Beijing, Shanghai, Hangzhou, Guangzhou and Shenzhen, due to "passive" considerations over driving requirements, applying for license plates and so on. However, the current state of congestion in megacities is still pretty bad and license plate purchasing restriction policies in cities like Beijing and Shanghai are still relatively strict. For example, in 2023, Shanghai stopped issuing its quota of special license plates for plug-in hybrid (including extended-range) vehicles. In the future, as the number of NEVs rapidly increases, policies for NEVs like road privileges will most likely be cancelled and license plates will become uniform again.

Purchase tax exemption: Consumers primarily purchase NEVs because of the relevant tax incentives, which include zero purchase tax and zero gas excise duties. There is a whole series of tax policy relief advantages that reduce the purchasing cost of NEVs to some extent. This is also one of the major factors in wanting to realize the equal price of oil and electricity. In 2023, NEVs will still be exempt from purchase tax and this will continue to drive sales. Although there will be alterations to the purchase tax policy from the beginning of 2024, the total tax exemption amount for 2024-2025 will still be as high as 30,000 yuan, and beginning in 2026 purchase tax will only be 5%, with a total tax deduction of 15,000 yuan. Tax benefits will therefore remain.

State subsidies withdraw while regional subsidies catch up: According to the Ministry of Finance, the subsidy policy for NEV purchases expired on December 31, 2022, as the 13-year-long “state subsidy” was officially retired from history. However, going into 2023, regional governments across China will successively introduce policies to support consumers purchasing NEVs, easing the pressure on end sales. These will include car purchase subsidies, purchase tax deductions, the issuance of car vouchers and giving NEVs free limited travel and parking among many other measures. Therefore it is clear that although the momentum of subsidies is slowing down, they are still proceeding at a gentle pace, and will still play a role in NEV sales in some regions.

Improved charging experience: the growth of EVs in China is gradually shifting away from being driven by government policy and license plate privileges to being driven by consumers’ actual demands. The price of recharging, time costs, convenience and other factors are undoubtedly key prerequisites for consumers to move over to EVs. In terms of policy, according to statistics, in 2022, of 200 battery charging and replacement policies, 38% mentioned promoting the construction of electricity replacement facilities primarily focused on Guangdong, Chongqing, Beijing, Shanghai and other regions where the promotion of NEVs has been relatively successful; 25% of policies mentioned using financial subsidies to encourage the construction and operation of charging and replacement facilities, primarily focused on Zhejiang, Guangdong and other coastal cities.

In terms of changes to consumer side policies, once consumers were assisted in gaining a relatively extensive understanding and acceptance of NEVs, then policies were introduced to stimulate interest, such as road privileges and subsidies. Then there was a shift to infrastructure construction and technology upgrades, which helped consumers free themselves from a “passive” mindset to a “proactive” mindset.

1.4 Three Main Stages of NEPV Development

Over the past decade, Chinese NEVs have undergone a rapid development process from being almost nonexistent to readily available. Can this momentum of rapid growth be sustained in the long-term?

After tracking the industry for a long time, the New Energy Times divided the development of China’s NEPV industry into three stages.

The first stage was before 2020 when the NEV industry overall was still in the incubation period. Initially, the government relied on large financial subsidies to encourage the growth of leading companies both upstream and downstream in the industry chain. During this process, manufacturers released products that were primarily focused on B-end transportation and the A00-class market, focusing on gaps in the transportation end and fuel vehicle market, and relying on government subsidies to support the whole industry chain’s growth. In this stage, new energy models had no price advantage over fuel models and it was more about differentiating competition.

The second stage was from 2021 to 2022 when NEVs had a competitive advantage in certain market segments. As the industrial chain was gradually established, the government began to slowly reduce financial subsidies. Automotive manufacturers looked to exploit the practical advantages of NEVs, and in the high-end vehicle segment, equipped highly intelligent configurations to compete with high-end fuel vehicles. In the entry segment, manufacturers fully exploited cost advantages to be competitive. NEVs rapidly penetrated into the high-end and entry sectors, and the entire market took on a “dumbbell-shaped” structure with high penetration rates at either extreme.

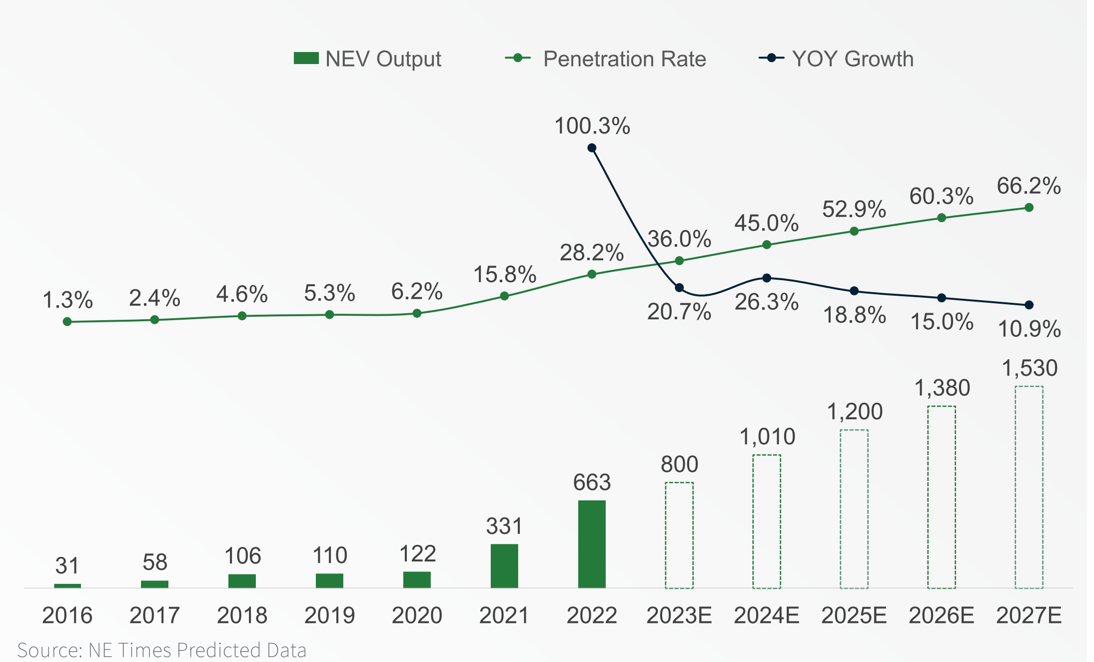
Next, the industry will enter the third stage: large-scale commercialization. NE vehicles will enter into fierce competition with fuel vehicles in every market sector. At that time, the industry will face a range of new issues such as how to ensure governmental fiscal levies, how to realize and maintain profits and whether consumer acceptance can move forward to the next level.

Figure 6: Various Stages of China's NEPV Market's Development

	Stage 1: Industry incubation	Stage 2: Differentiation competition	Stage 3: Large-scale commercialization
	~2020Y	2021Y~2022Y	2023Y~
Government	Rely on large-scale fiscal subsidies, encourage growth of leading companies up and downstream	Reduce fiscal subsidies	Gradually withdraw monetary policies
Manufacturers	Launched products are mainly subsidy oriented	Develop products for the gaps in the fuel vehicle market	NEV products start to compete directly with fuel vehicles
Markets	Aimed at B-end market and A00-class low price products	Dumbbell-shaped market with high penetration at both extremes	Aimed at mainstream market, increase overall penetration rate

Based on our long-term observations on the layout of mainstream automotive manufacturers in China, the development of the electric supply chain and overall market trends, we have tried to make the following appraisal on the future production scale of Chinese NEPVs: we predict that by 2024, the annual production of Chinese NEVPs will exceed 10 million and continue to maintain growth. By 2027, the penetration rate of Chinese NEPVs will exceed 65% and dominate the mainstream market.

Figure 7: China's NEPV Market Scale Prediction (Unit: 10,000)



Source: NE Times Predicted Data

Brief Summary

In the current market stage, car manufacturers are striving to release more cost-effective and cheaper NEVs to achieve a truly market driven environment as quickly as possible. Only by doing this can a new transition be brought about in the industry and one that is more conducive to its positive development. With joint promotion from BYD, Geely, Great Wall and other manufacturers, some PHEVs would already be able to "arm wrestle" fuel vehicles and thus see a surge in sales in tier 3 and tier 4 cities; however the majority of BEVs must still wait for further effort from OEMs before this is possible.

With the NEV industry's development, high-voltage controllers have undergone a rapid and radical change. How to integrate more features, realize higher efficiency and guarantee safety readiness at a limited cost and vehicle layout are questions that the entire industry is working hard to resolve.

PART

02

Chapter 2

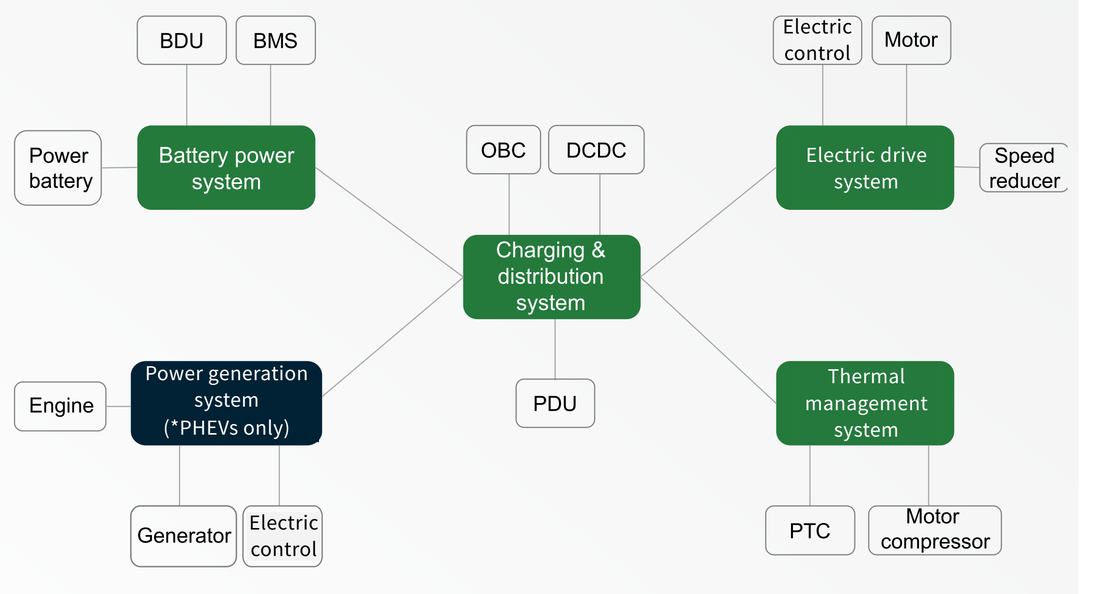
Development Trends of NEV High-voltage Controller

2.1 Upgrade of NEV High-voltage Architecture

2.1.1 Complete High-voltage Architecture is the Basis of NEVs

NEVs are driven purely by electricity. As drive power increased, in order to reduce running current, improve efficiency and save costs, all NEVs adopted high-voltage architecture. The voltage grade of all mainstream NEVs is over 300V, which is well above safe voltage levels. To guarantee the safety and stable operation of high-voltage platforms, NEVs are equipped with complete high-voltage architecture. This primarily includes power battery systems, charging and distribution systems, electric drive systems and thermal management systems. In PHEVs, this also includes power generation systems.

Figure 8: NEV High-voltage Architecture



Source: NE Times

Whereas:

The battery power system is the power supply unit for all electrical appliances, with power batteries at its core, a battery management system (BMS) as the controller unit and battery disconnect unit (BDU) as the security protection unit. The BMS protects and monitors the battery system, prevents over discharge, overcharge, overheating and triggers advance thermal runaway warnings. Battery power input and output are both in DC.

The electric drive system is responsible for powering a vehicle, with the motor as its core, it converts electric energy into mechanical energy to drive the wheels. The control unit is the motor controller. As all motors use AC drives, motor controllers require DC to be converted to AC, while also controlling the motor's torque and power output. To match wheel torque requirements, it is necessary to add a speed reducer between the motor and the wheel to achieve torque amplification, most speed reducers are single gear, with only a small number of vehicles using multi gears.

The charging and distribution system is responsible for charging the vehicle and unifying power distribution when externally discharging, to ensure that each power unit is supplying power normally. This primarily includes the onboard controller (OBC), DCDC converter and power distribution unit (PDU). Of which, the OBC is a vehicle charger that is primarily responsible for converting AC from the power grid to DC and charging the power battery. Some OBCs have external discharge functions that can output AC externally. The DCDC converter can provide voltage conversion for low-voltage appliances outside of the high-voltage system and supply power to low-voltage power units. The PDU is a power distribution unit that rationally distributes power to different electrical appliances and ensures stable operation.

The thermal management system primarily ensures that every component of an NEV is free from the effects of temperature shocks, primarily supplying suitable operational temperature control to the passenger compartment, electric drive system and power battery. The core components of the thermal management system include the electrical AC compressor, positive temperature coefficient (PTC) heater, valve body, HVAC and heat exchanger. Compared with traditional fuel vehicle thermal management systems, the electrical AC compressor and PTC heater in NEVs are newly added components, and the valve body is an upgraded component. Because thermal management systems in NEVs involve a lot more components, while at the same time requiring both heating and cooling, they are much more complex than those in traditional fuel vehicles. To improve efficiency, NEV thermal management systems tend to use centralized solutions, which, in addition to hardware, greatly increases control difficulty.

The power generation system is only installed on dual motor hybrid vehicles and primarily converts kinetic energy from the engine to electric energy, supplying power to the vehicle's entire power system, including the engine, generator and motor controller. During operation, this system only supplies electrical and thermal power in most working conditions, other components are as those described above.

2.1.2 800V is the Future Direction for High-voltage Architecture

In terms of types of NEVs, 400V is the mainstream voltage platform for BEVs on the market. According to insurance data statistics, in 2022, 400V platform vehicles accounted for 83% of Chinese passenger vehicles. After that were low-voltage 144V platforms, accounting for 16.4% that were primarily used for A00-class entry vehicles. 800V platforms (including voltage rated at 600V) were still overall in the initial stage. Due to their ability to recharge rapidly and their power consumption performance, 800V platforms took the lead in gaining favor and application in mid-to-high-end vehicles, with almost 20,000 units sold overall. PHEVs on the market primarily use 400V platforms due to the lack of demand for rapid recharging.

In comparison to 400V platforms, the advantage of 800V platforms lies primarily in the following two aspects:

- 800V power batteries recharge faster and more efficiently than 400V, ease consumers' anxiety over recharging to a great extent and improve the user experience.

- 800V platforms have lower energy consumption at high power output, especially when used with silicon carbide (SiC) power semiconductors and pure electrical mileage can be effectively improved.

The iterative process of mainstream car manufacturers' platforms shows that the majority have plans for 800V platforms. However, there are certain differences in the 800V platform application strategies among different companies. China OEM-new forces are the most enthusiastic, with all newly developed vehicles in the future using 800V platforms. Other car manufacturers are relatively conservative and use 800V platforms for some of their high-end vehicles. Therefore, for the foreseeable future, the majority of manufacturers' 800V and 400V platforms will remain in a coexistence phase.

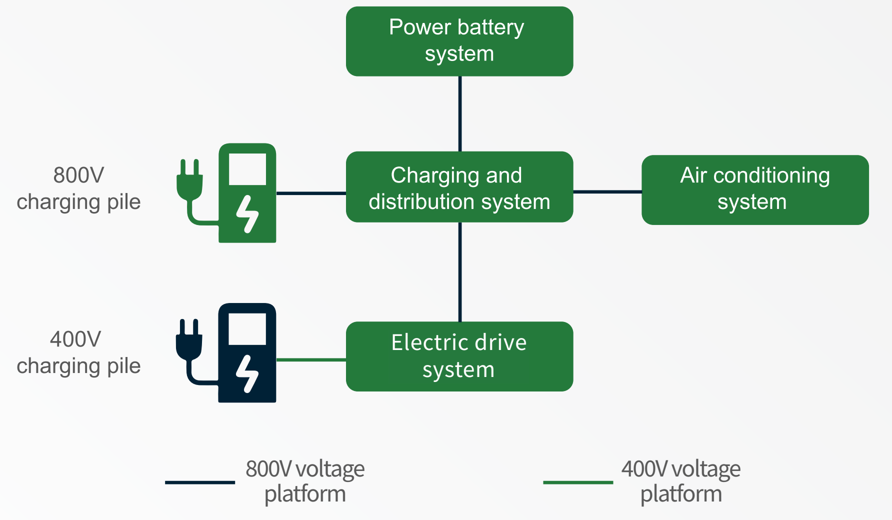
Figure 9: Iterative Process of Mainstream Car Manufacturers' Platforms

OEMs	Supports 800V High-voltage Vehicle Platforms
XPeng	F, H Platform
Changan	EPA2, SDA Platform
Geely	EPA, SEA-1 Plus Platform
GAC Aion	GEP3.0 Platform
Chery	E0X Platform
Li Auto	W Platform
NIO	NT3.0 Platform
IM Motors	E3 Platform

Source: NE Times

Of the 800V platforms, there are a variety of upgrade solutions for whole vehicle high-voltage platforms. The trend is toward using high-voltage for the whole system to guarantee that voltage for the entire system is stable and uniform. In addition, in order to be compatible with existing 400V platform DC charging piles, a booster unit is added, with the most common booster units at present integrated into the electric drive system and using the same power device as the motor controller, thus helping to reduce costs.

Figure 10: 800V Platform DC Solution



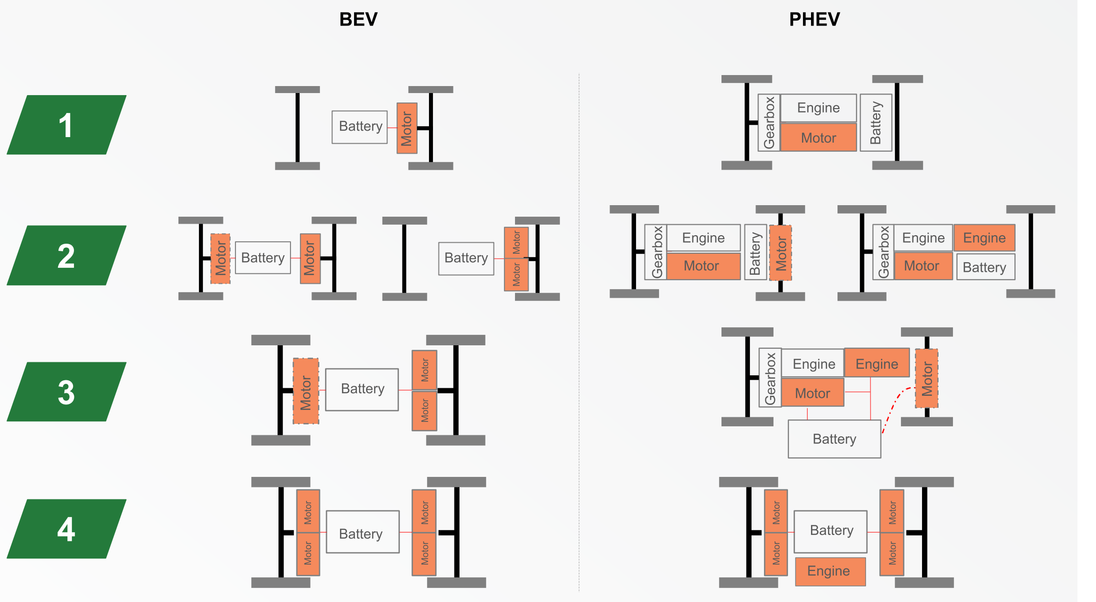
Source: NE Times

2.2 Current Situation and Technological Trends of Main Inverter Controller

2.2.1 Flexible Drive Arrangement

Due to the small size of the electric drive, it can be directly fitted to the drive shaft or even onto the drive wheel, which means it is not affected by limitations on carrying volume. On 4-wheel drive vehicles, a motor can be directly fitted separately on the front and rear axles.

Figure 11: NEV Motor Installation Layout



Source: NE Times

According to data from compulsory traffic insurance purchased, new energy auxiliary parts data compiled by the NE Times shows that in 2022, the number of installed motors was 6,882,500, equal to 1.31 times that the number of vehicles sold.

In order to achieve more power, dual motor high-power drives are used in high-end vehicles, that is, a single motor controller controls two motor drives. At present, such vehicles have been released, but those vehicles installed with this technology have not yet been officially launched in China.

Figure 12: OEMs that Use Dual Motor Solutions and the Corresponding Power

Brand	Model	Power of Dual Motor System
BYD	Yangwang U9	440-480kW
Tesla	Model S plaid	500kW
Aion	Aion Hyper SSR	540kW

Source: NE Times

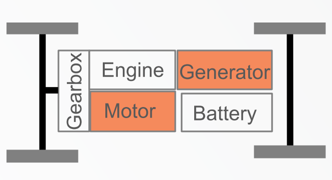
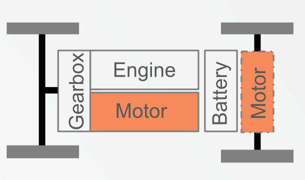
In hybrid systems, because single motor hybrids have poor fuel consumption when running at low battery, hybrid technology, best represented by the P2 and P2.5, has suffered declining market shares year by year. Dual motor hybrids have a clear advantage in terms of feed fuel consumption, and that advantage only becomes ever more evident when combined with long-range battery power. Therefore, car manufacturers, represented best by Chinese brands, launched products that are based on the dual motor hybrid model, and promptly dominated the market.

In 2022, dual motor hybrid technology PHEVs were sold 1,561,800 units, accounting for 91.5%. Of those, independent brands sold 1,514,500 units, accounting for 97% of the dual motor PHEV market and occupying a commanding market lead.

The engine, generator and drive motor systems of hybrid models using an FF or F4 layout are highly integrated, whereby a single motor controller includes two groups of modules that control both the generator and the drive motor forming a five-in-one integrated structure.

In order to be compatible with existing rear drive pure electric platforms, FR layout hybrid models adopt front range extender rear drive electric drive configurations. With this solution, the vehicle is equipped with two sets of motor controllers: the first set is integrated with the engine and the generator and installed in the front cabin of the car. With the exception of Great Wall's power generation + drive, car manufacturers such as Changan Deepal, Neta and Leapmotor only use this solution for generating electricity. The other set is integrated with the drive motor and installed on the rear axle.

Figure 13: Hybrid System Layout Configuration

FF Layout	FR Layout/F4 Layout
	
BYD, Li Auto, Geely, Great Wall (Lemon Hybrid), GAC Motor	Deepal, Leapmotor, AITO, Great Wall (Hi4)

Source: NE Times

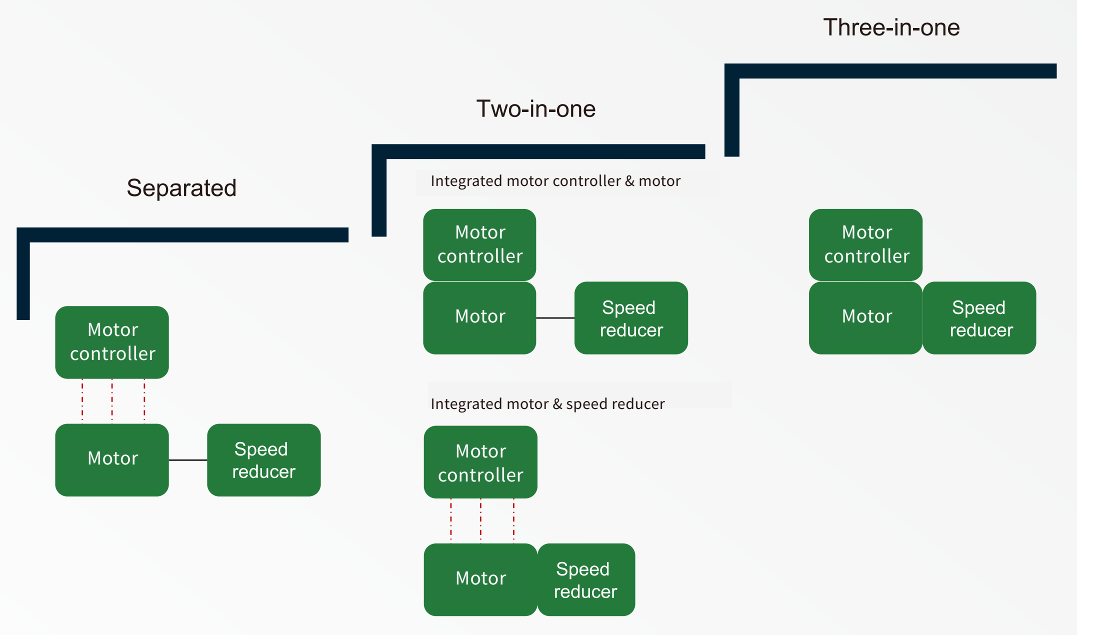
2.2.2 High Level of System Integration

To meet vehicle dynamics, economy and other demands, electrically driven products must be low cost, high performance, miniaturized and light weight, which has led to the trend toward integrated, high-speed and high-efficiency technology.

The integration of motors, controllers, speed reducers and other components is the mainstream application solution for electric drive assembly at present. Once integrated, savings can be made on shell structure, high-voltage wiring and the use of bearings, and lower costs can be achieved. EMI can also be optimized to reduce system weight and increase power density, while at the same time improving system efficiency and overall decreasing costs and increasing benefits.

Integrated electric drive systems are a two-in-one integration of early motors and controllers or motors and speed reducers which gradually developed into a three-in-one integrated motor, controller and speed reducer structure. Today, this has already further developed into a highly-integrated structure with all three components sharing one shell.

Figure 14: Integrated Motor, Controller and Speed Reducer Structure



Source: NE Times

Take BYD as an example, in 2018, BYD released their brand new e platform at the Beijing Auto Show Show. In contrast to the original separated scheme design, the e platform adopted a highly-integrated three-in-one system design which boasted 25% weight reduction, 30% volume reduction and 33% cost reduction.

By 2022, integrated electric drive schemes accounted for 79.5%. Of which, the three-in-one design dominated the mainstream and accounted for 85.5%. Second, came the multi-in-1 design (over 3 integrated components), which accounted for 12.1%. The two-in-one design was mainly used as a low power solution for early models or A00 models and only accounted for 2.4%.

Even higher integration is one of the key future development orientations. In particular, when integrated with OBC, DCDC and PDU, it is possible to effectively reduce the use of connectors, wiring and shell structure components. According to Changan's "original power super integrated electric drive" data, after all-in-one integration, it is possible to achieve 10% weight reduction, 5% volume reduction, 4.9% efficiency increase and 37% power density increase.

NE data shows that in 2022, there were 414,000 multi-in-1 sets installed, accounting for 9.6%. The trend toward multi-in-1 integration will become even more pronounced in 2023 as the cost advantages of multi-in-1 systems becomes more apparent.

Figure 15:Some OEMs Adopting Multi-in-1 Design

Car Manufacturer	Platform or Model	Integration Design	Supplier
Changan Deepal	EPAI Platform	7-in-1	In-house
BYD	e-Platform 3.0	8-in-1	In-house
Maple Auto	Maple 30X, 80V	5-in-1	Enpower
JAC	JAC iEV5E	5-in-1	Enpower
FAW	Bestune NAT	5-in-1	Huawei

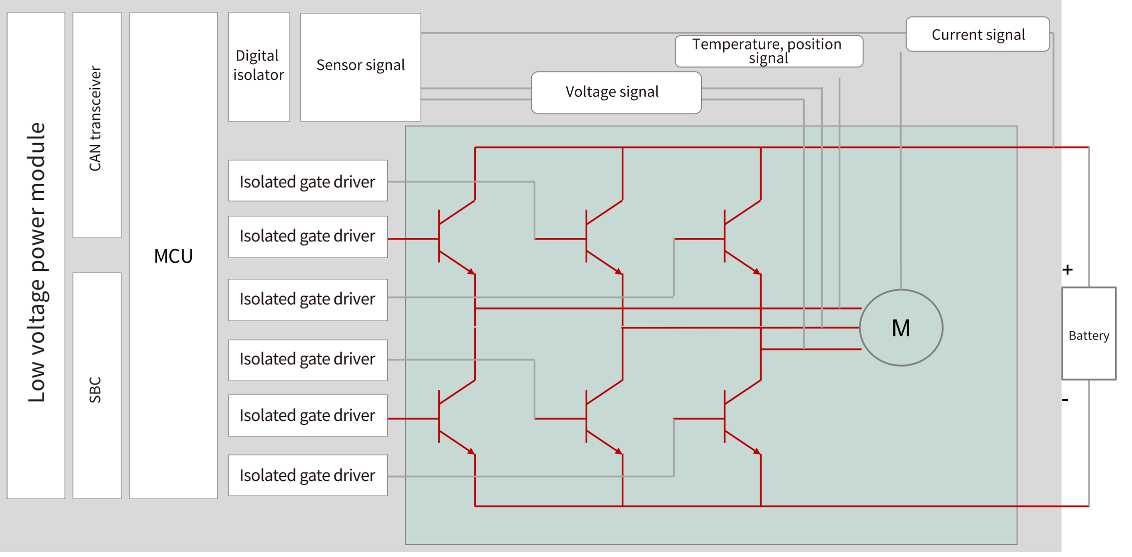
Source: NE Times

High-voltage Controller Chips for New Energy Vehicles in China
Development Trends of NEV High-voltage Controller 02

2.2.3 Motor Controller Requirements

In electric drives, the motor is controlled by the motor controller. The motor controller is composed of a low-voltage control unit and a high-voltage drive unit. The low-voltage control unit includes a motor control unit (MCU), CAN transceiver, SBC/PMIC power supply, gate drive, signal detection module and a power supply module. High-voltage drive units primarily consist of power devices, such as power modules or discretes. To guarantee high and low voltage safety, high and low voltage isolators must be used between the low-voltage control unit and the high-voltage drive unit for voltage isolation.

Figure 16: Motor Controller Structure Diagram



(Grey section depicts the low-voltage control unit; green section depicts the high-voltage drive unit) Source: NE Times

The main function of high-voltage drive units is to convert DC (power battery) to AC (drive motor). This accounts for almost 50% of the entire motor controller product's cost and is its most important component. Therefore, a very large part of the developmental orientation of motor controllers is decided by the power device.

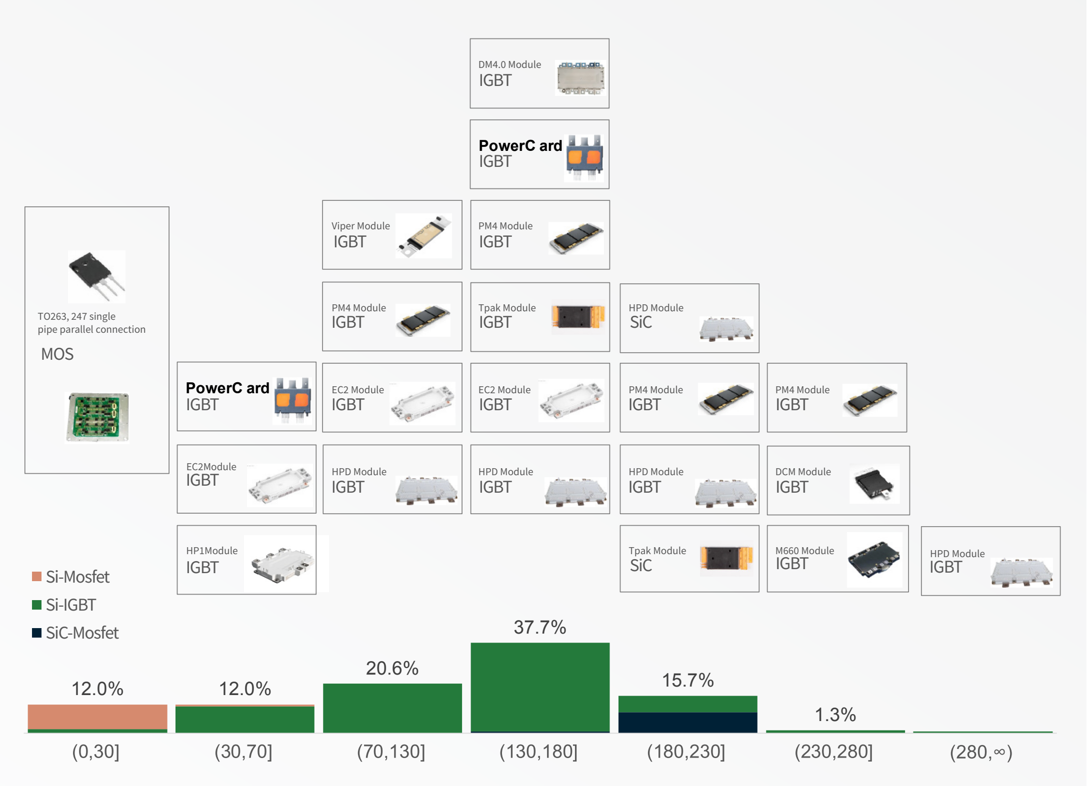
Third generation power semiconductor technology, best represented by SiC and GaN, is a principle orientation for upgrading. In terms of technological developments, the application of SiC is clearly faster than GaN in NEVs. Compared to Si IGBTs, SiC MOSFETs lose less power. This is especially true in 800V high-voltage platforms, where energy loss can be saved in high-frequency mode and pure electric mileage can be increased. Therefore, there is more of a tendency to use SiC MOSFETs in 800V main inverter controllers. SiC still has some advantages even in 400V platforms.

However, at present SiC is relatively expensive (around 2-3 times more than the equivalent IGBT module), therefore, it is only used in high-end vehicles or 4-wheel drive vehicles. In the future, as the cost of SiC comes down, the proportion of SiC used in 400V platforms will increase alongside that in 800V platforms.

At present, many car manufacturers are already positioned in the SiC field. New industry forces, best represented by XPeng, already have SiC products in 800V high-voltage platforms. Tesla, BYD and others also use SiC technology in 400V platforms to reduce loss.

Moreover, there will be relatively large changes to the way power devices are packaged. According to NE's statistical data, power modules based on Infineon's HPD occupy the main market share currently, accounting for 65.2%; moreover, modules from different manufacturers can be replaced via pin to pin. However, at higher power ranges (>180KW), the proportion of packaging technology, best represented by plastic packaging, begins to increase, like TPAK and DCM.

Figure 17: 2022 NEV Electronic Control Power Segment Distribution and Corresponding Power Device Applications

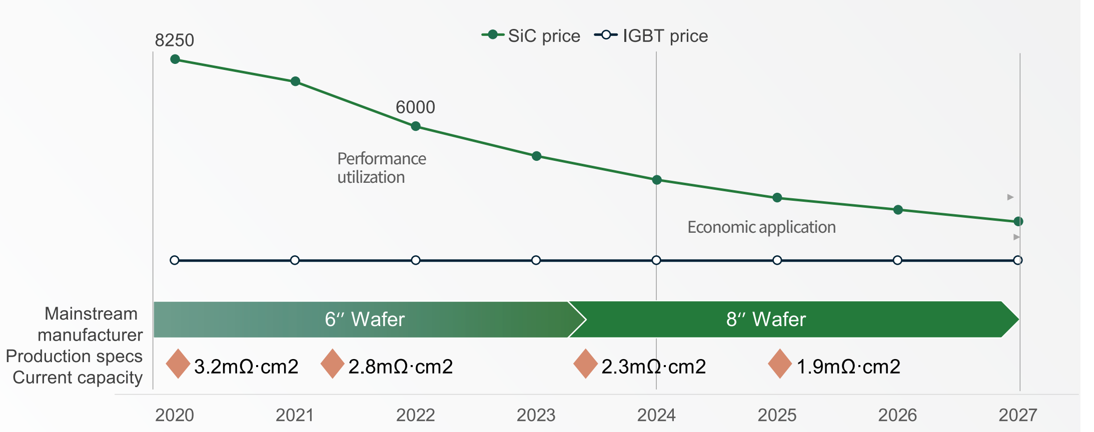


Source: NE Times

At present the main type of modules using SiC are TPAK and full-bridge potting modules, while half-bridge plastic packaging modules are rapidly becoming more widespread. Driven by Tesla, in 2022, more than 440,000 vehicles were installed with the TPAK module, accounting for 81%.

In the future, as SiC modules are applied on a larger scale, and larger SiC wafers (8 inches) are mass produced, it is predicted that the price of SiC modules will fall drastically. However, it is very unlikely that they will achieve price parity with existing IGBT modules. NE Times estimates that the price of SiC modules will be around 1.2-1.3 times compared to the current price. This is the primary factor restricting the large-scale application of SiC in NEVs. NE Times predicts that by 2027, SiC modules will account for 44% and will not completely replace IGBT module products.

Figure 18: Predicted Cost of SiC Power Modules



Source: NE Times

The application of third-generation power semiconductors, represented by SiCs, also drives the upgrade of gate drivers in low-voltage controllers. This will be gone into in more details in the third chapter on components.

Aside from power modules, the functional safety of motor controllers is also a main orientation for upgrade. The primary function of the MCU in the low-voltage control unit of the motor controller is to drive the motor via vector control, receive VCU instructions through CAN communication and provide feedback of its own operation status, while at the same time monitoring system operation status and guaranteeing normal operation of the system through sensor feedback from the high-voltage drive unit and motor data information. Because the electric drive undertakes an important role in the running of the whole vehicle, if any failure occurs during driving, it could lead to a major safety accident. Therefore, the electric drive controller must strictly comply with functional safety requirements. The relevant international standard is ISO26262 and the corresponding standard in China is GB/T 34590. To improve functional safety levels, the corresponding functional safety requirements must be met in terms of hardware. For example, regarding controller chips, heterogeneous multi-core MCU chip are used. Sensor wise, safer position sensors, multi-channel current sensors, and isolation gate drive chip technology that integrates driving, protection, and diagnostic functions are adopted.

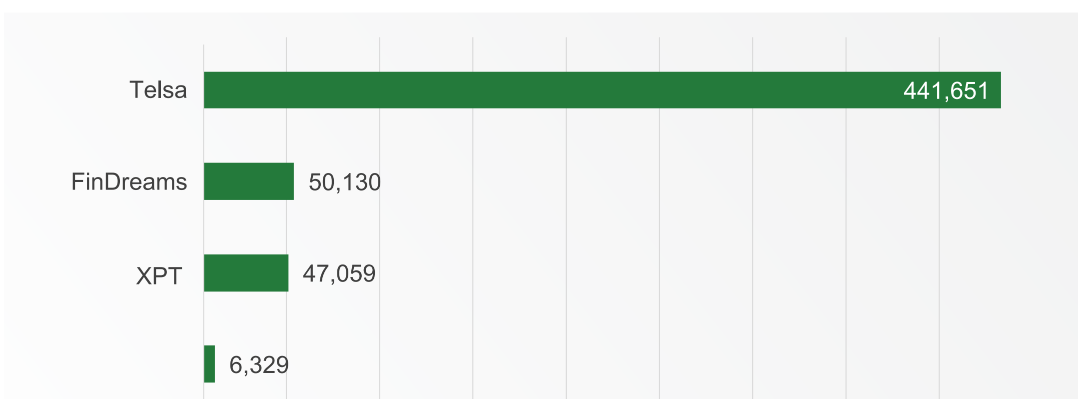
2.2.4 Motor Controller Suppliers

Driven by the market and technology, sales of self-developed or self-produced electric drive products from car manufacturers, like by BYD and Tesla, began to increase. This is particularly true in the 3-in-1 or even multi-in-1 markets where car manufacturers that have complete team layout are even more inclined to produce or develop on their own.

According to NE data, in the 3-in-1 market in 2022, the proportion of car manufacturers with self-developed systems reached 57.3%. In the multi-in-1 market, that proportion was 92.64%.

In terms of multi-in-1 (>3) system integration, at present there are a total of four companies that have started large-scale matching. These are FinDreams, Empower, Changan New Energy and Huawei Digital Power. Apart from Empower and Huawei, the rest are all car manufacturers.

Figure 19: Multi-in-1 System Supplier Installation Volume



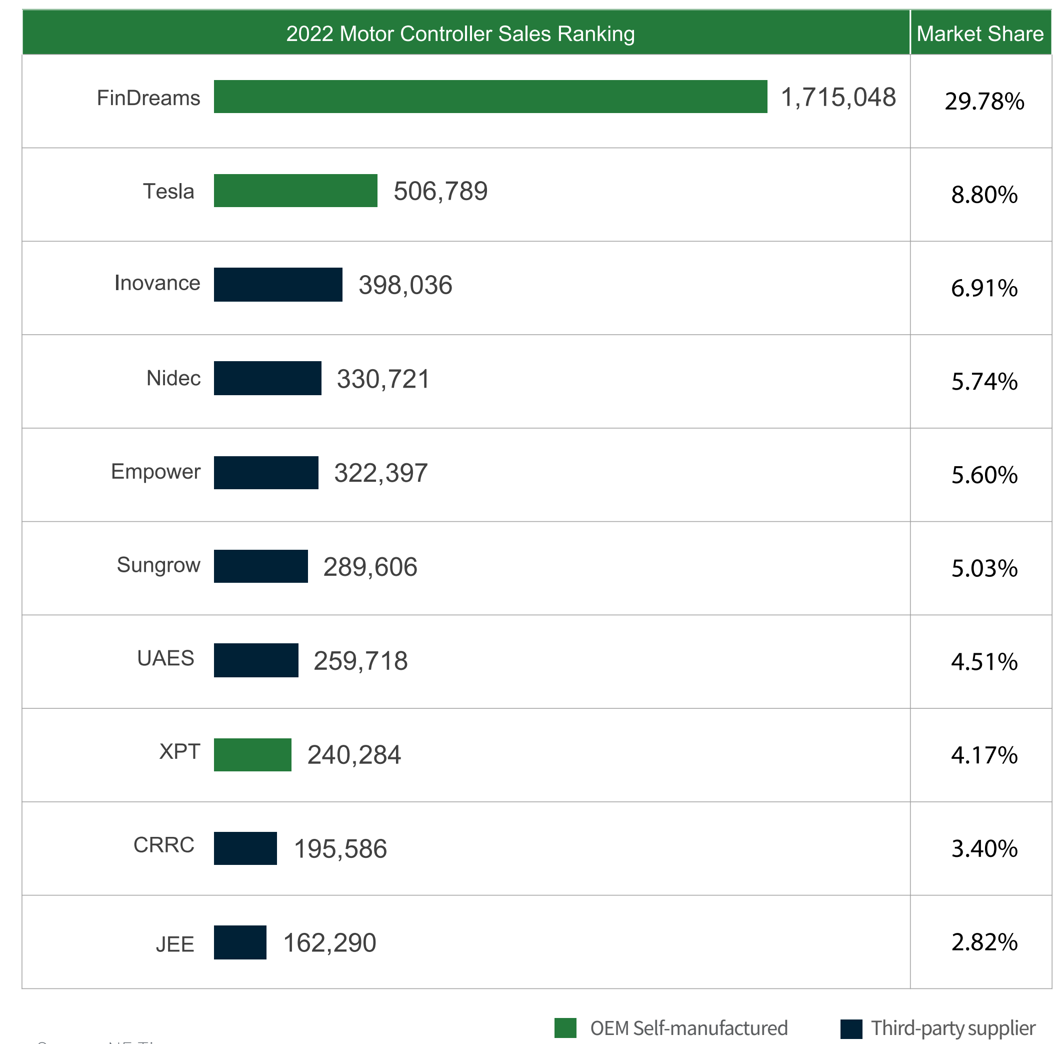
Source: NE Times

The components involved in an entire multi-in-1 system are numerous and, apart from a small number of car manufacturers that are fully qualified, the majority of companies choose to resolve system integration issues first, relying on external suppliers for core components. Against this background, in response to the trend toward car manufacturers developing and producing their own components, electronic controller suppliers have started to shift from tier 1 to tier 2, supplying system components to OEMs. In the 3-in1 and multi-in-1 markets, around 11.7% of car manufacturers choose to outsource motor controller components.

In terms of the entire motor controller market, in 2022, the scale of the Chinese NEPV motor controller market was 5.76 million sets for YOY growth as high as 77%. Of that, the top 10 suppliers provided 4,415,200 sets, accounting for 76.6% of the market.

Looking at suppliers' actual sales performance, it can be seen that suppliers with a vehicle background have a leading position in the market. FinDreams and Tesla occupy first and second position with a market share of 38.6%.

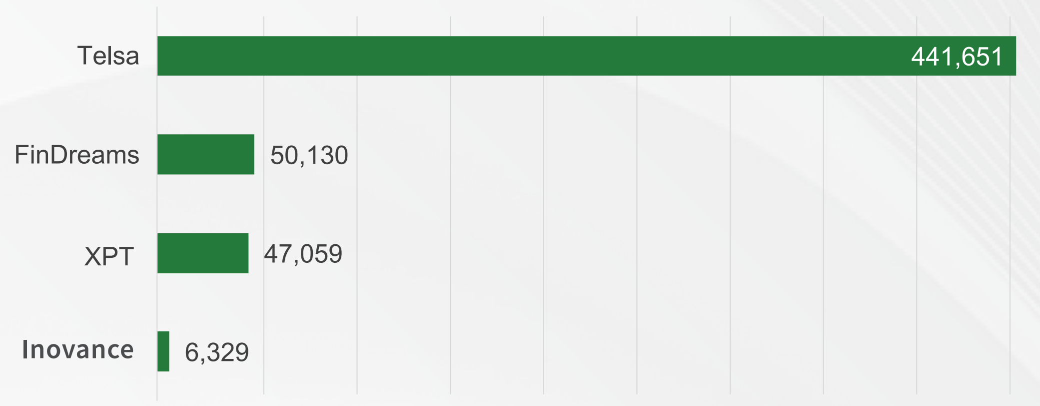
Figure 20: 2022 NEPV Motor Control Installation Volume (Including Hybrid)



Source: NE Times

In terms of SiC, in 2022, a total of four companies have scaled up their adoption of SiC electronic control products, namely Tesla, FinDreams, XPT and Innovance. Except for Innovance's application of SiC on the 800V voltage platform, all other companies use it on the 400V platform.

Figure 21: 2022 SiC Motor Controller Suppliers Installation Volume



Source: NE Times

Brief Summary

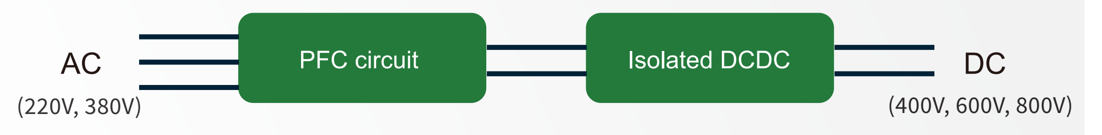
With the development of NEVs, the market for electric drive systems is looking exceedingly promising. In particular, driven by the continued growth of the four-wheel and PHEV markets, the growth of motors and motor controllers is going to eclipse that of vehicles. From a technological perspective, multi-in-1 integration technology and third-generation power semiconductor application technology are still in the early phase, and there is still a relatively large space for new technology applications in the future. Looking at the market competition structure, OEMs will increase self-production and transform the competitive structure of the industry chain. It is worth noting that OEMs prefer to produce their own systems and will still purchase motors, motor controllers and other components to maximize the benefits of scale.

2.3 OBC/DCDC Technology Trends

2.3.1 Current Situation and Technological Trends

At present there are two main methods for NEVs to recharge: AC charging piles and DC charging piles. Because power batteries input DC, when charging with AC, the AC power source needs to be converted to DC. In NEVs, the role of OBCs is to convert AC electricity to DC electricity for battery charging.

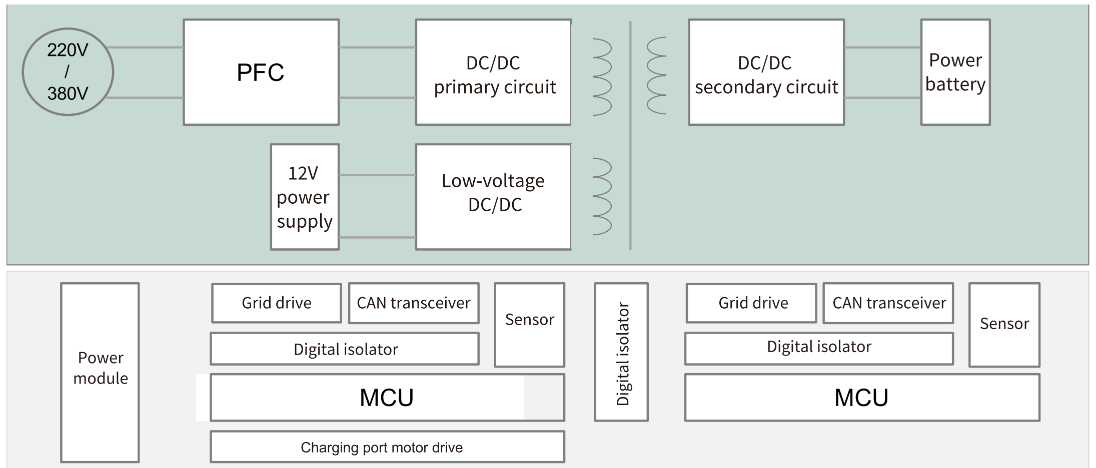
Figure 22: OBC Structural Diagram



At present, the majority of vehicles come equipped with OBCs, only a small amount do not have them equipped. For example, network operated vehicles with power replacement as a business model and some high-end vehicles that use low power DC charging.

In terms of power supply device integration, considering that the full bridge rated voltage of the vehicle charger and high-voltage DC/DC is the same, the two components can reuse high-frequency transformers and high-voltage power devices. Especially after control level integration and power level integration, compared to discrete layout, the usage of materials such as power devices, driver chips, control chips, high-voltage connectors, and shells can be significantly reduced, achieving lightweight, miniaturization, and low cost. Therefore, nowadays OBC is mostly integrated with DC/DC components.

Figure 23: OBC Integrated Circuit Structural Diagram

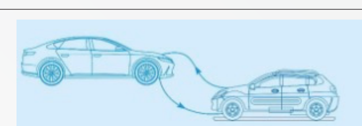
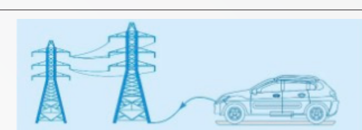


Source: NE Times

At present, OBC and DC/DC integration already dominates the mainstream market, with 4,669,600 sets sold in 2022 accounting for 91.5%.

Aside from the orientation toward integration, as NEVs' market share increases, there will be a trend toward diversifying their use scenarios. As for OBCs, on top of satisfying the charging function, it is worth noting the external discharge function they have, which would make the flexible use of electricity convenient for users and could subsequently realize two-way power flow between the vehicle and the grid.

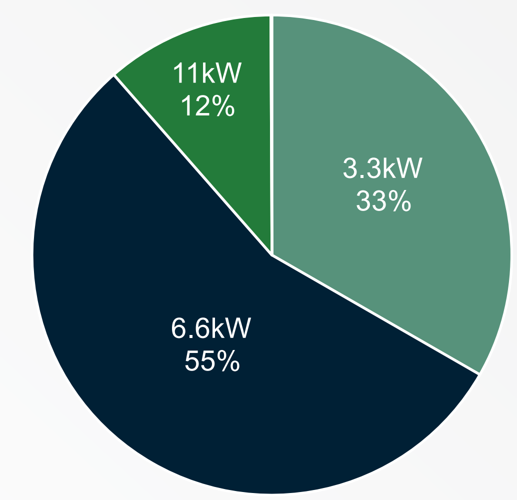
Figure 24: V2X Common Scenarios

Common Forms of V2X	Scenario Description	Examples
V2L	Power batteries can be used to supply power to external equipment, and used as a mobile energy storage unit or emergency power supply	
V2V	Power batteries can be used to supply power to other NEVs and charge them	
V2G	Power batteries can supply power to the power grid and be used as an energy storage unit	

Source: VMAX' s Prospectus

As the electrical power of individual EVs continues to increase, so does the power of OBCs. At present, mainstream power usage is at 6.6kw, which accounted for 53.6% in 2022. After that it was 3.3kw, accounting for 34.4%. 11kw has also started to be stably equipped, accounting for 12%, and is primarily used in luxury brand long-range models.

Figure 25: Different Power OBC Installation Volume Share



Source: NE Times

Like main inverter controllers, and compared to silicon-based power devices, SiC enjoys high switching efficiency and higher thermal endurance properties, especially 11kw power level OBC products. OBCs that use SiC products have a higher power density and higher efficiency. Therefore market share is gradually increasing.

2.3.2 Introduction to OBC/DCDC Companies

According to China vehicle terminal insurance data, the NE Times statistically compiled the installation volume of new energy key components for statistical reference. For the year 2022, the total installation volume of OBCs in NEPVs was 5,128,700 sets with YOY growth of 77.6%. Of that, the top 10 suppliers accounted for 91.6% with high market concentration.

Looking at the top companies, there are two main camps in the NEPV OBC market:

- OEMs, represented best by BYD and Tesla, with a total market share of 36.5%.
- Third party suppliers, represented best by VMAX, Enpower and Shinry, with a market share of 63.5%.

Independent brand power supply companies dominated the mainstream market. In 2022, the installation volume of independent brands was 4,452,000 sets, accounting for 87.2%, much higher than foreign brand suppliers.

Figure 26: Top 10 NEPV OBC Supporting Companies in 2022

OBC Sales Rankings 2022		Market Share
FinDreams	1,469,872	28.7%
VMAX	1,048,156	20.4%
Tesla	441,651	8.6%
Enpower	438,953	8.6%
EVTech	434,213	8.5%
Shinry	301,740	5.9%
TC Charger	215,887	4.2%
Kostal	179,842	3.5%
Huawei Digital Power	157,753	3.1%
Lihua	107,740	2.1%

Self-manufactured: FinDreams, Tesla; Third party supplier: VMAX, Enpower, EVTech, Shinry, TC Charger, Kostal, Huawei Digital Power, Lihua

Source: NE Times

Brief Summary:

OBC is an important component in the power distribution system and in terms of technological makeup they are already mature. Although the future trend is to be integrated into the electric drive system in a multi-in-1 structure, deep integration technology is not yet mature and OBC/DCDC will still exist as independent modules; moreover, only physical integration with the shell has been achieved, with PCB integration or chip integration still not possible. Looking at supplier layout, OEMs are not that interested in self-producing OBC components, only a few car manufacturers, including BYD, produce their own OBCs, while the majority still chooses to outsource, and this is true even in multi-in-1 systems.

2.4 BMS Technology Trends

2.4.1 Current Situation and Technological Trends

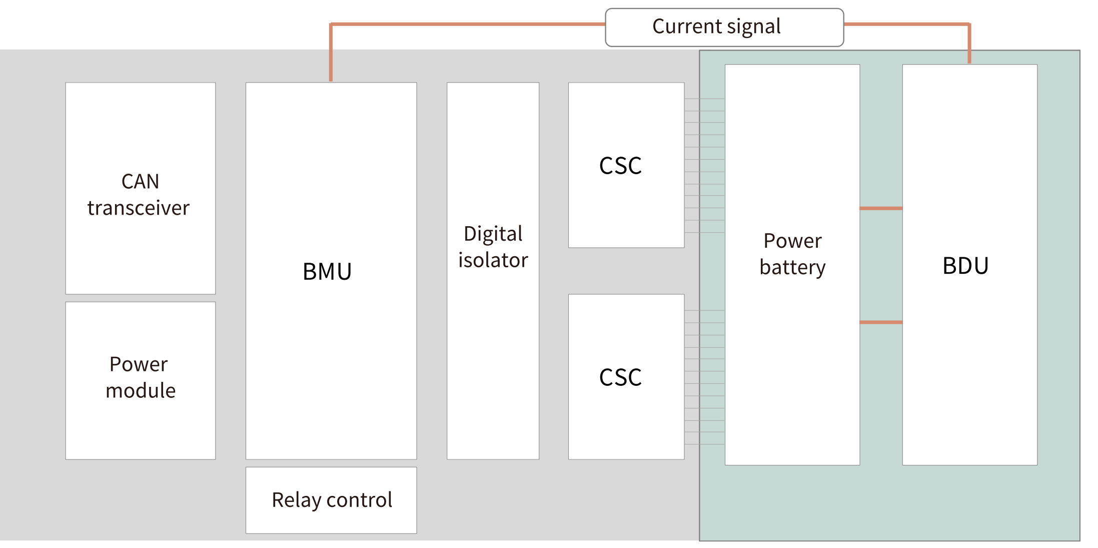
A BMS is a controller unit for power battery that is responsible for the collection and calculation of battery voltage, temperature and state of charge (SOC) data, and controlling the power battery's charging and discharging process to protect the battery.

A battery management system (BMS) is primarily made up of the three major components of hardware, underlying software and application layer software. The hardware architecture can be divided into centralized architecture and distributed architecture according to the layout of the battery management unit (BMU) and cell supervisory circuit (CSC).

Centralized architecture concentrates all of the electric control components into an integrated circuit board. In other words, the sampling chip, controlling chip and disconnected chip are all arranged on a single circuit board, connecting to the battery through the sampling harness. Although the structure of centralized architecture is simple, for high-capacity batteries, sampling harness design is relatively difficult and collection channels are very hard to scale, so they are only used in low-capacity battery systems. For example, in A00 EVs or PHEVs.

At present, most passenger vehicles use distributed architecture. Distributed architecture primarily includes the motherboard BMU and slave board CSC. The CSC is mainly responsible for signal sampling, including unit voltage, module voltage and module temperature, and is directly installed on the battery unit. CSCs and BMUs use CAN or a daisy chain to communicate, and the BMU primarily uploads or strategically controls the signals it collects. On top of this, it includes a high-voltage battery junction box (BJB), which is used mainly as a fuse to monitor and control operation of the battery pack; if the system detects that the battery pack is in an abnormal condition, it will cut off the high-voltage loop. Some BJBs are integrated into BMUs.

Figure 27: BMS Structural Diagram



Source: NE Times

Under the influence of 800V high-voltage platforms, the number of batteries in a series increases, the number of batteries collected by the CSC also increases and the corresponding number of analog front end (AFE) chips increases or the number of collection channels for single chips needs to be increased.

Apart from the influence of 800V, in terms of communication, the CSC and BMU use wireless communication to replace wiring harness communication, which can improve overall battery space utilization and reduce the difficulty of wiring harness layout. In terms of the underlying software, as well as supporting conventional SOC/SOH/SOF estimates, the BMS needs to support the functional safety requirements of ASIL C. In terms of the application layer, the BMS needs to support FOTA capabilities.

Moreover, the BMS required data needs to establish communication with the cloud database. On the one hand, this satisfies regulatory requirements by uploading battery operating data, and on the other hand, it runs diagnostics for some thermal runaway strategy on the cloud server, which has more computing power, to ensure early warning of battery pack thermal runaway and take the necessary preventive measures.

There is a relatively close relationship between the BMS and the type of power battery and voltage. In 2022, annual BMS sales were 5,233,100 sets, with YOY growth of 80.9%. Of those sales, 3.3 million were for lithium iron phosphate (LFP) batteries, accounting for 63%, and 1,932,800 were for ternary batteries, accounting for 37%. As battery technology continues to improve, new types of batteries keep getting proposed. For example, 4680 large cylinder batteries, semi-solid batteries and sodium-ion batteries, lithium manganese iron phosphate batteries and so on. Grouping solutions are also being constantly altered. For example, solutions that use a variety of mixed batteries.

2.4.2 BMS Companies

Of BMS products, algorithm schemes are just as important as hardware. Therefore, there is a split between companies that specialize in algorithms and those that specialize in hardware production. In the algorithm field, development is primarily led by OEMs or battery companies that can provide PACK. The production of hardware is given over to OEMs and in 2022 this field accounted for 75.3%.

In terms of suppliers, FinDreams Battery and CATL are ranked in first and second place respectively. Between them they achieved sales of 2,465,000 and occupied over 42% of the market share, more than 3rd-placed to 10th-placed combined. The top 10 suppliers account for 77.5% of the total market share.

Figure 28: Top 10 Companies Supporting BMS for NEPVs in 2022

	OBC Sales Rankings 2022	Market Share
FinDreams Battery	1,611,724	30.8%
CATL	659,503	12.6%
Tesla	441,651	8.4%
Sinoev	392,025	7.5%
Ligo	358,588	6.9%
UAES	188,190	3.6%
Joyson	159,392	3%
Shanghai Jieneng	145,466	2.8%
GVB	121,517	2.3%
VREMT	110,819	2.1%

Source: NE Times

Car manufacturer and Pack self-manufactured | Third party supplier

Brief Summary:

Innovation in underlying hardware for BMSs relies primarily on the innovation of underlying chip technology, including in AFE chips. For car manufacturers and battery manufacturers, BMS innovation is mainly focused on the application layer and signal communications, like cloud-end BMSs and wireless BMSs. In terms of supplier structure, the market is still led by car manufacturers and power battery manufacturers, but production is relatively flexible, with OEMs still widely used. Even with outsourced BMS products, some clients will also specify key chips to ensure product stability.

2.5 Trends in Thermal Management Technology

2.5.1 Current Situation and Trends in Thermal Management

Typical changes in thermal management when comparing NEVs, particularly pure EVs, to fuel vehicles:

- No engine providing a fixed heat source.
- In addition to the passenger compartment, power battery also need heating and cooling.
- There are more components that need cooling and their distribution is relatively dispersed.

On top of that, new energy sources are more sensitive to the energy consumption of thermal management systems. According to thermal management requirements, different parts such as the battery pack environment, power electronics and motor heat dissipation are added, and therefore there are greater and more refined cooling/heating demands, which lead to greater load on the system and more complex configurations.

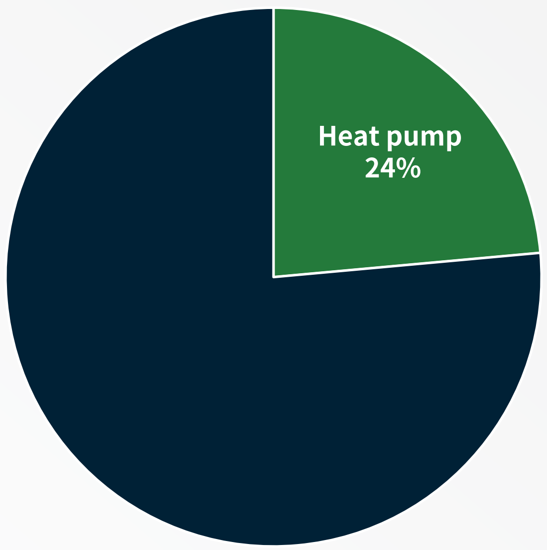
Early designs for NEV thermal management used distributed solutions.

To satisfy the heating requirements for passenger compartments and power batteries, two sets of independent PTC heaters are used for heating, it is just that the type of PTC heaters vary somewhat. That is, the passenger compartment is heated by a PTC air heater, and because the power battery uses liquid heating, it uses a PTC water heater, which warms the power battery after warming the liquid. To satisfy cooling requirements, a motor compressor is used in place of the original mechanical compressor. In addition, an electric water pump replaces the original mechanical water pump. A heat-exchange circuit is added, which usually has three components: the passenger compartment heat-exchange circuit, electric drive heat-exchange circuit and the power battery heat-exchange circuit. The refrigerant circuit and coolant circuit remain separate.

Although this solution resolves issues of NEV thermal management, energy consumption is high. Especially in the winter cold, thermal management consumes too much battery power and leads directly to a severely reduced driving range.

Therefore, a heat pump AC compressor is used to replace the original unidirectional refrigeration motor compressor. The heat pump AC not only cools but also heats. Compared to the PTC heating solution, when the heat pump AC is providing heat its COP (coefficient of performance) value is 2-3, whereas PTC heating is less than 1, therefore, it consumes less energy when heating and can improve the driving range in winter. At present, heat pump AC has already gone mainstream, accounting for 24% in 2022.

Figure 29: Sales Proportion of Vehicles with Heat Pump in 2022



Source: Compiled by the NE Times

As the scale of the NEV market continues to expand, thermal management technology will develop further and centralized thermal management technology will start to be applied. Centralized thermal management technology distributes circuits in a unified and centralized manner by installing thermal management modules, so that temperature control is no longer purely reliant on independent cold sources or heat sources, but can realize thermal management by superimposing heat exchange between different components while also reducing system energy consumption. In particular the heating part can utilize waste heat from the power battery and electric drive to heat the passenger compartment, and reduce reliance on the heat pump AC or PTC heater, particularly reliance on the PTC heater.

This centralized thermal management solution can divide thermal management into four major modules: the front end heat dissipation module, centralized thermal management module, passenger compartment module and the interior heat source module.

Of these, the front end heat dissipation module is primarily composed of a radiator. Like traditional radiators, it can be arranged at the front end of the car. Considering the model design of electric vehicles, if installed in the front spare tank, then a part can be arranged at a slant.

The thermal management modules mainly consist of an all-in-one valve body assembly (including valve body and motor), cooling liquid pot, controller (which may not be required and realized via the domain controller), heat exchanger and so on, some of which are integrated with electric AC compressors. Although PTC heaters are not integrated in this module, they still belong to the module.

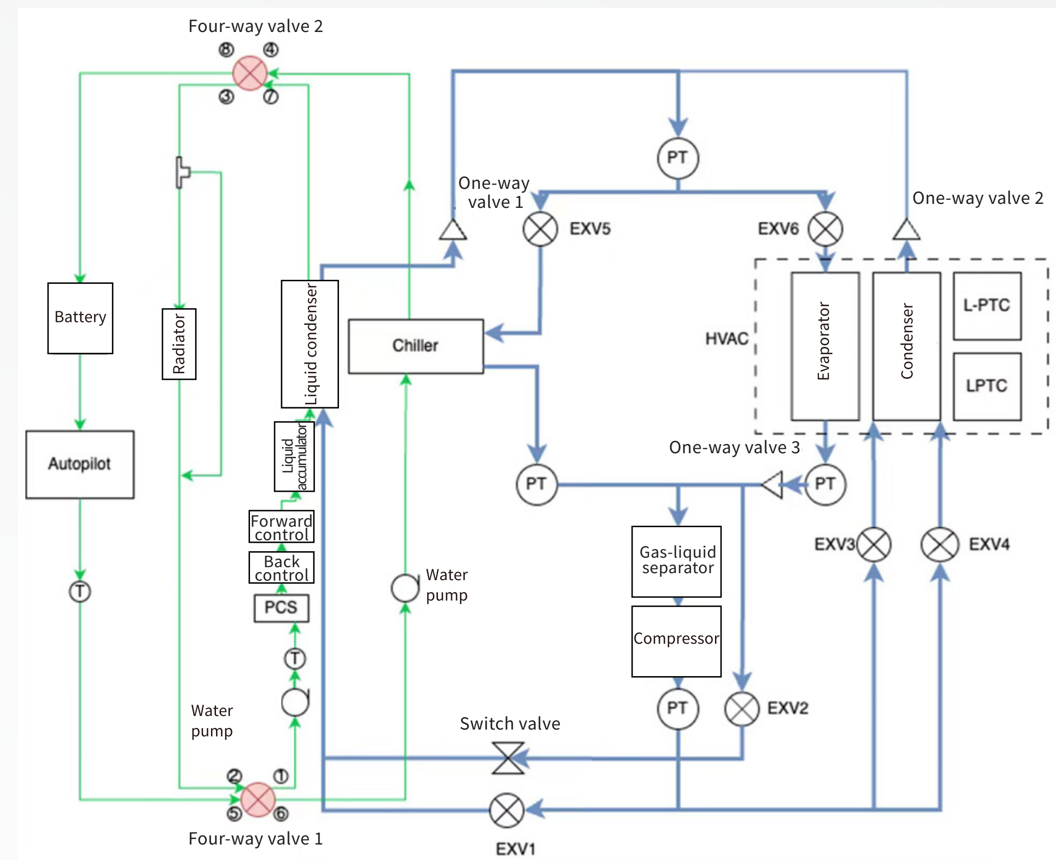
The passenger compartment module includes a fan and HVAC assembly.

The internal heat source module primarily includes an electric drive, power battery, domain controller thermal management and other integrated components in the thermal management part.

The key to this integrated thermal management solution lies in the design of the thermal management module. At present, there are three main forms of integration.

- Only integrates the refrigerant side. A typical example being some BYD vehicles.
- Only integrates the coolant side. A typical example being the Roewe iMAX8.
- Integrates the refrigerant side and the coolant side, in other words a full-integration solution. A typical example being the Tesla Model Y.

Figure 30: Diagram of Tesla Integrated Thermal Management System



Source: Compiled by NE Times

Compared to the first and second integration solution, the full-integration solution has a higher level of integration, the corresponding processing requirements for all-in-one valve body assembly are higher, and more space is required in terms of vehicle layout. Take the Tesla Model Y for example, it uses an integrated 8-way valve design solution that controls the opening and check valve action of the electronic expansion valve to control refrigerant circulation, and controls the location of the 8-way valve to control refrigerant circulation. Of these, the temperature sensor collects the temperature of the coolant liquid allowing for precise temperature control. This solution has 15 modes, 12 of which are for heating and three are for cooling. The parts it controls include all of the integrated motor drives in the body domain controller.

This full-integration solution is estimated to begin mass production in the second half of 2024. Although the role the PTC heating plays in this solution is clearly reduced, PTC water heating will remain in use. However, this will vary in specific manufacturers' structural style.

Once hardware has been integrated, the control part will also be upgraded. The previous distributed control has changed to centralized control, and there are three main control schemes at present.

- Complete domain controller integrated control solution. Thermal management control is integrated into the ZCU,(Zonal Control Unit) in this solution. According to the ZCU's layout scheme, the thermal controller can even be split up and integrated into two ZCU's. In addition, the motor drive can also be integrated into the ZC, that is, there is no separate controller for the valve or pump.

- Installing a separate thermal management controller, integrated controller and motor drive, and integrating the pump and valve into the thermal management controller.

- Domain controller + split-type drive. The motor controller is still integrated into the motor, but the control scheme operates within the domain controller, and the motor controller is only responsible for the motor drive. The motor controller tends to be standardized in this solution, both adopting integrated System-on-Chip (SoC), and realizing power supply, drive and control in one chip, as well as reducing control requirements while at the same time minimizing hardware costs as much as possible. Even a single SoC requirement can control multiple motors of the same type.

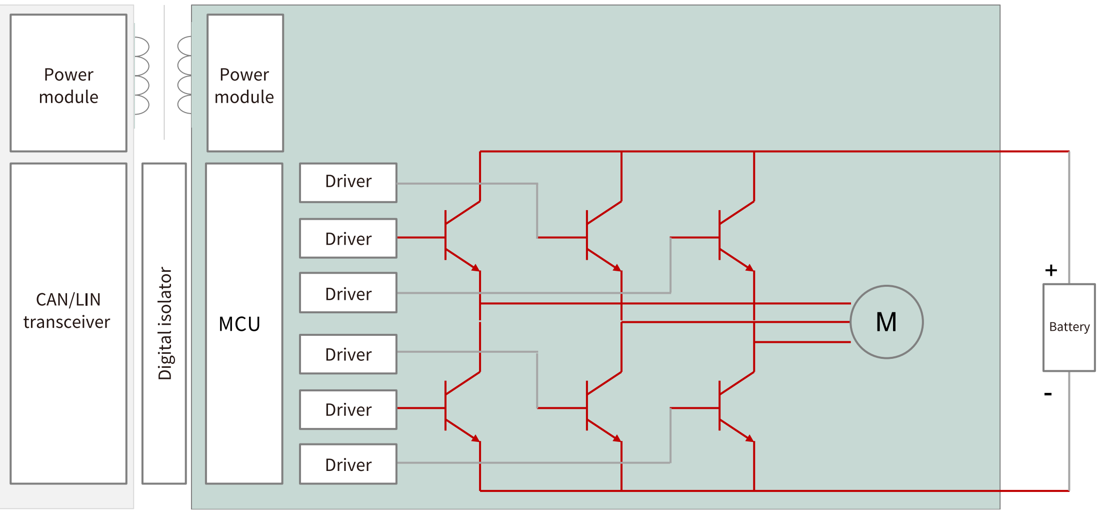
At present, this solution is not fully finalized and discussions are still underway.

In addition to thermal management modules, motor compressors (supports heat pumps) and PTC heaters are important components of thermal management. As both components are high voltage, it is necessary to consider issues of high and low voltage isolation. Taking AC compressors as an example, there are currently two main solutions:

- The MCU is installed on the low-voltage side and high-voltage power components are controlled by isolating the drive. Similar to the motor controller solution.

- MCU is installed on the high-voltage side and the MCU and low-voltage side are isolated by utilizing a digital isolator; the drive does not need to be isolated.

Figure 31: Structural Diagram of Electric AC Compressor Controller



Source: NE Times

In terms of cost, the second solution performs better and it is therefore used more often at present.

With an 800V high-voltage platform, the AC compressor and PTC heater both require a corresponding high-voltage level. Of them, for the electric AC compressor, it is necessary to consider improving work efficiency and reducing energy consumption. For controlling PTC heaters, it is only necessary to consider voltage endurance. In 800V platforms, IGBTs are upgraded to SiC.

Moreover, to improve heating performance in cold environments, carbon dioxide (R744a) heat technology is starting to be applied. Compared to the current R134a and R1234yf refrigerants, carbon dioxide refrigerants require more pressure, around 8-10 times that currently required, and although compressor displacement can be significantly reduced under the same performance, high pressure brings about increased sealing requirements for pipes, interfaces and the compressor itself, and leads to an increase in overall system costs. Taking Volkswagen's MEB platform carbon dioxide heat pump as an example, its optional installation price is 9,000 RMB, way higher than other heat pump AC options. Therefore, only a few vehicles support optional installation at present. In the future, unless the cost of carbon dioxide heat pumps can be effectively reduced or there are mandatory requirements for environmental reasons, carbon dioxide heat pumps will never be applied on a large scale.

2.5.2 Motor Compressor/PTC Heater Manufacturer

In terms of global supply relationships, motor compressor manufacturers like DENSO, Hanon, Valeo and Sanden still lead the market. However, as the China NEV market's growth accelerates, Chinese manufacturers, like BYD, Suzhou Zhongcheng, Everland, Highly, FAWER and Shenzhen Aiwei, in the 400V motor compressor field have enjoyed rapid growth. In addition, although Sanden-Hasco is a joint venture, it enjoys relative business autonomy and has won a substantial market share. In terms of 800V motor compressors, Chinese manufacturers have also achieved mass production. For example, XPeng's G9 comes installed with Welling's 800V platform motor compressor product. This product uses a SiC power device and can reach maximum revolution speeds of 12,000rpm.

Apart from at Tesla, full-integration thermal management modules are still in the early stage at present. However, Chinese companies like Tuopu and Sanhua have already realized large-scale installation, and manufacturers like Fulin P.M., Welling, Feilong and Johnson Electric have begun active layout.

Brief Summary:

Driving range has been an issue that has plagued NEVs throughout their development, in particular the issue of how to maintain stable driving range during winter. Highly-efficient thermal management systems can get maximum utilization from heat sources within the car to maintain thermal stability. This is not just unidirectional heating, it requires the thermal management component to be upgraded at system level to coordinate heat control among all components with the car. At the same time, the integrated thermal management solution can efficiently use energy to maximize efficiency even when cooling is required during the summer. The development of thermal management systems is inseparable from the technological upgrading of core components. In winter, PTC heaters are the main units of power consumption. Using heat pump ACs can effectively resolve this issue. Therefore, thermal management system integration and heat pump ACs have always been an important technological orientation, while the importance of PTC heaters has gradually declined.

PART

03

Chapter 3

Development Trends of Key Components: Analog Chips

3.1 Analog Chip Classification and Value

3.1.1 Analog Chip Classification

According to circuit configuration, high-voltage control systems are basically composed of five major modules: the control module, communication signal module, signal detection module, power module and the drive module.

Among them:

The control module uses a MCU or DSP to control the processor and is primarily responsible for controlling the storage or operation of algorithms.

The communication signal module includes CANs, LINs, isolators and other signal processing modules.

The signal detection module includes voltage sampling, current sensors and temperature sensors, of which the current sensors are especially important.

The power module is primarily responsible for providing stable power supply and switches for all modules including the control module.

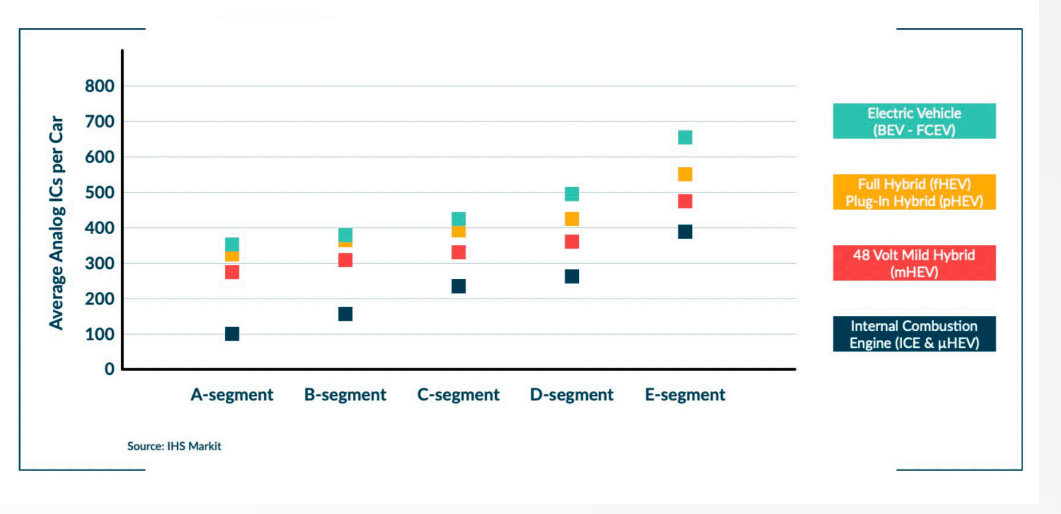
The drive module is primarily responsible for carrying out control strategies, such as drive power device switches and drive motor operation.

In addition to the fact that the control module is a digital chip, the other modules in the high-voltage controller all belong to the field of analog chips, and have the following distinct features:

Analog chip technology is relatively mature and more work needs to be done to ensure product stability and cost performance. Signal to noise ratio (SNR), stability, precision, power consumption and other features of analog chips do not significantly improve as processes are reduced, but high processing affects the product's long-term stability and increases costs. Therefore, process advancement is not really necessary for analog chips and the majority of processes are concentrated below 28nm.

There are many different categories, large consumption and rich application fields of analog chips. Take B-class vehicles for example, traditional fuel vehicles use around 160 analog chips, whereas that number rises to 400 in EVs, and over 650 in C-class EVs. In addition to the vehicle industry, industrial engineering, energy, consumption and other fields also use a large volume of analog chips.

Figure 32: Analog Chip Usage Per Vehicle



Source: Melexis

High-voltage controllers in NEVs use a huge number of analog chips. According to estimates, they use over 20 isolated driver chips, more than 10 communication chips and more than 10 current sensors. Moreover, a single chip costs 3-6 yuan, so their total value far exceeds MCUs.

Figure 33: Type and Usage of Analog Chips in NEV High-voltage Controllers

	Main Inverter	AC Compressor	OBC/DCDC	BMS	PTC	Total
Isolated Driver IC	6	3	16	1	1	22
Isolated Sampling IC	2	2	4	-	2	10
Communication IC	1	1	2	1	1	6
Digital Isolator	2	1	3	1	-	7
Current Sensor	3	-	3	1	-	7
Power Module	2	3	1	1	1	6

some chips must have isolation capability
Source : NE Times

3.1.2 Analog Chip Quantity Value

According to data from IC Insights, the automotive industry is the second largest application for analog chips besides the tele-communication industry. In 2022, the demand for automotive chips accounted for around 24% of the analog chip market.

Data released by the EV 100 Forum shows that in 2020, the global quantity value of analog chips per vehicle was around 150 US dollars. Driven by intelligent and electrification technology, by 2027, the quantity value of analog chips per car will reach 300 US dollars, with a compact annual growth rate of 10%. Wang Shengyang, chairman of Chinese chip company NOVOSENSE, also has confidence in the analog chip market for cars.

According to calculations, the quantity value of analog chips in the motor, power battery and electronic control system exceeds RMB 400, more than the quantity value of control chips.

Brief Summary:

Analog chips have an important position in high-voltage controllers. Although the quantity value of a single analog chip is less than that of digital chips like MCUs, the volume of applications and categories of use are far greater than those of MCUs, and the total quantity value and selection complexity of analog chips are also much higher.

3.2 Automotive-grade Chip Requirements

3.2.1 Automotive-grade Chip Standards

Due to the complexity of vehicle operating conditions and the fact they must meet a certain design life, the first considerations for automotive-grade chips are safety and reliability.

Figure 34: Comparison on Chip Requirement for Different Grades

	Consumer Grade	Industry Grade	Automotive Grade
Application	Mobiles, computers, smart homes, etc	Production equipment	Automotive electronics
Temperature	-20-70℃	-40-85℃	-40-150℃
Humidity	-	Customized according to work environment	0-100%
Reject Ratio	One in a million	Three in a thousand	One in a billion
Lifespan	3-5 years	5-10 years	15-20 years
System Cost	Normal	Relatively high	High
Special Requirements	Waterproof, etc	Waterproof, damp proof, corrosion proof, etc.	Enhanced heat dissipation, high low temperature impact, anti-interference, etc.

Source: Compiled by the NE Times

Among automotive-grade certifications, international certification standards include AEC-Q100, ISO 26262 and IATF 16949.

Of them:

The IATF 16949 label primarily determines whether a chip manufacturer has automotive-grade chip design and production process control ability, focusing mainly on production.

AEC-Q100 focuses on quality reliability.

ISO26262 focuses on functional safety.

In addition to the above standards, some car manufacturers also have their own verification systems to meet.

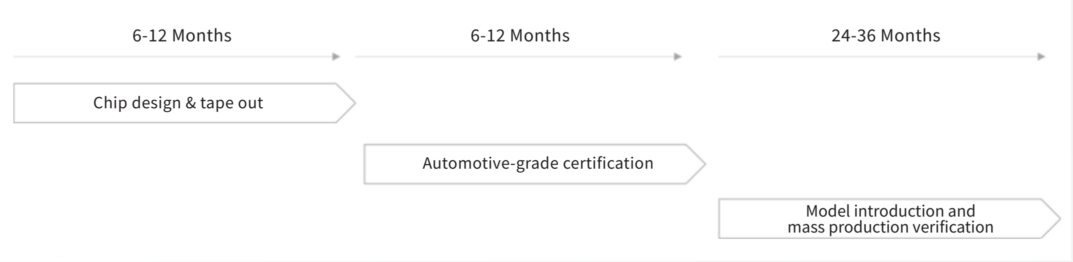
Figure 35: Automotive-grade Chip Certification Standards

	Standard Categories
International Certification Standards	IATF 16949
	ISO 26262
	AEC-Q
Special Standard Requirements	Car manufacturer has its own verification process and corresponding standards

Source: Compiled by the NE Times

Another characteristic of automotive-grade chips is their long cycle. Most chips take as long as 3-5 years from development until they are fitted onto a vehicle. This long cycle means that chip manufacturers must understand OEM and Tier 1s' needs at all times, while also having technological foresight.

Figure 36: Automotive-grade Chip Development Cycle



Source: Compiled by the NE Times

To guarantee that high-security is maintained at all times throughout the long-cycle development process, chip manufacturers must establish an effectual system for the entire chip design and manufacture in order to safeguard the stable mass production of automotive-grade chips. Take the basis of passing an AEC-Q system test as an example:

1. Improving product reliability in the design phase.

During the early design phase, consideration to reliability, stability and uniformity of automotive-grade chips must be given, as well as considering the operating conditions, such as wide temperature range (-40-150 ℃), high vibration, lots of dust, electromagnetic interference and oil vapor contamination. Therefore, during design, some performance margin must first be reserved, that is, design performance must be higher than the actual working performance. As for common failure modes, diagnostic and early warning circuits should be added in advance. Structural shielding, protective circuits and other measures must also be added to prevent external environmental impacts.

For products that meet the ISO26262 requirements, the manufacturer must proceed according to the ISO2626 process development system and product development system.

2. Guaranteeing product quality stability during the manufacturing phase.

During manufacturing, production standards must be strictly adhered to, such as the IATF16949 and VDA6.3 process audit standards. If production is outsourced, these standards must be strictly complied with when selecting an OEM.

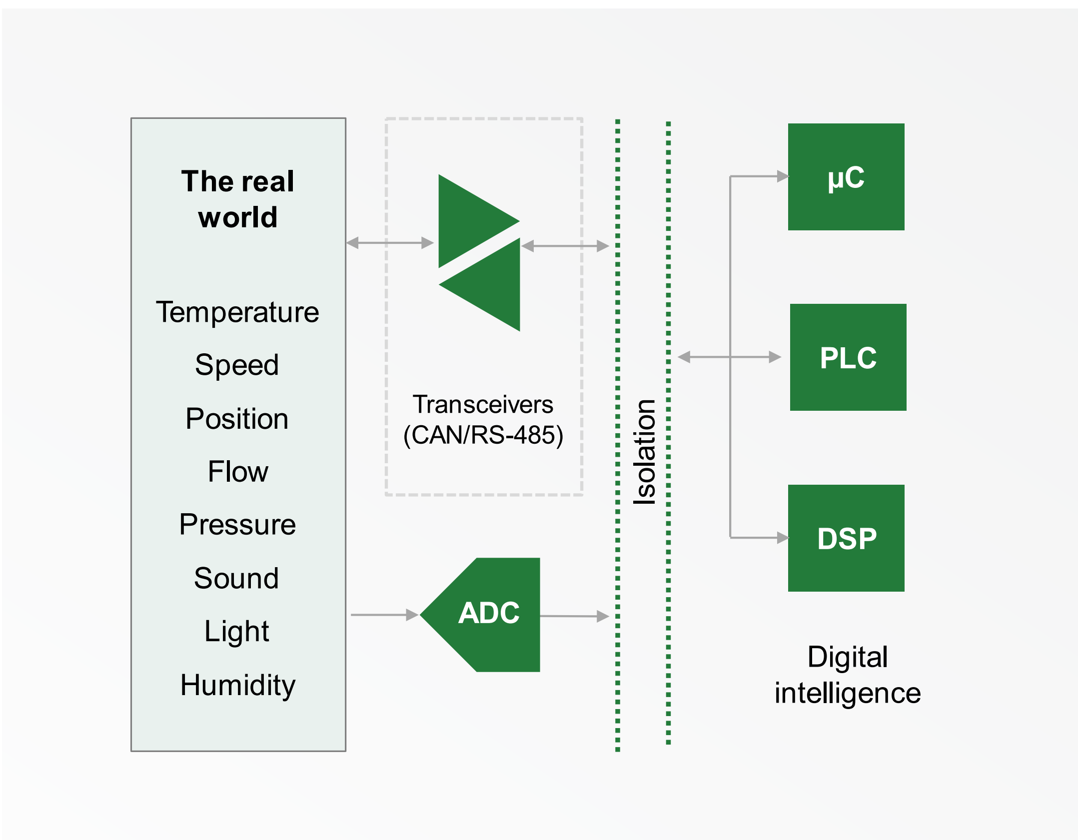
3. Carefully evaluate the reliability of different product batches during the verification phase.

As with certification standards, design rules and production management and control systems are an important indicator in measuring an automotive-grade chip enterprise. Differing from certification standards, stable and mature automotive-grade chip companies have accumulated long-term experience and possess their own design protocols and production management and control systems to ensure product quality.

3.2.2. Introduction to Isolation Technology in Automotive-grade Chips

The voltage for electrical power systems on NEVs is generally within the dangerous voltage range at over 350V and sometimes as high as 900V. On the one hand, high-voltage can cause personal safety risks to users, and on the other hand, it can present risks to the controller. To guarantee the safe use of vehicles, NEVs must adopt isolation technology. Isolation technology allows the control signal to transfer between high-voltage and low-voltage units, and can prevent any dangerous DC or uncontrolled transient current from flowing out of the system and damaging the control system or even inflicting harm on external users. Moreover, after adopting isolation technology, signal anti-noise performance can be improved and signal transmission made more stable.

Figure 37: Principle of High-voltage Isolators

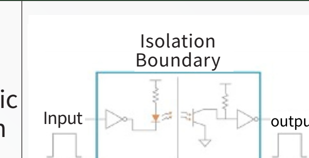
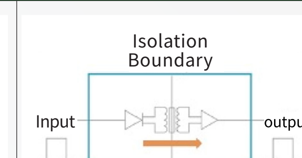
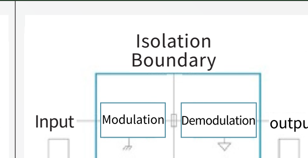
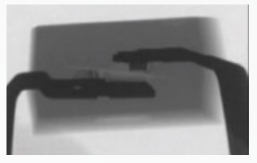
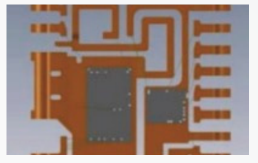
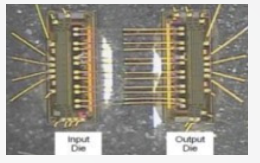


In terms of technology road map, isolation devices can be divided into transformer isolators, optocoupler isolators and digital isolators. Although transformer isolators have relatively low transmission delay, they can transmit signals and energy at the same time; however, they are relatively bulky and unfit for design and instillation. With its small size and strong anti-interference advantages, optocoupler isolator technology was once the only solution on the market during the 1990s. However, in the NEV field, issues around complex power supply and optical attenuation under long-term operation had a certain impact on application. Digital isolators have the clear advantages of being small and integrated, which lead to digital isolators being widely used in NEV high-voltage applications. Digital isolation chips can also be divided into magnetic and capacitive coupling isolators.

Magnetic coupling technology was first introduced by ADI in 2007 and used polyimide (PI) material to separate the two coils, with the PI acting as an isolation barrier. After improvement, PI was upgraded to an SiO_2 isolated gate, which saw it popularized and applied on a large scale. Infineon, Renesas and ROHM all use this solution.

Capacitive coupling technology was first developed by SiliconLabs in 2009. It provides isolation through two high-voltage capacitors on separate silicon chips connected in series and the electronic transmitting and receiving circuits coupled to the high-voltage capacitor provide signal transmission. In addition to SiliconLabs, TI uses this technology solution and Chinese manufacturer NOVOSENSE also uses capacitive coupling isolation technology. There is not any clear discrepancy in technological performance between magnetic isolation and capacitive isolation, and the two can quickly replace one another during practical application.

Figure 38: Types of High-Voltage Isolation Technology

	Optocoupler Isolators	Magnetic Coupling Isolators	Capacitive Coupling Isolators
Schematic Diagram			
Example			

Three main evaluation criteria for isolator technology:

- Isolation voltage level
- Signal delay consistency
- CMTI

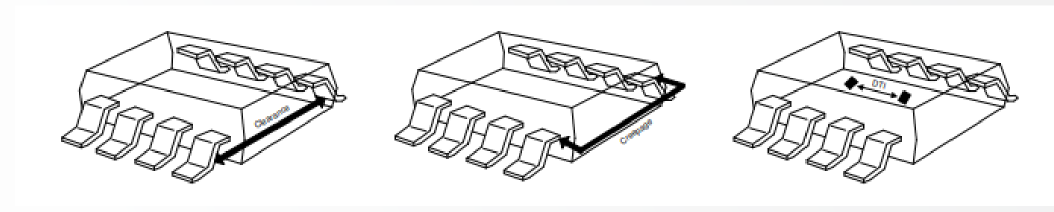
The isolation voltage strength is primarily dictated by the isolating material. The Figure below shows common seen isolating materials and their isolating capacity (Vrms/um). Of those, optocoupler technology has relatively high requirements for material transparency, so air and epoxy resin are generally selected. Materials with relatively good isolation strength like PI or SiO_2 are usually selected for digital isolator chips. Compared with PI, SiO_2 is more reliable, especially in humid working environments and it's the most popular solution at present.

Figure 39: Comparison of Insulating Materials for Digital Isolators

Insulating Material	Dielectric Strength	Breakdown Voltage >10 kVrms Dielectric Thickness
Air	~1Vrms/um	10mm
Epoxy Resin	~20Vrms/um	0.5mm
SiO_2 Filled Moulding Compound	~100Vrms/um	0.1mm
PI	~300Vrms/um	33µm
SiO_2	~500Vrms/um	20µm

In addition to the absolute value of voltage isolation strength, three key parameters are also commonly used to evaluate voltage isolation. They are, creepage, clearance and distance through insulation (DTI).

Figure 40: Parameter Description Diagram



- Clearance is the shortest distance between two conductive parts measured through air.
- Creepage is the shortest distance between two conductive parts measured along the surface of the isolating material.
- DTI is the shortest distance through the isolation filler medium between the conductors.

As well as having to meet voltage endurance requirements, isolation chips must also guarantee that the control signal is transmitted from one end (low voltage) to the other end (high voltage), in other words, signal transmission capability.

There are three types of signal transmission in digital isolation chips.

- OOK (on-off keying) technology
- Boundary type pulse code modulation technology
- Edge direct transmission technology

OOK technology is also called binary amplitude shift keying (2ASK). When the modulated signal is logical 1, the carrier is on; when the modulated signal is logical 0, the carrier is off. The structure of the transmitting and receiving units in OOK technology is simple, and it will only transmit the carrier and consume energy when logical is 1 or 0, meaning it can save power.

In edge-type pulse code modulation technology, when the modulated signal switches from logical 0 to logical 1, the carrier pulse train (sequence) is M narrow pulses; when the modulated signal switches from logical 1 to logical 0, the carrier pulse train (sequence) is N narrow pulses, and the receiving unit determines the state of the modulated signal according to the number of narrow pulses of the carrier pulse train. In high-frequency conditions, the modulated signal frequency switches between logical 0 and logical 1, and energy consumption is higher.

Edge direct transmission technology applies rising and falling edge direct transmission signal technology. That is, when the input signal switches from logical 0 to the rising edge of logical 1 and when it switches from logical 1 to the falling edge of logical 0, the “allow AC, block DC” characteristic of capacitive coupling is applied, and the signal is directly transmitted to the receiving unit via capacitive coupling. Because the modulation and demodulation method has not been used, there is no high-frequency carrier and power consumption is very low.

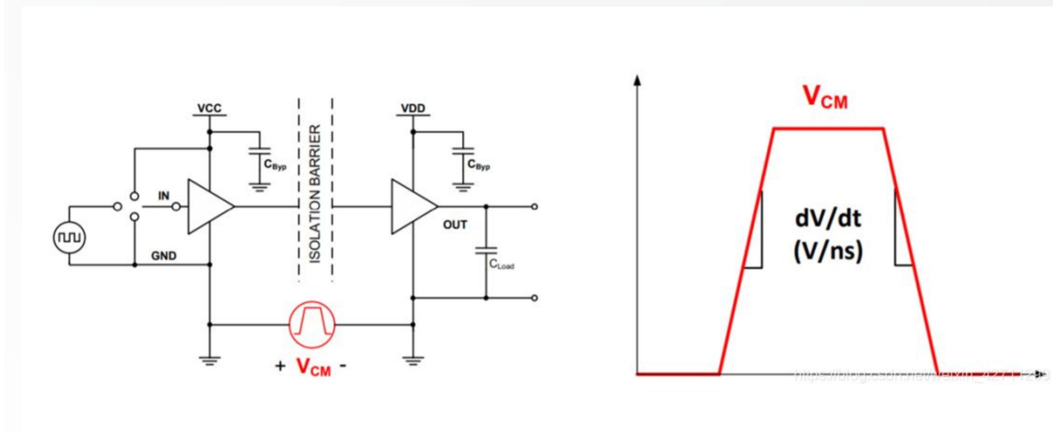
Compared to previous two methods of signal transmission, the other major advantage of the OOK technology code modulation method is that common mode transient immunity (CMTI) is stronger. The NOVOSENSE NSi82xx Series applies Adaptive OOK technology to upgrade its transient interference immunity to over 200kV/us. This can be directly applied in GaN, SiC and other high-speed switch scenarios to meet the stringent requirements for quick transient interference immunity.

Figure 41: NOVOSENSE NSi82xx Series

Source: NOVOSENSE

CMTI refers to the isolator’s ability to withstand common-mode noise transients. Common-mode noise refers to high noise transients that can cause the isolator to lose signal integrity or “spiking” in high frequency environments, and then leads to system modulation failure. This can even produce an error signal and trigger two power MOSFETs to connect at the same time, causing a short circuit and putting the system at risk.

Figure 42: Causes of CMTI



CMTI is one of the most important indicators in isolation products. CMTI refers to the minimum rise or fall dv/dt (kV/μs or V/ns) that transients pass through the isolated layer and damage the drive output state requires. The higher this value is, the higher the isolation chip’s immunity to interference is.

Current parameters for mainstream digital isolators are as follows:

Digital Isolator Comparison	NOVOSENSE NSI82 Product Series	ADI ADUM14 Product Series	TI ISO77 Product Series	Skyworks Si86 Product Series
Voltage Endurance	5kVrms	5kVrms	5kVrms	5kVrms
Creepage Distance	8mm	8mm	8mm	8mm
Isolation Level	Enhanced isolation	Enhanced isolation	Enhanced isolation	Basic isolation
DTI	28um	25.5um	21um	14um
Signal Delay (typ.)	10ns	13ns	11ns	10ns
CMTI(min.)	200kv/us	100kv/us	100kv/us	50kv/us

Source: Compiled by the NE Times

3.2.3 Power Module Technology in Automotive-grade Chips

When controllers are operating normally, they must meet different voltage requirements, with the common MCU requiring 1.3V, 3.3V and 5V, sensors and communication chips requiring 3-5V, and memory requiring 1.8-3.3V. At the same time, they must also guarantee the stability and reliability of voltage, to prevent controller failure due to power supply instability.

There are two main types of power management chips: LDO and DC/DC. High-voltage controllers mainly use LDO power modules (low dropout voltage regulators) for power supply. LDO power supply has the advantages of good stability and fast load response.

LDO power supply was first introduced in 1970 by the American company National Semiconductor (now part of Texas Instruments). In the automotive field, the international standard ISO 7637 is an EMC standard (the corresponding Chinese standard is GB/T 21437) designed for automotive 12V and 24V power supply systems. At present, most manufacturers refer to the ISO 7637 standard or make adjustments according to this standard.

As technology continues to advance, in addition to raising parameters, it is also necessary to meet the complex demands of the automotive field. For example, requiring higher input voltage range to ensure output voltage stability. Lower static power consumption is required to reduce the energy loss of controllers on standby. On top of that, self-protection functions are also required, so that in extreme working conditions, the power can be shut off immediately to ensure system safety. In some NEVs, isolation functions are also required.

Taking the NOVOSENSE NSR3x Series as an example, the voltage output range is as high as 3-40V and supports transient voltage of 45V. Static power is only 5uA and the turn-off current is 270nA, supporting current limiting protection and over temperature protection.

At present, the parameters for mainstream digital isolators are as follows:

Power Management IC Comparison	NOVOSENSE NSR31/3/5 High-voltage LDO Product Series	Infineon 40V High-voltage LDO Product Series	TI 40V High-voltage LDO Product Series	ROHM 40V High-voltage LDO Product Series	ST 40V High-voltage LDO Product Series
Input Voltage	3-40V	4.5-40V	3-40V	3-42V	5.6-40V
Output Current	150/300/500mA	150/300/500mA	150/300/500mA	150mA/500mA	150mA/500mA
Output Voltage	Fixed 2.5-V, 3.3-V, 5-V and adjustable output(1.2V~18V)	3.3V, 5V	2.5V, 3.3V, 5V	3.3V, 5V	3.3V, 5V
Static Current	5uA	40uA	15uA	17uA	50uA

Source: Compiled by the NE Times

3.2.4 Current Sensor Technology in Automotive-grade Chips

Current sensors can instantly feedback current signal and the operating status of the monitoring system, and all new energy high-voltage system controllers require current sensors. By monitoring current information, a BMS can conduct battery capacity estimation, and fault detection and diagnosis, ensuring safety. In controllers, current data feedback can be used to determine the motor power and torque at that time, and then reach controller output targets. In OBCs, it is necessary to detect real-time power levels to evaluate the battery charge status and disconnect in time to prevent over charging.

- Accuracy: Measurement results of current sensors should be very close to the true value.
- Linearity: The relationship between output electrical signal and measured current should be linear.
- Thermal adaptability: Can still maintain stable output in different temperatures.
- Signal bandwidth: Frequency range of current sensor signal sampling

In addition to the above indicators, when running NEVs, power batteries operate on DC power, while motor controllers and electric ACs operate on AC power. Therefore, the corresponding current sensors are divided between AC and DC sensors.

In terms of type, NEV current measurement methods can be divided into two types: resistance measurement and electromagnetic measurement. Resistance measurement is best represented by shunt current sensors and electromagnetic measurement by Hall current sensors. Shunt current sensors have high precision, a wide range and strong anti-interference characteristics, but the cost is much higher than that of Hall current sensors. In terms of application progress, due to their high precision, shunt current sensors are mainly applied to DC power supply measurement in power batteries and very rarely applied to AC power supply measurement. Hall-type current sensors are the absolute mainstream of AC power supply measurement.

Hall sensors can conduct measurement without coming into direct contact with the object being measured. In complex environments, their reliability and service life are both great advantages, and are thus widely applied to all fields of vehicle state parameters such as measuring switches, angles, speed and current.

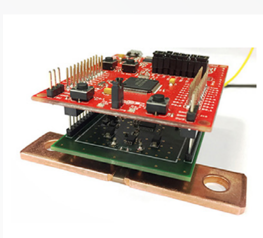
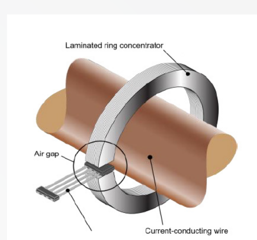
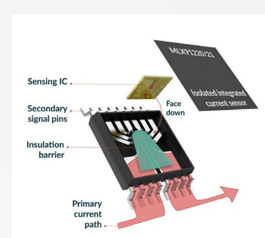
In NEVs, Hall-effect current sensors can be divided into two types according to the different packages: current sensor modules (also known as the traditional type) and integrated current sensor ICs (Hall IC).

Current sensor modules are composed of key components like magnetic core, Hall chips and operational amplifiers. When the current passes through the magnetic core, it interacts with it and creates a magnetic field. The magnetic field then concentrated at the air gap in the magnetic core, the Hall element senses the magnetic field and outputs hall voltage , and the voltage signal is output after operational amplifier processing. Because the voltage signal meets a certain linear relationship with the current, the corresponding current value can be measured through output voltage measurement, and achieve the goal of current detection. The current sensor module can directly measure wire current and so this method is known as direct measurement. The current voltage module's greatest disadvantage is that the magnetic core is relatively large and installation space is therefore limited. However, it can measure high current values and has a strong anti-interference capability. At present, circuit detection in motor controllers mainly adopts this solution, and current measurement capacity can be as high as over 200A.

Integrated current sensor ICs' main feature is that they can remove magnetic cores, and current detection is achieved indirectly by sensing the magnetic field generated by the current flowing through the internal primary conductor of the chip (Hall IC) based on magnetic field detection technology. Compared with current sensor modules, they are much smaller and can be flexibly positioned.

Structurally constrained, when measuring large current, current sensor ICs face product heat dissipation challenges, and therefore the level of current measurement they can achieve is lower than that of current sensor modules. Because of their small size and flexible placement advantages, at present they are mostly used in AC/DC converters like OBCs and DCDCs, that is, components with a low current rating. In addition, because the current flows through the sensor itself, in addition to meeting accuracy requirements, the chip-shaped Hall current sensor packaging structure must also meet high isolation requirements.

Figure 43: Different Types of Current Sensor

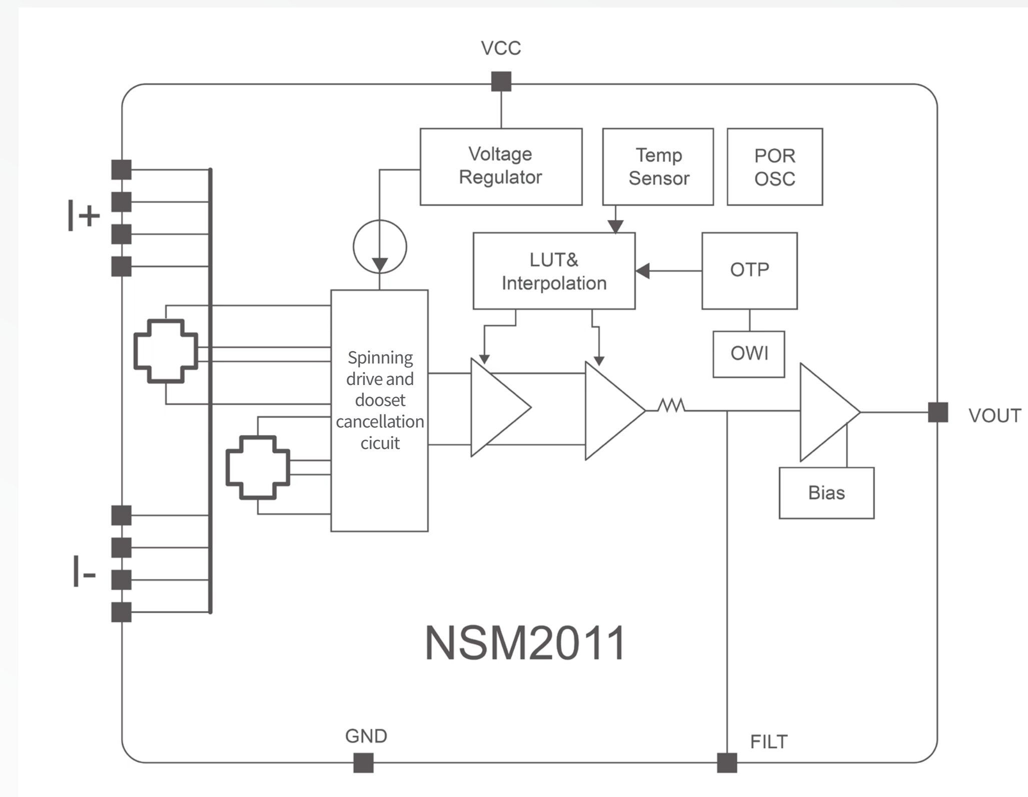
	Shunt Current Sensors	Traditional Hall Current Sensors	Chip-shaped Hall Current Sensors
Schematic Diagram			
Application	Power batteries	Power batteries,inverters	OBC、DCDC

Source: Compiled by the NE Times

At present, only a small number of companies, like Melexis, NOVOSENSE and Allegro, can provide solutions for chip-shaped current sensors and the product form differs in the actual application in each company.

Taking the NOVOSENSE NSM201x Series as an example, it adopts a single-chip integrated technology solution, which has a typical primary side resistance value of 0.85mΩ, and effectively reduces heating while conducting large current sensing. Its working voltage level for basic Insulation is 1550Vpk and it can endure 10kV surge voltage and 13kA surge current without adding any protective devices. It also has a dielectric withstand voltage of 5000Vrms, easily meeting the voltage and current surge requirements for NEVs. Internally, it adopts dual Hall differential sampling and can effectively reduce the impact of external common-mode magnetic fields.

Figure 44: NOVOSENSE NSM201x Series Functional Block Diagram



Source: NOVOSENSE

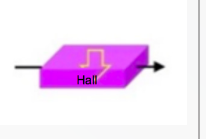
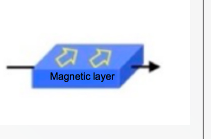
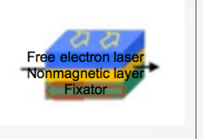
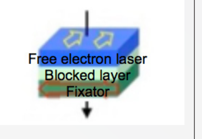
At present, core parameters for the mainstream chip-shaped Hall current sensor are as follows:

Current Sensor Comparison	NOVOSENSE NSM2011/13/15 Product Series	Allegro ACS724MA Product Series	Melexis MLX91220 Product Series
Total Output Error	Max ±2% (-40-125°C); Typ ±1% (25-125°C)	Max ±2.5% (25-125°C); Typ ±3% (-40-25°C)	Max 2-3% (-40-125° C) (Total error derived by calculating several error values)
Offset Error	max ±10mv (25-125°C)	max ±15mv (25-125°C); Typ ±20mv (-40-25°C)	max 10mv (25°C)
Signal Bandwidth	240/320khz	120khz	100khz
Nonlinearity	0.2% typ	±1% typ	/
Conductor Res	850u ohm	850u ohm	700u ohm
BasicIsolation	1550v pk/1097v rms	1550v pk/1097v rms	1500v pk
PTI	I,600	II, 400v-599v	600

Source: Compiled by the NE Times

In addition to the types of current sensors described above, magnetoresistive effect sensors are one new research direction. Magnetoresistance effect refers to when current passes through semiconductor materials and its resistance value changes as the applied magnetic field changes, therefore, by measuring that resistance value, magnetic field strength measurement can be achieved. Magnetoresistive sensors are also an electromagnetic measurement. They can be divided into anisotropic magnetoresistance effect (AMR) elements, giant magnetoresistance effect (GMR) elements, and tunnel magnetoresistance effect (TMR) elements. Magnetoresistive effect sensors have certain advantages in terms of accuracy, sensitivity and power consumption compared to Hall effect sensors. In particular, TMR technology has extremely high sensitivity and wide range of impedance adjustment flexibility, it can adapt to a wide range of application requirements. However, in terms of application, magnetoresistive current sensors have not been adopted in NEVs on a large scale at present.

Figure 45: Types of Magnetoresistive Current Sensors

	Hall	AMR	GMR	TMR
Schematic Diagram				
Power Consumption (mA)	5-20	1-10	1-10	0.001-0.01
Size (mm)	1x1	1x1	2x2	0.5x0.5
Sensitivity (mvV/Oe)	0.05	1	3	20

3.2.5 Gate Drive Technology in Automotive-grade Chips

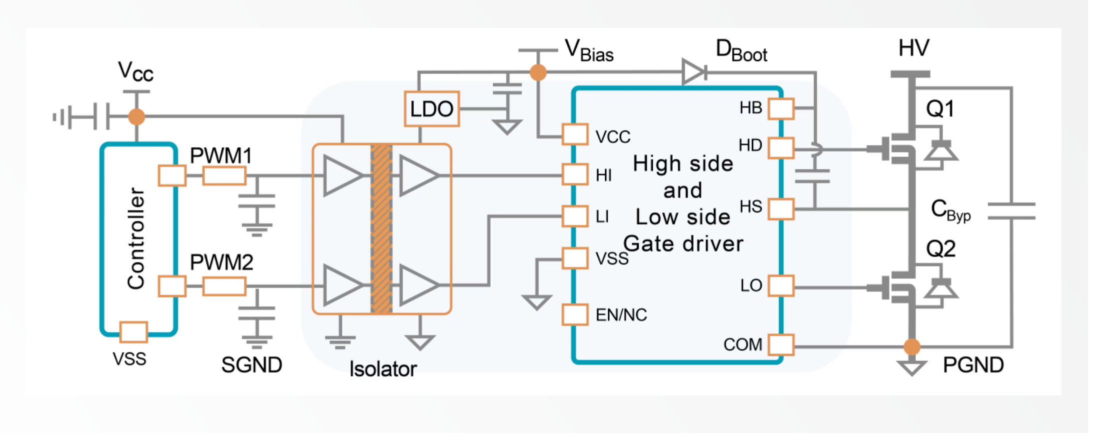
The gate driver products can source and sink gate current into power transistors to turn it on and off, and meet the requirement of high-voltage electric switching and drive.

Gate drivers can offer single or separate output options. Compared to single output, separate output drivers provide individual on and off paths that can independently control the sink and source current intensity making them the mainstream solution at present.

In high frequency power supply system with power transistors working in half-bridge topology, to prevent shoot-through issue (high-side and low-side transistors switch on at the same time) and guarantee the safe switching of the power device, there is a period called “dead time” which is designed to turn off the two power devices on the high-side and low-side simultaneously. As dead time causes a loss of efficiency, the gate drivers’ hardware dead time needs to be designed as minimal as possible. The relative factors specs are pulse width distortion, propagation delay, and signal rise and fall time. In addition, an integrated interlock function is also needed to prevent power transistors shoot-through issue.

For NEVs, gate drivers are used in high-voltage systems. So theyoften require isolation functions, that is, integrating the digital isolator and gate driver into one package. Therefore, in addition to considering the characteristics of gate drivers applied in high-voltage systems, it is also necessary to comprehensively consider isolator performance.

Figure 46: Integrated Digital Isolator and Gate Driver Circuit Diagram



Isolated gate driver parameters of mainstream companies are as follows:

Driver IC Comparison		NOVOSENSE	TI	Infineon
		NSI6651	ISO5452	1ED020I12-F2
Isolation Technology		Capacitive	Capacitive	Transformer
Isolation Rating (UL 1577)		5.7kVrms Reinforced	5.7kVrms Reinforced	5.7kVrms Basic
Isolation	CMTI (min)	150 V/ns	50 V/ns	50 V/ns
	Working Voltage	2121V	1420V	1420V
Output Driver	Max Drive Current	+10A/-10A	+2.5A/-5A	+2A/-2A
	VCC2-VEE2 Output Voltage (max)	32V	30V	28V
Driver Specs	Propagation Delay (max)	130ns	110ns	195ns
Iq	VCC1 / VCC2 Iq (max)	4mA/7mA	4.5mA / 6mA	9mA / 6mA
Protection	Miller Clamp Current (max)	4A	2A	2A
	DESAT Protection	Yes	Yes	Yes
	Fault Reset	Yes	Yes	Yes
AEC-Q100	AEC-Q100	Yes	Yes	Yes
Temperature	Tj_Max	150°C	150°C	150°C
Package		16-pin SOIC	16-pin SOIC	16-pin SOIC

Source: Compiled by the NE Times

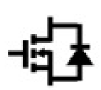
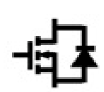
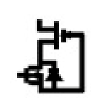
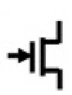
Because IGBTs, SiC and GaN have different working characteristics, the corresponding gate drivers assigned for each are also different. Particularly with the development of the third-generation power semiconductor application, such as SiC and GaN, which present new challenges to the gate drivers. These challenges are primarily derived from two factors: sharp increase in switching frequency and different switching characteristics.

Compared with silicon-based IGBT, the switching frequencies of SiC and GaN are much higher. Therefore, during gate driver IC design, there must be relatively little dead time setting to match it. In addition, it is also necessary to consider the propagation delay time of the signal when calculating the dead time.. Furthermore, in high voltage controller drive system, the one-drive-one (one gate driver controls one power transistor) mode is usually adopted. So the different parameter matching among different chips should also be considered. At the same time, due to the increase of switching frequency, the EMI interference issues brought by power transistor switching are even more challenging. Gate drivers must have higher CMTI performance in order to guarantee safe operation of the system.

In addition to switching frequency, the driving characteristics of SiC and GaN are also quite different from those of silicon-based IGBTs. Since the gate opening voltage of SiC is lower, it is more easily to mistaken turn-on due to the circuit crosstalk in practical application. Therefore negative gate turn-off voltage is usually recommended for use with SiC. GaN power transistors can be divided into D-Mode and E-Mode. The D-Mode GaN is compatible with traditional silicon device gate drivers, whereas E-Mode gate drivers are more complex, with lower drive voltage requirements, and in order to ensure safe turn-off, negative voltage is also usually used.

Currently SiC power device is still in a relatively early stage in system applications. So we usually see gate drivers are compatibly designed or used in both IGBT and SiC applications. But with the gradual expansion of SiC application, specialized gate driver chip of SiC will be gradually applied.

Figure 47: Gate Driver Requirements for Different Types of Power Semiconductors

	Si-MOSFET	IGBT	SiC-MOSFET	GaN	
Schematic Design					
Power Device Operating Voltage	<200V	>300V	>400V	<650V	
Gate Driver Voltage (Maximum Voltage Range)	0-15V (±20V)	-10-15V (±20V)	15-15V (-10-25V)	-5-10V (±18V)	-4-6V (-10-7V)

In addition to requiring highly efficient and stable operation, as functional safety requirements increase, when facing the highest functional safety ASIL-D requirement, gate drivers are required to achieve higher performance, particularly on below two specs:

ICs with sufficiently low rate of failures in time (FIT). FIT must be lower than 10 in order to meet ASIL-D requirements.

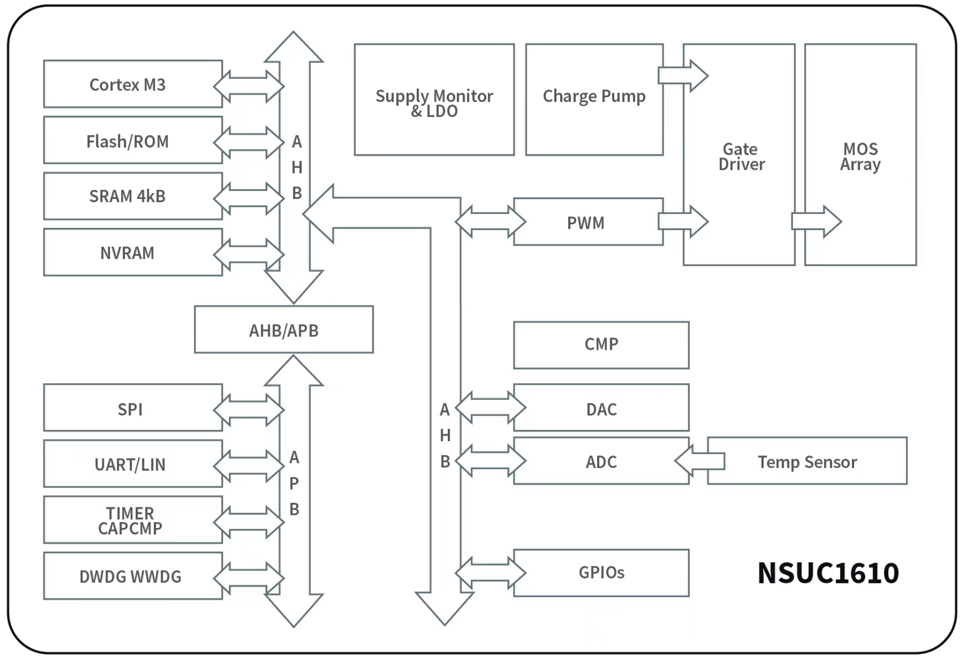
Added diagnostic and redundancy capabilities. Diagnostics can detect potential risks in real time and keep the system in a safe state. Redundancy offers multiple backups, so that when a component fails, the backup unit is launched to guarantee system stability.

3.2.6 Micro & Special Motor Driver SoCs for Automotive-grade Chip Technology

As integrated thermal management technology advances, to better realize the model selection and platformization of electronic valves and pump components, single chip integrated micro & special l motor drive system-on-chips (SoC) are starting to be applied. This solution takes the original MCU, power supply, MOS drive and LIN communication module, and integrates them into one package, greatly simplifying peripheral circuits, reducing peripheral devices, realizing the standardization of interface and control algorithms, and reducing system costs, while at the same time improving reliability.

Taking the NOVOSENSE NSUC1610 as an example, this product integrates a Cortex M3 processor, power MOSFET and DAC. It supports a 4-wire LIN bus and dual-channel temperature sensor which can be used for power-side over temperature shutdown and low-voltage-side temperature detection inside the chip.

Figure 48: NOVOSENSE NSUC1610 Diagram



Source: NOVOSENSE

As integrated thermal management modules become finalized in the future, there will be demands for SoC products that can drive multiple small motors at the same time, further reducing development costs and product costs.

Brief Summary:

The automotive industry is one of the main markets for analog chips. However, the requirements for automotive-grade chips are high and they have long cycles; analog chips are no exception in this respect. In addition, the unique nature of NEV high-voltage control products puts new demands on chips, with a typical example being the high-voltage isolation capabilities all key chips must have. At the same time, it cannot be ignored that driven by cost, the requirements on chips are becoming more segmented; the flexible selection and use of current sensors being a case in point. As many new technological applications for new energy technology emerge in the future, such as third-generation semiconductors and integrated thermal management technology, corresponding chip technology will need to meet new technical demands being constantly driven by the need for high functional safety.

3.3 Analog Chip Supplier Rankings

Due to the wide variety of analog chips and the low price of individual units, choosing the right product is an important part of the downstream controller development process. Long product cycles in the car manufacturing industry also ensure the relative stability of the automotive analog chip market.

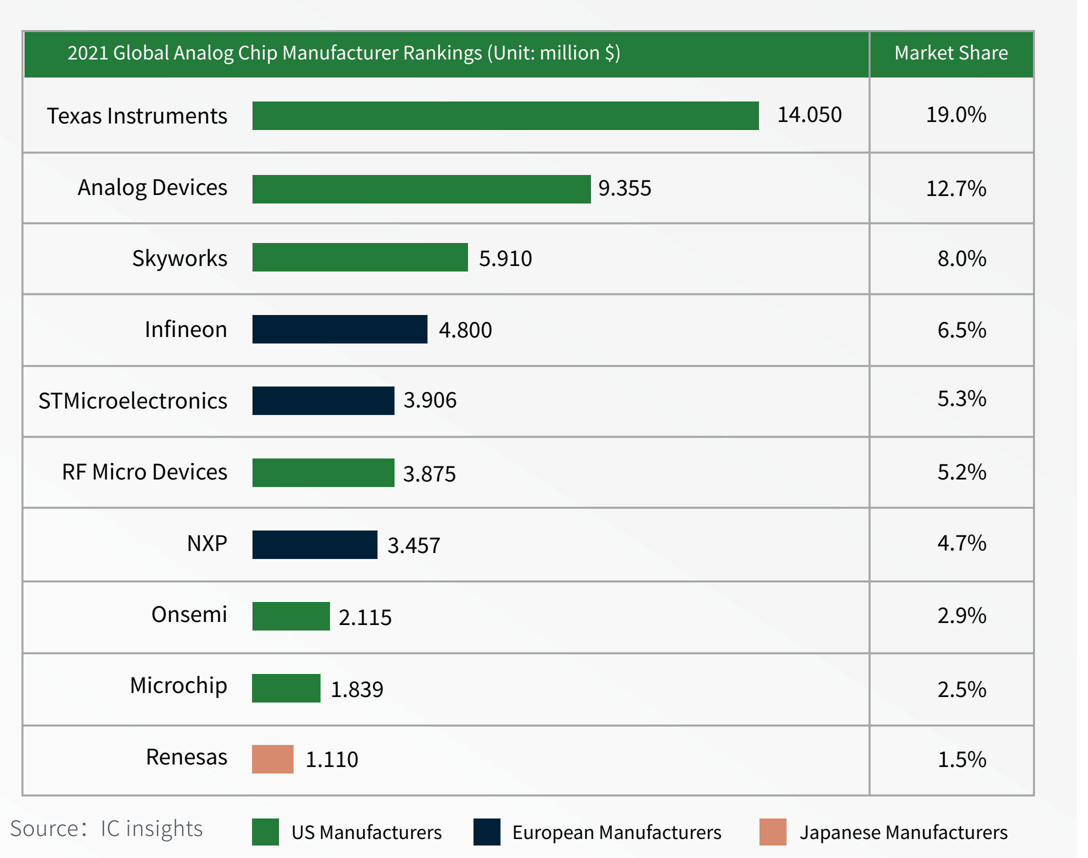
Stable downstream customer demand has always been key to maintaining steady sales for chip manufacturers. To this end, chip companies usually expand the application field or product line to achieve this purpose. With the fast development of the NEV industry, the automotive field has become one of the fastest growing areas for chip demand. Particularly, the overall background of leapfrog development in China's NEV industry and the chip shortage brought about by a lack of industry supply in 2021 and 2022, has gifted Chinese chip manufacturers a rare development opportunity.

In 2023, the pressures on chip supply eased, with some manufacturers even taking the initiative to cut prices to try and win over the market. For China domestic chip manufacturers, in addition to staying competitive in single technology products, rich product portfolio is the true embodiment of current market competitiveness. In terms of the richness of diversification, China chip manufacturers like NOVOSENSE have already narrowed the gap between themselves and international leading chip manufacturers, and only fall behind on certain types of products.

Figure 49: Product Coverage of Mainstream Chip Companies

Chip Type	Infineon	ADI	TI	ROHM	ST	Renesas	NOVOSENSE
Control Processors	Y		Y		Y	Y	
Communication Interfaces (CAN/LIN)	Y	Y	Y	Y	Y		Y
Isolator Chips	Y	Y	Y		Y		Y
Amplifiers & Comparators		Y	Y	Y	Y	Y	Y
Sensors	Y	Y	Y	Y	Y	Y	Y
Power Management	Y	Y	Y	Y	Y	Y	Y
Drive Chips	Y	Y	Y	Y	Y		Y
Power Devices	Y		Y	Y	Y	Y	Y

Figure 50: Rankings of Global Analog Chip Manufacturer (2021)



Source: IC insights

Brief Summary:

With such a large number of automotive-grade chip applications and a complex variety, a diversified product layout will help chip manufacturers meet customers' needs to the greatest extent, and reduce the workload of client and supplier management, and product type selection.

PART

04

Conclusion

In recent years, the NEV market has witnessed a leap in growth and as more and more car manufacturers release products that follow up on that growth, the NEV market will retain its strong growth potential, with the whole market expected to exceed 10 million units by 2025. As an important component of NEVs, the market applications for high-voltage architecture are also enjoying rapid growth. Developing alongside the market are the corresponding technological levels, and in pursuing efficiency while considering costs, 800V platforms, highly integrated controller technology and centralized thermal management technology will be rapidly applied. This improvement in technology will also bring about a transformation in the supply layout, particularly with the impact of OEMs choosing to develop their own systems. Tier 1 will gradually transfer to tier 2 and focus even harder on their own strong product areas.

The changes downstream will also transmit to the upstream chip domain. In terms of technology, chip technology must meet 800V high-voltage and high functional safety requirements. In terms of the supply layout, as the demand for chips is high and complex in variety, chip manufacturers' products must cover as wide a range as possible in order to reduce the costs of type selection and supplier management to the greatest degree.

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