Application Note

NOVOSENSE

Introduction to Level Shifters

AN-13-0011

Author: Xiutao Lou

AN-13-0011

NOVOSENSE

Introduction to Level Shifters

ABSTRACT

Amid trends toward electric vehicles (EVs), energy efficiency, industrial intelligence, and portable consumer electronics, level shifters serve as a cornerstone for interconnecting modern electronic systems across different voltage domains. New highly integrated microcontrollers and processors have relatively low I/O voltages, necessitating level shifters to align with the higher I/O voltages of peripheral devices. When selecting level shifters, system designers primarily consider factors such as target voltage level, bit width or channel count, current drive capability requirement, data rate, and directionality. NOVOSENSE currently offers three types of level shifters – unidirectional, direction-controlled, and auto-bidirectional, catering to design requirements of diverse applications. This application note mainly discusses the functions of NOVOSENSE's existing level shifters and design considerations.

AN-13-0011

Introduction to Level Shifters

INDEX

1.Unidirectional / Direction-Controlled Level Shifters

1.1.Unidirectional Level Shifters

Unidirectional level shifters perform one-way voltage level translation on input signals at the device input and deliver the translated signal to the device output. NOVOSENSE's unidirectional level shifter product family includes NCA8244, NCA8244L, and NCA8541, all powered by a single supply. Their internal block diagrams are shown in Figures 1.1 and 1.2.

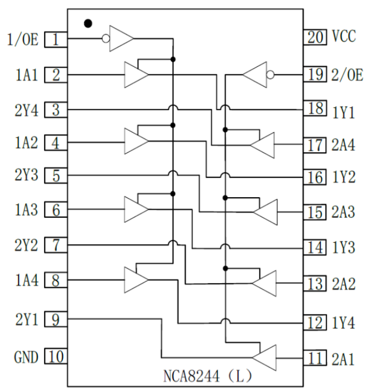

Figure 1.1 Internal Block Diagram of NCA8244(L)

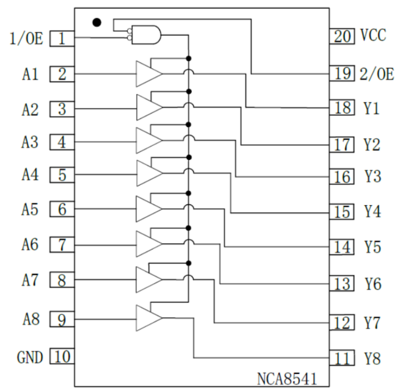

Figure 1.2 Internal Block Diagram of NCA8541

The NCA8244 and NCA8244L share the same internal architecture, providing four channels in each direction (i.e., 4 forward and 4 reverse). Each direction has an independent Output Enable (/OE) input, which is active-low. When /OE is low, the NCA8244-Q1 transmits data from A to Y; when /OE is high, the output enters a high-impedance state. The main difference between the NCA8244 and NCA8244L lies in their supply voltage ranges.

Additionally, the NCA8541 offers eight unidirectional channels (i.e., 8 forward), and features two Output Enable (/OE) inputs, both active-low. When both /OE1 and /OE2 are enabled, the NCA8541-Q1 transmits data from A to Y; if either /OE is high, the output enters a high-impedance state.

1.2.Direction-Controlled Level Shifters

Direction-controlled level shifters feature one or more direction-control pins, allowing system engineers to flexibly configure input/output directions or even achieve bidirectional simultaneous translation on a single device, offering greater design flexibility. NOVOSENSE's existing direction-controlled level shifter portfolio includes NCA8T245, NCA8245, NCA8245L, and NCA84245. Their internal block diagrams are shown in Figures 1.3, 1.4, and 1.5.

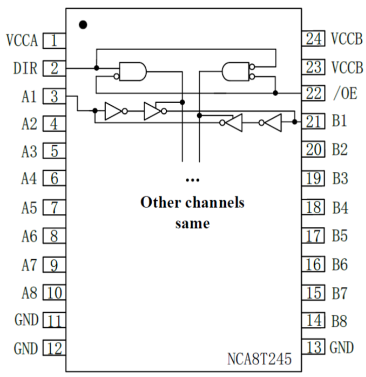

Figure 1.3 Internal Block Diagram of NCA8T245

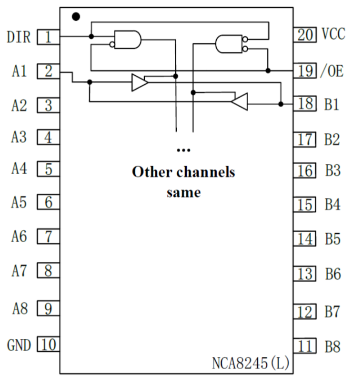

Figure 1.4 Internal Block Diagram of NCA8245(L)

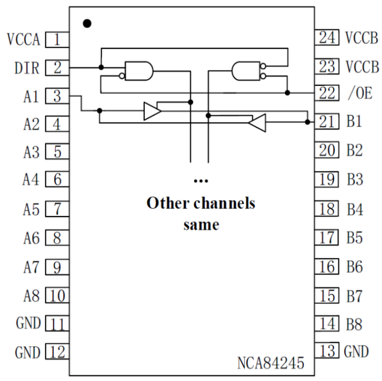

Figure 1.5 Internal Block Diagram of NCA84245

The NCA8T245 is powered by two independent supplies (VCCA and VCCB), each supporting a voltage range of 1.65V to 5.5V. Port A tracks VCCA, while Port B follows VCCB, enabling bidirectional voltage translation between 1.8V, 2.5V, 3.3V, and 5.5V. The device features a direction control (DIR) input for bidirectional data transmission. When DIR is high, data is transmitted from A to B; when DIR is low, data is transmitted from B to A.

The NCA8245, NCA8245L, NCA84245, and NCA8T245 share the same internal functional block diagram, each featuring DIR and OE pins with identical functionality. It’s noted that the NCA8245 and NCA8245L are single-supply devices, with main difference in their supply voltage ranges. The NCA84245 is dual-supply device, and differs from the NCA8T245 in its supply voltage range.

1.3.Applications

(1) Unidirectional level shifters are most suitable for applications where signals need to be transmitted in a single direction only. Typical examples include reset signals and clock synchronization signals.

(2) Direction-controlled level shifters offer superior flexibility and ease of use, allowing a single controller (e.g., an MCU) to control the data transmission timing on the bus and dynamically switch transmission directions. However, they requires additional GPIO resources from the MCU.

(3) Both unidirectional and direction-controlled level shifters feature strong steady-state drive capability (see Section 1.4 for maximum load current specifications), making them ideal for applications with long trace lengths and high loads.

NOVOSENSE

1.4.Product Comparison

Product	Supply Voltage	Total Channels	Forward/ Reverse Channels	Input Type	Output Type	Key Features	Max Load Current (mA)	Quality Grade	Package
NCA8T245	VCCA= 1.65 - 5.5V; VCCB= 1.65 - 5.5V	8	8 (Forward/ Reverse)	TTL/CMOS	3-State	Dual-supply, transmission direction control, /OE control	32	Industrial	TSSOP24
NCA8T245-Q1	VCCA= 1.65 - 5.5V; VCCB= 1.65 - 5.5V	8	8 (Forward/ Reverse)	TTL/CMOS	3-State	Dual-supply, transmission direction control, /OE control	32	Automotive	TSSOP24
NCA8244	4.5 - 5.5V	8	4 (Forward) / 4 (Reverse)	TTL	3-State	Single supply, dual /OE control	24	Industrial	TSSOP20
NCA8244-Q1	4.5 - 5.5V	8	4 (Forward) / 4 (Reverse)	CMOS	3-State	Single supply, dual /OE control	24	Automotive	TSSOP20
NCA8244L	1.65 - 3.6V	8	4 (Forward) / 4 (Reverse)	TTL/CMOS	3-State	Single supply, dual /OE control	24	Industrial	TSSOP20
NCA8244L-Q1	1.65 - 3.6V	8	4 (Forward) / 4 (Reverse)	TTL/CMOS	3-State	Single supply, dual /OE control	24	Automotive	TSSOP20
NCA8245	4.5 - 5.5V	8	8 (Forward/ Reverse)	TTL	3-State	Single-supply, transmission direction control, /OE control	24	Industrial	TSSOP20
NCA8245-Q1	4.5 - 5.5V	8	8 (Forward/ Reverse)	TTL	3-State	Single-supply, transmission direction control, /OE control	24	Automotive	TSSOP20
NCA8245L	1.65 - 3.6V	8	8 (Forward/ Reverse)	TTL/CMOS	3-State	Single-supply, transmission direction control, /OE control	24	Industrial	TSSOP20
NCA8245L-Q1	1.65 - 3.6V	8	8 (Forward/ Reverse)	TTL/CMOS	3-State	Single-supply, transmission direction control, /OE control	24	Automotive	TSSOP20
NCA8541	4.5 - 5.5V	8	8 (Forward)	TTL	3-State	Single supply, dual /OE control	24	Industrial	TSSOP20
NCA8541-Q1	4.5 - 5.5V	8	8 (Forward)	TTL	3-State	Single supply, dual /OE control	24	Automotive	TSSOP20
NCA84245	VCCA= 4.5 - 5.5V; VCCB= 2.7 - 3.6V	8	8 (Forward/ Reverse)	TTL	3-State	Dual-supply, transmission direction control, /OE control	24	Industrial	TSSOP24
NCA84245-Q1	VCCA= 4.5 - 5.5V; VCCB= 2.7 - 3.6V	8	8 (Forward/ Reverse)	TTL	3-State	Dual-supply, transmission direction control, /OE control	24	Automotive	TSSOP24

NOVOSENSE

1.5.Design Considerations

(1) Select the appropriate level shifter type: unidirectional or direction-controlled.
(2) Ensure that power supply voltage is consistent with the specifications provided in the datasheet.
(3) Place 0.1μF decoupling capacitors near the power supply pins to minimize voltage noise.
(4) During power-up/down, connect /OE to VCC through a pull-up resistor to guarantee high-impedance outputs.
(5) All unused inputs must be connected to either VCC or GND to avoid excessive supply current.

2.Auto-Bidirectional Level Shifters

Auto-bidirectional level shifters automatically detect communication direction and operate accordingly. If a processor's GPIO requires bidirectional signal transmission, an auto-direction sensing voltage level shifter can provide a robust solution. As the name suggests, this type of level shifter does not require the use of direction control signals, with each channel supporting independent data transmission or reception. This eliminates the requirement for processor GPIOs to control DIR inputs, thereby simplifying the development of software drivers. NOVOSENSE offers three series of auto-bidirectional level shifters: NCA9306, NCAS0104, and NCAB0104.

2.1.NCA9306

The NCA9306 is primarily designed for level shifting in I2C communication processes and features dual power supplies. The internal channels are previously constructed using passive FETs, which do not inherently have driving capability and rely on external power sources. A common application circuit is shown in Figure 2.1.

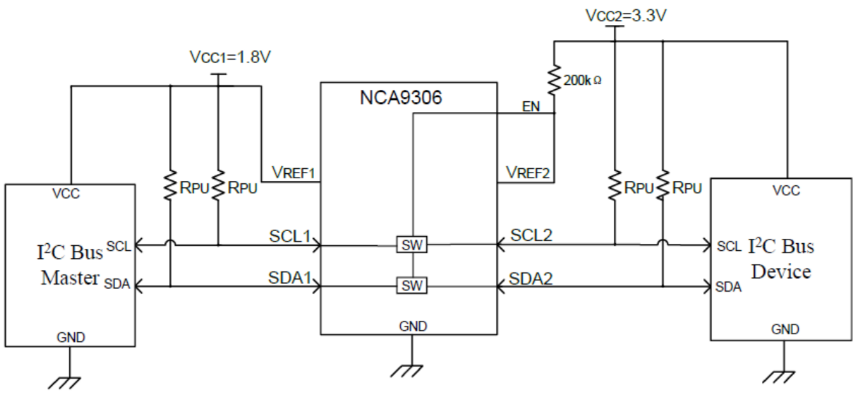

Figure 2.1 Typical Application Circuit of NCA9306

2.1.1 Operating Principle

The internal FET switches turn on during the low-level pulse of the input signal and turn off during the high-level pulse. This allows the pull-up resistors on the output side to pull the signal to the desired voltage level during the high-level pulse. In the circuit shown in Figure 2.1, the gate voltage of the internal FETs is VREF1 + Vth. Unlike traditional NMOS transistors, the FETs in the internal channel use the configuration shown in Figure 2.2, which minimizes leakage current, and allows source/drain interchangeability for bidirectional communication.

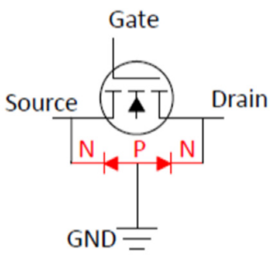

Figure 2.2 Schematic of Internal FET Structure

2.1.2 Design Considerations

(1) The B-side (high-side) supply voltage VCC2 must be at least 0.8 V higher than the A-side (low-side) supply voltage VCC1. VREF2 should be shorted to EN and pulled up to the B-side supply voltage through a 200 kΩ resistor.

(2) On either A-side or B-side, resistors may pull up the signal to any voltage between VREF1 and 5V, allowing downward voltage translation to the B-side.

(3) When using an LDO for the A-side supply, verify its sink current capability. If not, add a weak pull-down resistor to ground.

(4) Signal integrity during level translation depends on multiple factors, including trace capacitance, output load, and pull-up resistor value. Generally, smaller pull-up resistors enable faster signal transitions but increase power consumption.

(5) Inputs driven by push-pull devices don't require pull-up resistors, but all other configurations require external pull-up resistors to ensure reliable operation.

2.2.NCAS0104

The NCAS0104 integrates N-channel transmission FETs, 10kΩ pull-up resistors, and rise time acceleration circuits, making it ideal for connecting devices or systems operating at different voltage levels while simplifying connections with open-drain (OD) interfaces, as shown in Figure 2.3. The NCAS0104 is classified as a weakly-buffered level shifter because it can maintain the output port at a high level under DC conditions. However, when bus direction changes are needed, the 10kΩ impedance buffer can be easily pulled low by system drivers connected to either Port A or Port B.

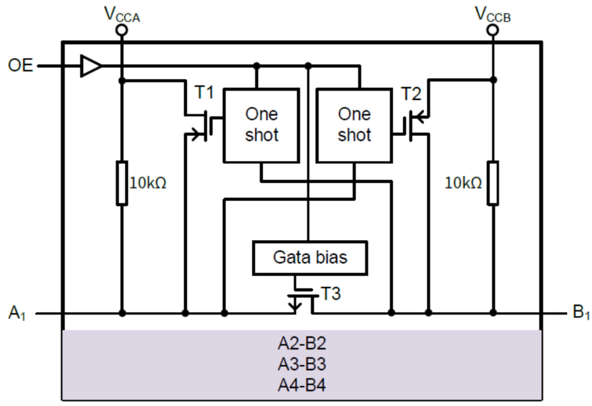

Figure 2.3 Internal Block Diagram of NCAS0104

2.2.1 Operating Principle

The NCAS0104 employs an FET-based architecture, utilizing N-channel transmission gate transistors to open or close the connection between Port A and Port B. Initially, both ports are kept at a static high level due to internal 10kΩ pull-up resistors. When the driver connected to either Port A or Port B has a low input level, the opposite port is pulled low through the FET. As the input voltage increases, once the FET stops conducting, both input and output ports will rise to their respective supply voltages due to the internal 10kΩ pull-up resistors.

To achieve higher data rates, these level shifters integrate rise time acceleration circuits that speed up the transition from low to high levels of the output signals. A one-shot circuit, combined with T1/T2 PMOS transistors, accelerates the switching speed of rising edge input signals. Upon detecting a rising edge on the input side, T1/T2 instantaneously turns on, quickly pulling up the output port level, reducing output impedance (approximately 50Ω), and accelerating the rising edge.

2.2.2 Design Considerations

(1) The NCAS0104 is suitable for driving high-impedance loads in applications with push-pull and open-drain interfaces.

(2) No DIR control signals are required to establish data flow direction.

(3) The OE input circuit is referenced to VCCA power supply. Avoid leaving the OE pin floating; if left unconnected, the OE pin may enter an undefined state, potentially causing undesired static current and increasing overall power consumption.

(4) While external pull-up resistors can be added to NCAS0104, their impact on VOL should be taken into consideration. External pull-ups in parallel with the internal 10kΩ pull-up resistor reduce the equivalent pull-up resistance, leading to higher sink current during low-level periods and increased VOL value.

(5) Avoid using external pull-down resistors. If necessary, carefully select their resistance values. The internal 10kΩ pull-up resistor and external pull-down resistor form a voltage divider network. An external pull-down resistor does not affect VOL output, but impacts VOH output (the smaller the external pull-down resistor, the lower the VOH value). Choose a sufficiently large resistance value to ensure that VOH meets requirements (above 50kΩ recommended).

(6) The NCAS0104 can drive slightly heavier impedance loads compared to the NCAB0104. However, for capacitive loads less than 70pF, the NCAB0104 might be a preferable choice.

(7) Minimize trace lengths and avoid using connectors to prevent introducing excessive load.

2.3.NCAB0104

The NCAB0104 integrates rise and fall time acceleration circuits along with a 4kΩ buffer circuit, making it a perfect match for connecting devices or systems operating at different voltage levels, as illustrated in Figure 2.4. NCAB0104 is classified as a weakly buffered level shifter because it can maintain output ports at high or low levels under DC conditions. However, when bus direction changes are needed, the 4kΩ impedance buffer can be easily driven by the system drivers connected to either Port A or Port B. Therefore, the NCAB0104 is suitable for light-load push-pull applications.

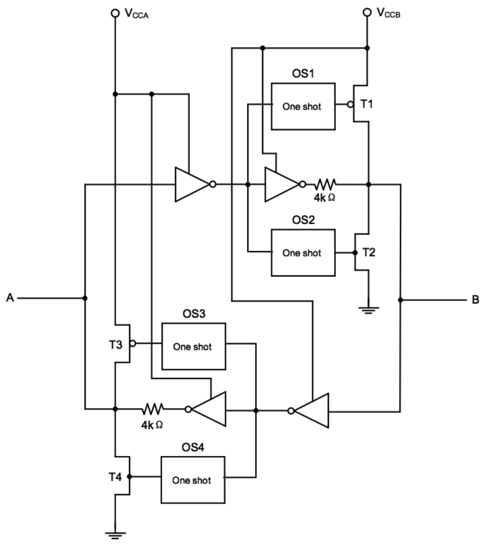

Figure 2.4 Internal Block Diagram of NCAB0104

2.3.1 Operating Principle

Upon detecting a rising edge on Port A, the OS1 one-shot circuit is activated. At this point, Port B is driven high by both the 4kΩ weak buffer and T1 PMOS, reducing Port B's output impedance during the oneshot circuit activation period. On the falling edge of Port A, the OS2 one-shot circuit is triggered. At this point, Port B is driven low by the 4kΩ weak buffer and T2 NMOS, lowering Port B's output impedance during the one-shot circuit activation period. The one-shot circuits reduce the output impedance during transitions, enabling the NCAB0104 to drive loads while maintaining fast propagation delays and edge rates.

Once the transition completes and the one-shot circuit times out, the buffer and 4kΩ pull-up resistor hold Port B's signal at a high or low level.

2.3.2 Design Considerations

(1) The NCAB0104 level shifter is suitable for driving high-impedance loads in push-pull applications.

(2) No DIR control signals are required to establish data flow direction.

(3) The OE input circuit is referenced to VCCA power supply. Avoid leaving the OE pin floating; if left unconnected, the OE pin may enter an undefined state, potentially causing undesired static current and increasing overall power consumption.

(4) If external pull-up or pull-down resistors are required, carefully select their resistance values due to the voltage divider network formed with the internal 4kΩ buffer. For instance, an external pull-up resistor does not affect VOH output but impacts VOL output (the smaller the external pull-up resistor, the larger the VOL value). Similarly, an external pull-down resistor does not affect VOL output but impacts VOH output (the smaller the external pull-down resistor, the smaller the VOH value). Therefore, choose sufficiently large resistance values to ensure that port VOH and VOL meet requirements (above 50k Ω recommended).

(5) To ensure reliable operation, system designers should keep the capacitive load on the NCAB0104 at 70pF or below.

(6) For excessive loads (caused by long traces or connectors), consider using series resistors to achieve impedance matching for better signal integrity.

2.4.Applications

Table 2.1 lists some common interface types.

Table 2.1 Recommended Part Numbers for Common Interface Types

Interface Type	NCA9306	NCAS0104	NCAB0104
I2C	✓	✓	
SMBus	✓	✓	
PMBus	✓	✓	
MDIO	✓	✓	
GPIO	✓	✓	✓
SPI		✓	✓
JTAG		✓	✓
I2S		✓	✓
UART	✓	✓	✓

NOVOSENSE

2.5.Key Differences in Auto-Bidirectional Series

Table 2.2 provides the key differences among three auto-bidirectional level shifters from NOVOSENSE.

Table 2.2 Parameter Comparison of Auto-Bidirectional Level Shifters

Category	NCA9306	NCAS0104	NCAB0104
Operating Principle	Rely on internal FET and external pull-up resistors	Rely on internal FET and internal pull-up resistors	Weak buffer circuit
One-Shot Circuit	No	Yes	Yes
Supported Input Types	Push-pull and open-drain	Push-pull and open-drain	Push-pull
I/O Port Voltage	Determined by external pull-up voltage, supporting multiple voltage translations	Port A follows VCCA, Port B follows VCCB	Port A follows VCCA; Port B follows VCCB
Supply Voltage Requirement	VCCB > VCCA + 0.8V	VCCB ≥ VCCA	VCCB ≥ VCCA
Steady-State Drive Strength	No DC driving capability	No DC driving capability	Weak drive strength with 4kΩ
Maximum Date Rate	800Kbps	Open-drain: 2Mbps Push-pull: 24Mbps	100Mbps
Supply Voltage Range	VREF1: 1.2V - 3.3V VREF2: 1.8V - 5.5V	VCCA: 1.1V - 3.6V VCCB: 1.65V - 5.5V	VCCA: 1.1V - 3.6V VCCB: 1.65V - 5.5V

NOVOSENSE

3.Revision History

Revision	Description	Author	Date
1.0	Create the Application Note	Xiutao Lou	2025/5/16