LVC07A: Applications
of an Open-Drain Hex Buffer

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Abstract

The Texas Instruments (TI™) LVC07A hex buffer, with open-drain outputs, and its inverting counterpart, LVC06A, operate in the 1.65-V to 3.6-V V_{CC} range, but can accept input voltages up to 5.5 V. Laboratory results show superior propagation times versus competitors, natural I_{off} protection, and output-breakdown capability versus a competitor. Applications of the LVC07A and LVC06A include bus-contention protection, voltage translation, and implementation of active-high wired-AND/active-low wired-OR functions.

Introduction

Low-voltage technology is a growing trend. The need for faster, less expensive, low-power devices is causing a shift to devices that operate at lower voltages. The TI LVC06A and LVC07A address these needs for low-voltage applications. The LVC07A is a noninverting hex buffer with an open-drain output, and the LVC06A is the inverting hex buffer (the LVC07A, plus an extra stage of inversion). These buffers/inverters are designed to operate in the 1.65-V to 3.6-V V_{CC} range; however, inputs and outputs can function with a 5.5-V V_{CC}. Figure 1 is a generalized circuit model of the LVC07A.
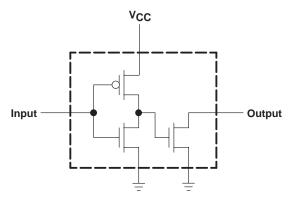

Figure 1. Generalized Circuit Model of LVC07A Showing Open-Drain Structure at Output

The LVC07A can be used in many applications. This application report concentrates on the following points:

- Laboratory results illustrating:
  - Fast propagation times
  - Natural output-leakage-protection capability. The open-drain structure provides natural I_{off} protection.
  - Breakdown features (output-voltage vs output-current plots) of the LVC07A versus a competitor's XXX07A

- Applications of the LVC07A include:
  - Bus-contention control
  - Voltage translation. Because the LVC07A is an open-drain device, it can be used for high-voltage to low-voltage translation, or low-voltage to high-voltage translation (for voltages not exceeding 5.5 V).
  - Implementation of active-high wired-AND or active-low wired-OR functions

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Laboratory Results

In the following discussion, the TI LVC07A and two competitors' XXX07A and YYY07 devices are compared. Comparisons include propagation delays obtained from the data sheets and I_{off} capability. The differences between TI, Competitor 1, and Competitor 2 devices are shown in Table 1.

Table 1. Differences Between TI LVC07A and Competitors' Devices

PARAMETER	TI	COMPETITOR 1 XXX07A	COMPETITOR 2 YYY07
Process	CMOS	Bipolar	Bipolar
Operating range V_{CC}	1.65 V to 5.5 V	4.5 V to 5.5 V	4.75 V to 5.25 V
Operating temperature	−40°C to 85°C	0°C to 70°C	0°C to 70°C
I_{CC} maximum specification	10 μA	45 mA	41 mA
I_I maximum specification	5 μA	100 μA	1 mA

Propagation Time

Fast propagation time is very important in designs using integrated circuits. The LVC07A provides very fast propagation times when compared with similar devices from Competitor 1 and Competitor 2. The propagation times were measured (and guardbanded) from 5.5 V to 1.65 V. Table 2 provides the propagation times (t_{pd}) of devices from TI, Competitor 1, and Competitor 2.

Table 2. t_{pd} for TI's LVC07A vs Competitors' Devices

PARAMETER	V_{CC}	TI LVC07A[†] 1.65 V TO 5.5 V, −40°C TO 85°C	COMPETITOR 1 XXX07A[‡] 4.5 V TO 5.5 V, 0°C TO 70°C	COMPETITOR 2 YYY07[§] 4.75 V TO 5.5 V, 0°C TO 70°C	UNIT
t_{pd}	5.0 ± 0.5 V	2.6	17.0	30.0	ns
	3.3 ± 0.3 V	2.9	N/A	N/A	
	2.5 ± 0.2 V	2.8	N/A	N/A	
	1.8 ± 0.15 V	3.5	N/A	N/A	

[†] V_{CC} = 5.0 ± 0.5 V, C_L = 50 pF, and R_L = 250 Ω
  V_{CC} = 3.3 ± 0.3 V, C_L = 50 pF, and R_L = 250 Ω
  For lower V_{CC}s, C_L = 30 pF and R_L = 250 Ω
[‡] C_L = 15 pF and R_L = 110 Ω
[§] C_L = 15 pF and R_L = 100 Ω

Natural Output-Leakage-Protection (I_{off}) Capability

The LVC07A device has no current paths to the V_{CC} pin at $V_{CC} = 0$ V because it has an open-drain output structure. The open-drain structure provides a high impedance at the output pin when powered off. This is especially important in partial-power-off applications where the device's low I_{off} leakage-current specification is significant. Partial-power-off operation mode is a key issue today in systems design, playing a major role in the personal computer (PC) market and the telecommunications industry.

In Figure 2, the I_{off} characteristic of the LVC07A comes into play when port A goes into the partial-power-off mode. The open-drain output of the LVC07A provides a path of very high resistance to V_{CC} so that the data flow is not disrupted on the bus, i.e., there is a very minimal amount of leakage from the bus to V_{CC}.

The LVC07A isolates port A from port B when it is necessary to power down port A, while leaving port B powered up (partial power down). The I_{off} capability allows port B to operate safely without being degraded by leakage when port A is powered down. This is essential if circuitry must be replaced without turning off the entire system, or if part of the system must be turned off to conserve power.
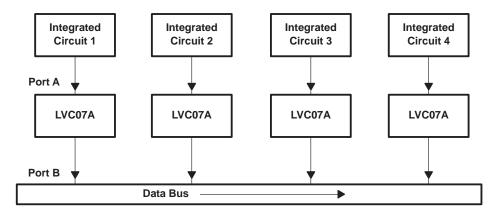

Figure 2. I_{off} Protection Concept Using LVC07A

The I_{off} specification in the data sheet is 10 µA for the LVC family. Figure 3 and Table 3 illustrate the I_{off} performance of the LVC06A and LVC07A. To obtain the data shown in Figure 3, V_{CC} was tied to 0 V and an increasing voltage was swept on the output. Measured values of I_{off} for the LVC06A and LVC07A for different V_{off} voltages are listed in Table 3.
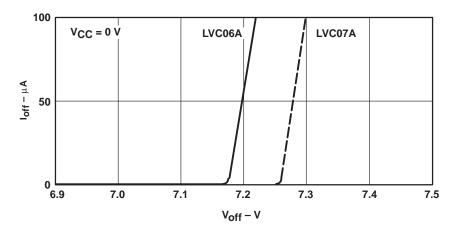

Figure 3. Output Leakage Current vs Output Voltage on Output Pins of LVC06A and LVC07A

Table 3. LVC06A and LVC07A Output Leakage Currents in Off State

V_{off} (V)	I_{off} (nA)	
	LVC06A	LVC07A
0	0.005	0.0021
2.222	1.957	0.4058
2.323	2.463	0.4997
2.424	2.991	0.6215
2.525	3.560	0.7816
2.626	4.201	1.02
3.535	10.85	5.545
3.636	11.96	6.415
5.05	44.64	35.36
5.454	66.75	54.61
5.555	74.11	60.96
5.656	82.55	68.36
6.06	127.1	110.1
6.161	143.6	124.6
6.262	162.5	141.3

Breakdown-Feature Comparison Between LVC07A and Competitor 1 XXX07A

Experiments were conducted on both the LVC07A and the Competitor 1 XXX07A to determine the output-current versus output-voltage characteristics at various V_{CC}s. Plots were made for the worst-case V_{CC} of 5.5 V. These plots illustrate the devices' ability to handle output voltages at the worst-case V_{CC}s. In the case of the LVC07A, the breakdown output voltage (V_{OH}) was 7.39 V for a V_{CC} of 5.5 V (see Figure 4).
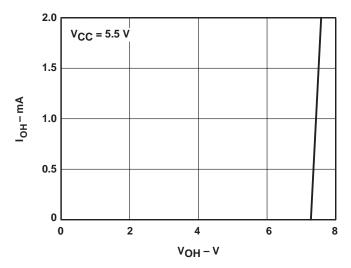

Figure 4. I_{OH} vs V_{OH} for the LVC07A at V_{CC} = 5.5 V

The Competitor 1 XXX07A has better output-breakdown capabilities than the TI device. The output breakdown voltage (V_{OH}) was 16.50 V for a V_{CC} of 5.5 V (see Figure 5).
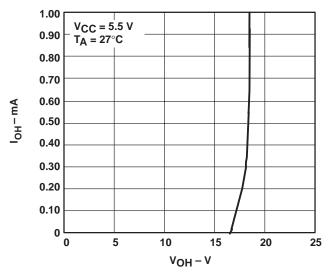

Figure 5. I_{OH} vs V_{OH} for Competitor 1 XXX07A for V_{CC} = 5.5 V

The Competitor 1 XXX07A is better suited for designs where high output voltages are desired and propagation delays are not as important. The TI LVC07A is desirable for designs where the voltage across the LVC07A output structure does not exceed the recommended specification of 5.5 V and *propagation times are important*.

LVC07A Applications

In this section, important applications of the LVC07A are discussed: bus-contention protection, voltage translation, and implementation of active-high wired-AND or active-low wired-OR functions.

Bus-Contention Protection

The open-drain feature of the LVC07A is useful in preventing bus contention. Figure 6 illustrates the concept of bus contention.
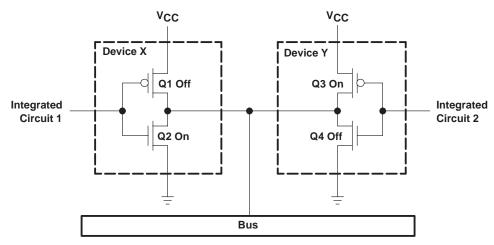

Figure 6. Bus-Contention Example Not Using LVC07A

If Q3 and Q2 were in the on state, a short circuit would be created that would destroy both Q2 and Q3. For example, if $V_{CC} = 5$ V and the on-state resistance of each transistor is 5 Ω, a current of 0.5 A would flow and easily destroy Q2 and Q3.

However, if the output structures in Figure 6 (devices X and Y) are replaced by the LVC07A (see Figure 7), the problem of bus contention is solved because the current flowing through the pulldown transistor (Q2) is controlled by the size of the resistor at the open-drain output.
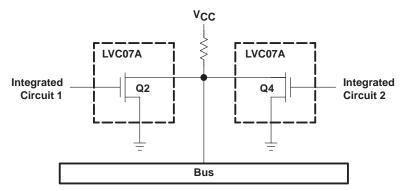

Figure 7. Bus-Contention Protection Using LVC07A

Voltage Translation

Voltage translation is essential for the operation of integrated circuits that have different voltage tolerances. The open-drain structure of the LVC07A presents the designer with the option of a voltage translator. Because the input structure of the LVC07A accepts voltages from 1.65 V to 5.5 V, voltage translation from a lower voltage to a higher voltage, or vice versa, is possible. Without the p-channel pullup on the output structure of the LVC07A, the entire output voltage drops across the n-channel transistor (see Figure 8). With the help of a pullup resistor that is connected to the designer's choice of voltage (not exceeding 5.5 V), voltage translation is achieved because the V_{IH} and V_{IL} levels supplied to the 5-V tolerant device in the circuit shown in Figure 9 are high enough to drive the 5-V tolerant device. If the output structure of the LVC07A were not open drain, the output voltage would drop across the p- and n-channel transistors, and would not provide enough drive to the 5-V-tolerant device.
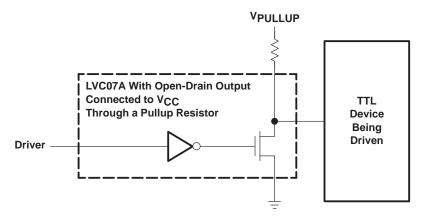

Figure 8. Circuit for Voltage Translation From Lower to Higher Voltages (CMOS to TTL)
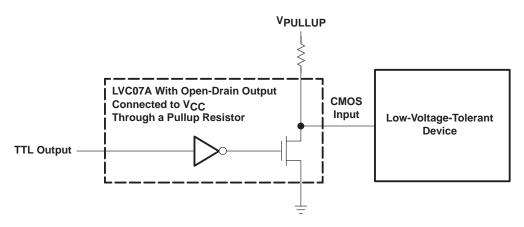
Figure 9. Circuit for Voltage Translation From Higher to Lower Voltages (TTL to CMOS)

The switching standard of 5-V CMOS devices is different than the switching standard for 5-V TTL and 3.3-V TTL devices (see Figure 10).

5 V	V_{CC}
4.44 V	V_{OH}
3.5 V	V_{IH}
2.5 V	V_t
1.5 V	V_{IL}
0.5 V	V_{OL}
0	GND

5-V CMOS Family

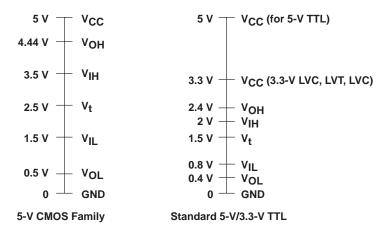| 5 V | V_{CC} (for 5-V TTL) |
3.3 V	V_{CC} (3.3-V LVC, LVT, LVC)
2.4 V	V_{OH}
2 V	V_{IH}
1.5 V	V_t
0.8 V	V_{IL}
0.4 V	V_{OL}
0	GND

Standard 5-V/3.3-V TTL

Figure 10. Comparison of 5-V CMOS and 5-/3.3-V TTL Switching Standards

The switching standards shown in Figure 10 clearly indicate that a TTL device cannot drive a CMOS device directly because the V_{IH}, V_{IL}, and V_t levels of the TTL devices are lower than the respective levels of the CMOS device. This problem can be solved by placing the LVC07A between the TTL and the CMOS devices. The pullup resistor from a V_{CC} not exceeding 5.5 V that is connected to the open-drain output of the LVC07A increases the V_{IH} levels sufficiently to drive the CMOS device, as illustrated in Figure 9. The capability of the LVC07A to provide voltage translation (high-to-low or low-to-high voltage) provides an essential function for future-technology integrated circuits using V_{CC} ranges of 1.8 V and below.

The voltage translation provided by the LVC07A also can be used between CMOS ports. Table 4 illustrates parameters necessary for voltage translation between two devices, A and B. Appropriate V_{CC}s (device A) and pullup voltages (applied on the output structure of the LVC07A) are included Table 4.

Table 4. Requirements for Voltage Translation Between Devices A and B

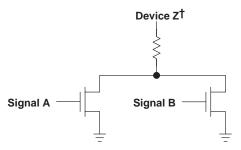| DEVICE A	DEVICE B	V_{CC}	V_{PULLUP}
5-V TTL	3.3-V TTL = 3.3-V CMOS	3.3 V	3.3 V
3.3-V TTL = 3.3-V CMOS	5-V TTL	3.3 V	5.5 V
2.5-V CMOS	5-V TTL	2.5 V	5.5 V
1.8-V CMOS	3.3-V/5-V TTL	1.8 V	3.3 V/5.5 V
1.5-V CMOS	3.3-V/5-V TTL	1.5 V	3.3 V/5.5 V

Implementation of Active-High Wired-AND or Active-Low Wired-OR Functions

Another useful function of the LVC07A open-drain feature is to provide active-high wired-AND or active-low wired-OR functions (see Figure 11).

† Open-drain structures of the LVC07A are connected together to provide either an active-high wired-AND or an active-low wired-OR function, depending on signal-A and signal-B levels.

Figure 11. Implementation of Active-High Wired-AND or Active-Low Wired-OR Function

Summary

The LVC07A hex buffer addresses requirements of today's low-voltage technology. The advantages of the LVC07A discussed in this application report are:

- Functionality in the 1.65-V to 5.5-V region
- Capability to provide voltage translation between CMOS and TTL or between TTL and CMOS devices
- Bus-contention protection
- Natural output-leakage (I_{off}) protection
- Provision for implementation of active-high wired-AND or active-low wired-OR functions

All of these characteristics make the LVC07A an ideal hex buffer/driver for designs involving PC motherboards and other designs in which signals must be translated between TTL and CMOS devices.

Acknowledgments

Glossary

A

Active-high wired-AND function	AND function in which one of the inputs is a constant logic 1
Active-low wired-AND function	OR function in which one of the inputs is a constant logic 0. It provides the same logic function as the active-high wired-AND function.

I

I_{off}	Specification used for partial-power-off applications. I_{off} is the leakage current through the output pin when V_{CC} is tied to ground and a voltage is applied at the output pin.

O

Open-drain output	Output that does not have a pullup transistor (p-channel)

P

Partial power off	System function in which it is desired to power off part of the system to conserve power

V

Voltage translation	Capability of transmitting a signal from a device with a low voltage tolerance to a device with a high voltage tolerance, or vice versa