

# SN54LS668, SN54LS669, SN74LS668, SN74LS669 SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

SDLS192 – APRIL 1977 – REVISED MARCH 1988

## 'LS668 . . . SYNCHRONOUS UP/DOWN DECADE COUNTERS 'LS669 . . . SYNCHRONOUS UP/DOWN BINARY COUNTERS

### Programmable Look-Ahead Up/Down Binary/Decade Counters

- Fully Synchronous Operation for Counting and Programming
- Internal Look-Ahead for Fast Counting
- Carry Output for n-Bit Cascading
- Fully Independent Clock Circuit
- Buffered Outputs

| TYPE           | TYPICAL MAXIMUM<br>CLOCK FREQUENCY |                  | TYPICAL<br>POWER<br>DISSIPATION |
|----------------|------------------------------------|------------------|---------------------------------|
|                | COUNTING<br>UP                     | COUNTING<br>DOWN |                                 |
| 'LS668, 'LS669 | 32 MHz                             | 32 MHz           | 100 mW                          |

### description

These synchronous presettable counters feature an internal carry look-ahead for cascading in high-speed counting applications. The 'LS668 are decade counters and the 'LS669 are 4-bit binary counters. Synchronous operation is provided by having all flip-flops clocked simultaneously so that the outputs change coincident with each other when so instructed by the count-enable inputs and internal gating. This mode of operation helps eliminate the output counting spikes that are normally associated with asynchronous (ripple-clock) counters. A buffered clock input triggers the four master-slave flip-flops on the rising (positive-going) edge of the clock waveform.

These counters are fully programmable; that is, the outputs may each be preset to either level. The load input circuitry allows loading with the carry-enable output of cascaded counters. As loading is synchronous, setting up a low level at the load input disables the counter and causes the outputs to agree with the data inputs after the next clock pulse.

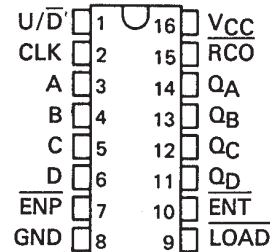
The carry look-ahead circuitry provides for cascading counters for n-bit synchronous applications without additional gating. Instrumental in accomplishing this function are two count-enable inputs ( $\bar{P}$  and  $\bar{T}$ ) must be low to count. The direction of the count is determined by the level of the up/down input. When the input is high, the counter counts up; when low, it counts down. Input  $\bar{T}$  is fed forward to enable the carry output. The carry output thus enabled will produce a low-level output pulse when the count is maximum counting up or zero counting down. This low-level overflow carry pulse can be used to enable successive cascaded stages. Transitions at the enable  $\bar{P}$  or  $\bar{T}$  inputs are allowed regardless of the level of the clock input. All inputs are diode-clamped to minimize transmission-line effects, thereby simplifying system design.

These counters feature a fully independent clock circuit. Changes at control inputs (enable  $\bar{P}$ , enable  $\bar{T}$ , load, up/down) that will modify the operating mode have no effect until clocking occurs. The function of the counter (whether enabled, disabled, loading, or counting) will be dictated solely by the conditions meeting the stable setup and hold times.

The 'LS668 and 'LS669 are completely new designs. Compared to the original 'LS168 and 'LS169, they feature 0-nanosecond minimum hold time, reduced input currents  $I_{IH}$  and  $I_{IL}$ , and all buffered outputs.

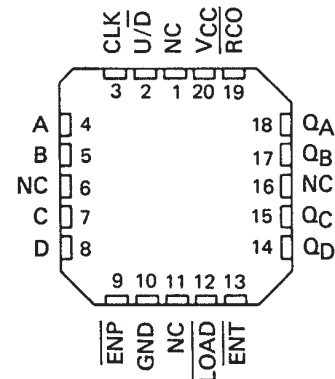
SN54LS668, SN54LS669 . . . J OR W PACKAGE  
SN74LS668, SN74LS669 . . . D OR N PACKAGE

(TOP VIEW)



SN54LS668, SN54LS669 . . . FK PACKAGE

(TOP VIEW)



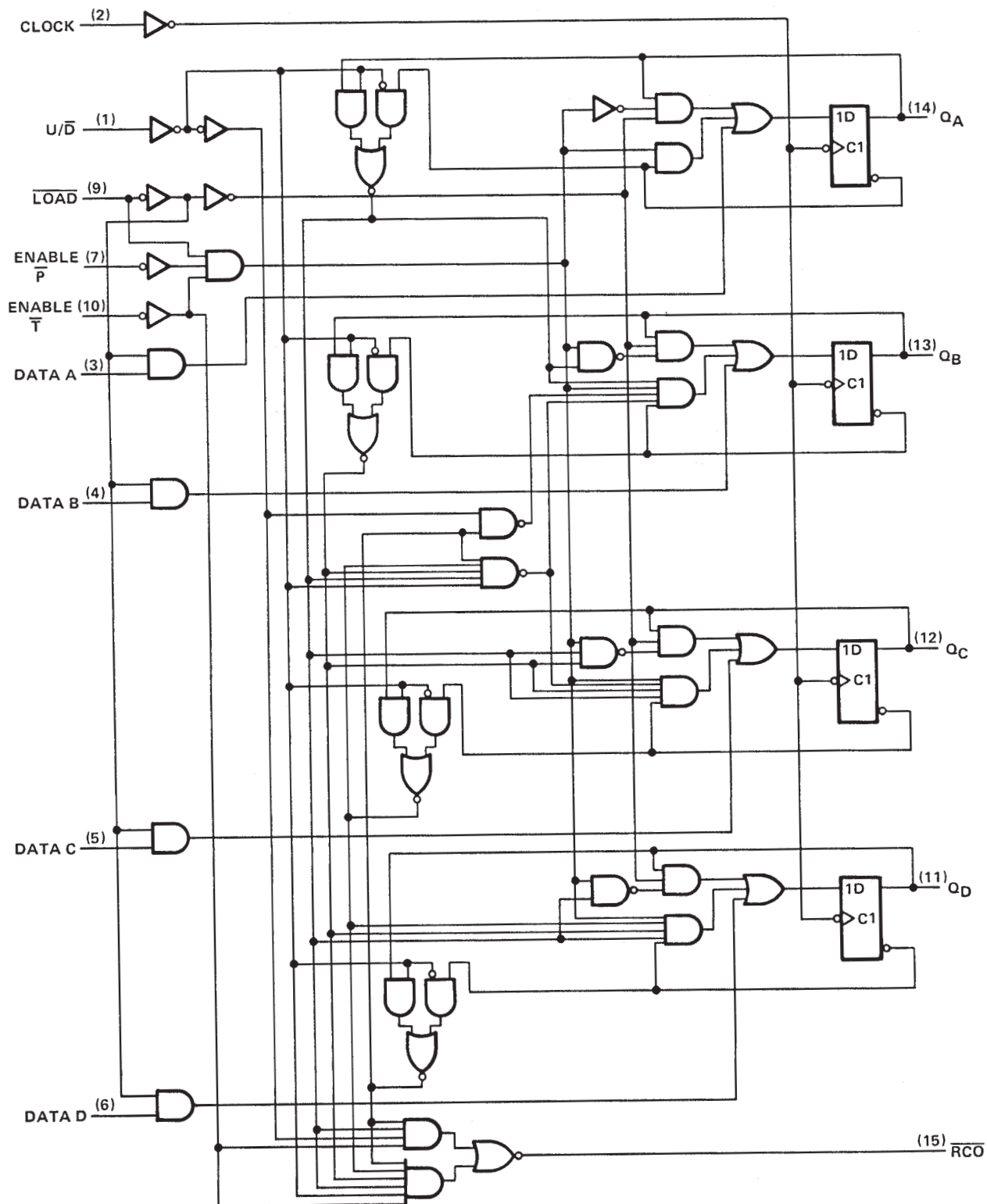
NC – No internal connection

# SN54LS668, SN74LS668 SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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logic diagram (positive logic)

SN54LS668, SN74LS668, DECADE COUNTERS



Pin numbers shown are for D, J, N, and W packages.



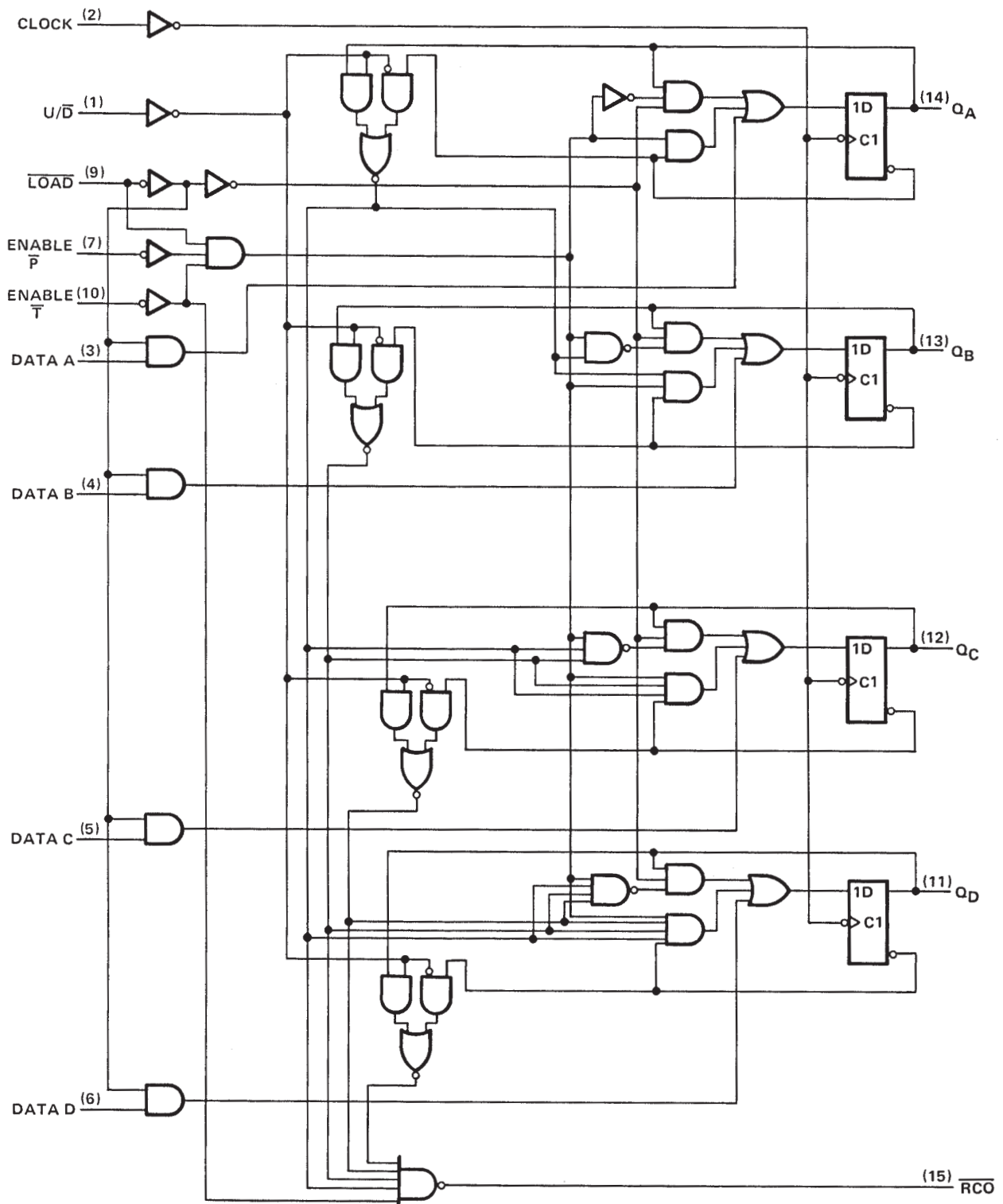
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# SN54LS669, SN74LS669 SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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logic diagram (positive logic) (continued)

SN54LS669, SN74LS669, BINARY COUNTERS



Pin numbers shown are for D, J, N, and W packages.

# SN54LS668, SN74LS668 SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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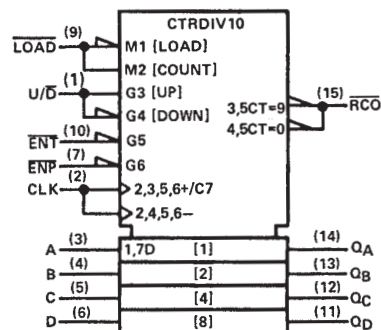
## 'LS668 DECADE COUNTERS

### typical load, count, and inhibit sequences

Illustrated below is the following sequence:

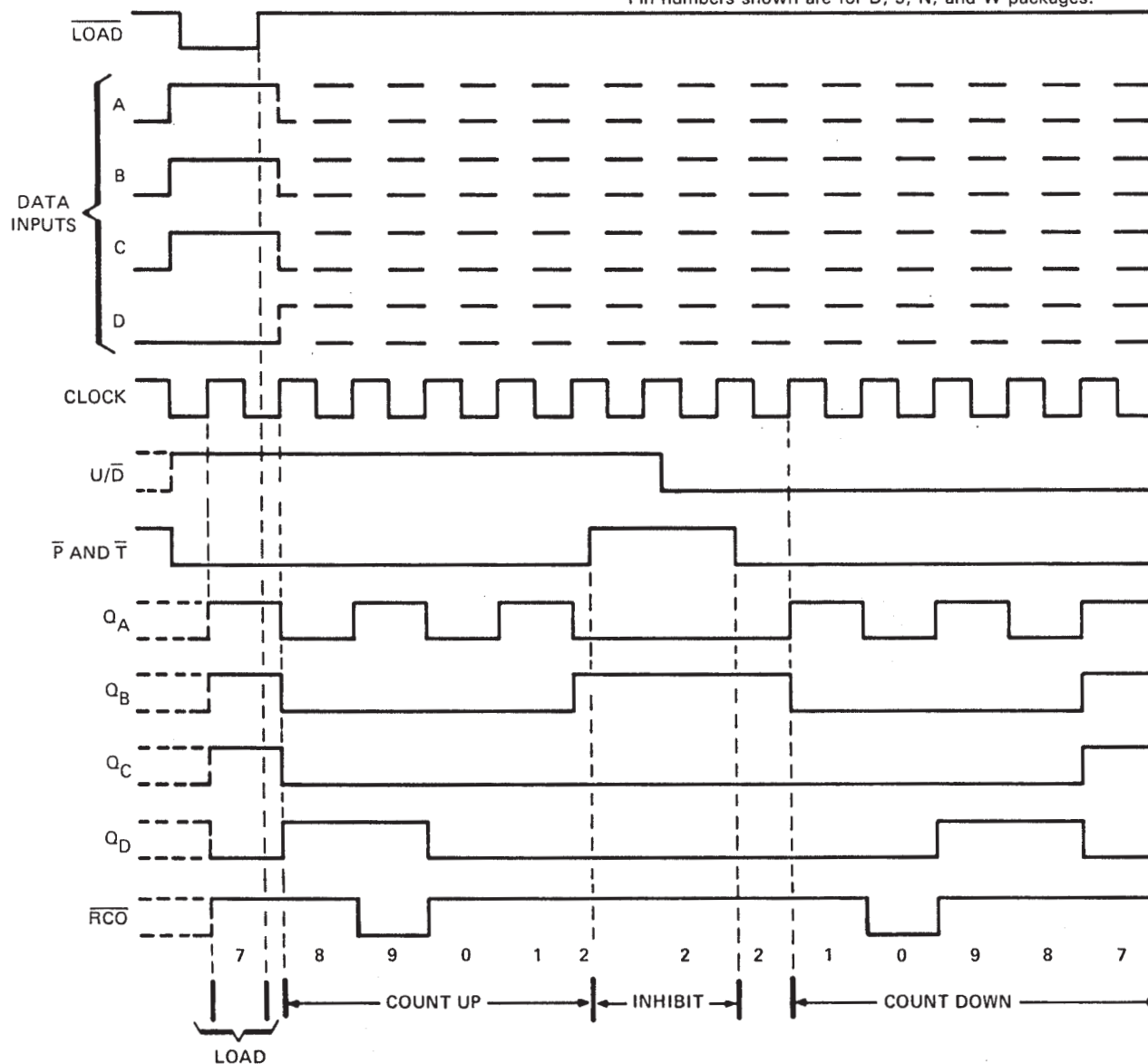
1. Load (preset) to BCD seven
2. Count up to eight, nine (maximum), zero, one, and two
3. Inhibit
4. Count down to one, zero (minimum), nine, eight, and seven

### logic symbol†



†This symbol is in accordance with ANSI/IEEE Std. 91-1984 and IEC Publication 617-12.

Pin numbers shown are for D, J, N, and W packages.



# SN54LS669, SN74LS669 SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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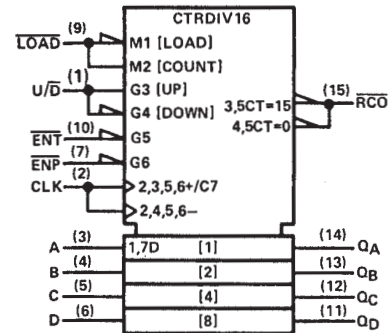
## 'LS669 BINARY COUNTERS

### typical load, count, and inhibit sequences

Illustrated below is the following sequence:

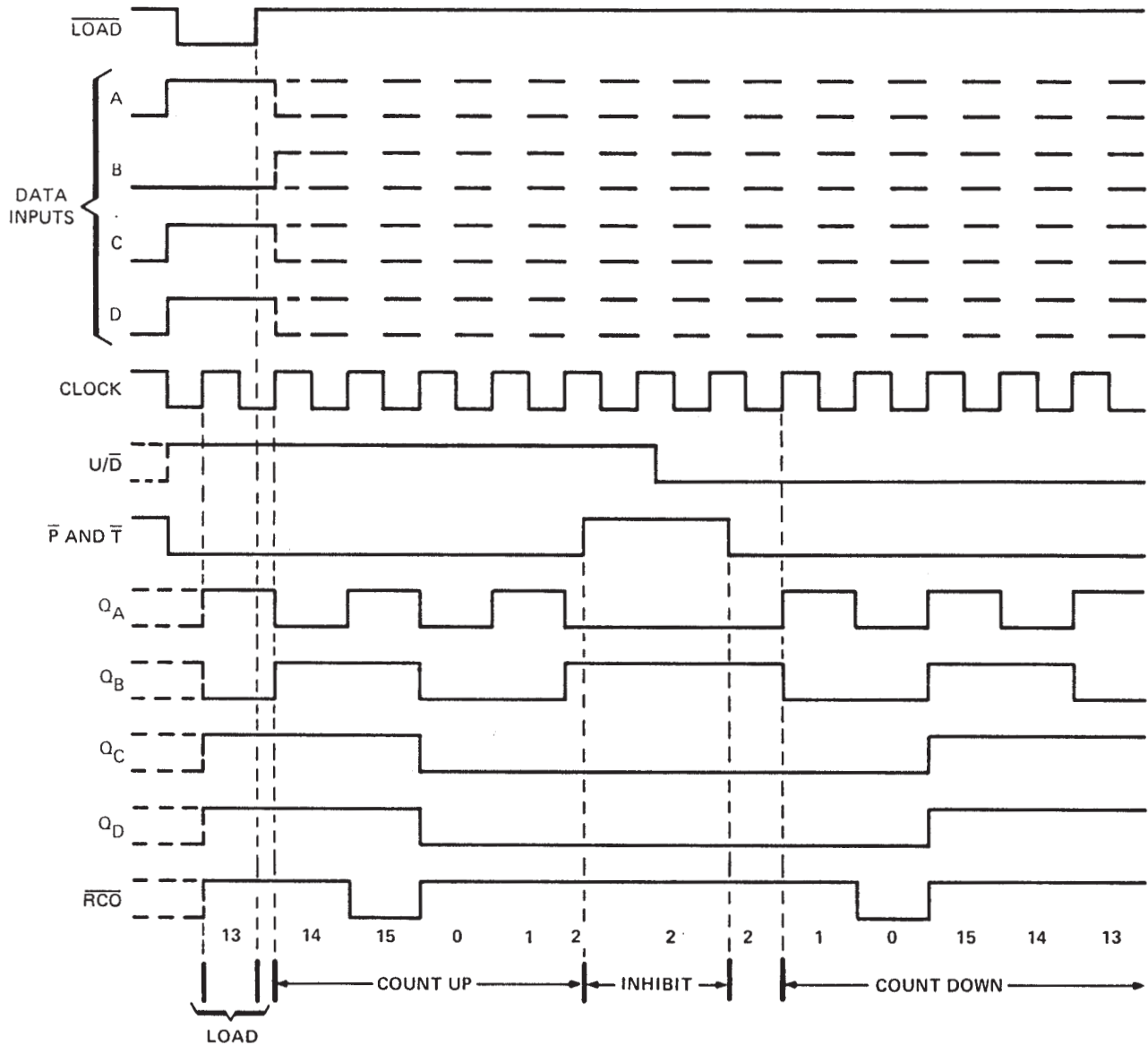
1. Load (preset) to binary thirteen
2. Count up to fourteen, fifteen (maximum), zero, one, and two
3. Inhibit
4. Count down to one, zero (minimum), fifteen, fourteen, and thirteen

### logic symbol†



†This symbol is in accordance with ANSI/IEEE Std. 91-1984 and IEC Publication 617-12.

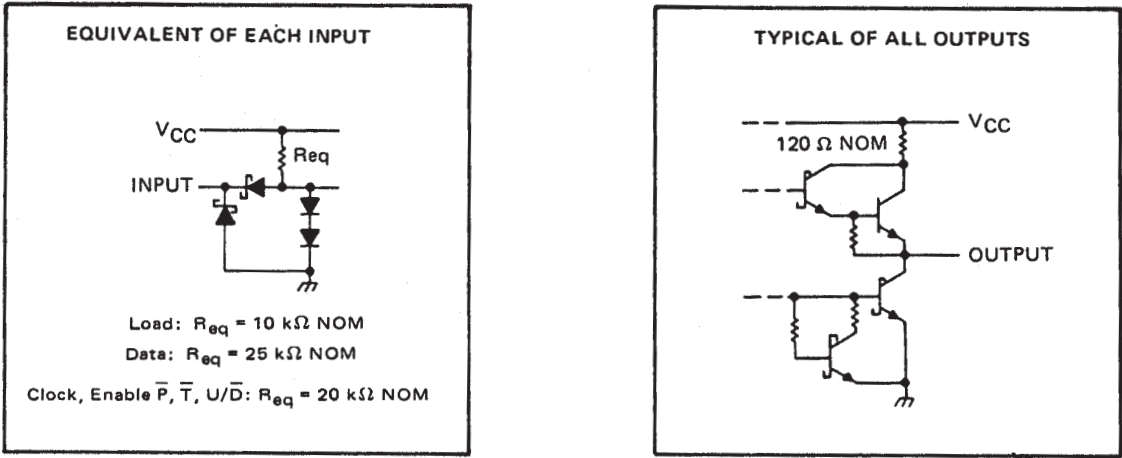
Pin numbers shown are for D, J, N, and W packages.



SN54LS668, SN54LS669, SN74LS668, SN74LS669  
SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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schematics of inputs and outputs



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

|                                                            |                                                |
|------------------------------------------------------------|------------------------------------------------|
| Supply voltage, $V_{CC}$ (see Note 1)                      | 7 V                                            |
| Input voltage                                              | 7 V                                            |
| Operating free-air temperature range: SN54LS668, SN54LS669 | $-55^{\circ}\text{C}$ to $125^{\circ}\text{C}$ |
| SN74LS668, SN74LS669                                       | $0^{\circ}\text{C}$ to $70^{\circ}\text{C}$    |
| Storage temperature range                                  | $-65^{\circ}\text{C}$ to $150^{\circ}\text{C}$ |

NOTE 1: Voltage values are with respect to network ground terminal.

recommended operating conditions

|                                                                          |                        | SN54LS668<br>SN54LS669 |     |      | SN74LS668<br>SN74LS669 |     |      | UNIT               |
|--------------------------------------------------------------------------|------------------------|------------------------|-----|------|------------------------|-----|------|--------------------|
|                                                                          |                        | MIN                    | NOM | MAX  | MIN                    | NOM | MAX  |                    |
| Supply voltage, $V_{CC}$                                                 |                        | 4.5                    | 5   | 5.5  | 4.75                   | 5   | 5.25 | V                  |
| High-level output current, $I_{OH}$                                      |                        |                        |     | -400 |                        |     | -400 | $\mu\text{A}$      |
| Low-level output current, $I_{OL}$                                       |                        |                        |     | 4    |                        |     | 8    | mA                 |
| Clock frequency, $f_{\text{clock}}$                                      |                        | 0                      |     | 25   | 0                      |     | 25   | MHz                |
| Width of clock pulse, $t_{w(\text{clock})}$ (high or low) (see Figure 1) |                        | 20                     |     |      | 20                     |     |      | ns                 |
| Setup time, $t_{su}$ (see Figure 1)                                      | Data inputs A, B, C, D | 25                     |     |      | 25                     |     |      | ns                 |
|                                                                          | ENP or ENT             | 40                     |     |      | 40                     |     |      |                    |
|                                                                          | LOAD                   | 30                     |     |      | 30                     |     |      |                    |
|                                                                          | U/D                    | 45                     |     |      | 45                     |     |      |                    |
| Hold time at any input with respect to clock, $t_h$ (see Figure 1)       |                        | 0                      |     |      | 0                      |     |      | ns                 |
| Operating free-air temperature, $T_A$                                    |                        | -55                    |     | 125  | 0                      |     | 70   | $^{\circ}\text{C}$ |

# SN54LS668, SN54LS669, SN74LS668, SN74LS669

## SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

| PARAMETER |                                        | TEST CONDITIONS†                                                                                    | SN54LS668<br>SN54LS669 |      |      | SN74LS668<br>SN74LS669 |      |      | UNIT          |
|-----------|----------------------------------------|-----------------------------------------------------------------------------------------------------|------------------------|------|------|------------------------|------|------|---------------|
|           |                                        |                                                                                                     | MIN                    | TYP‡ | MAX  | MIN                    | TYP‡ | MAX  |               |
| $V_{IH}$  | High-level input voltage               |                                                                                                     | 2                      |      |      | 2                      |      |      | V             |
| $V_{IL}$  | Low-level input voltage                |                                                                                                     |                        |      | 0.7  |                        |      | 0.8  | V             |
| $V_{IK}$  | Input clamp voltage                    | $V_{CC} = \text{MIN}, I_I = -18 \text{ mA}$                                                         |                        |      | -1.5 |                        |      | -1.5 | V             |
| $V_{OH}$  | High-level output voltage              | $V_{CC} = \text{MIN}, V_{IH} = 2 \text{ V}, V_{IL} = V_{IL \text{ max}}, I_{OH} = -400 \mu\text{A}$ | 2.5                    | 3.4  |      | 2.7                    | 3.4  |      | V             |
| $V_{OL}$  | Low-level output voltage               | $V_{CC} = \text{MIN}, V_{IH} = 2 \text{ V}, V_{IL} = V_{IL \text{ max}}, I_{OL} = 4 \text{ mA}$     | 0.25                   | 0.4  |      | 0.25                   | 0.4  |      | V             |
|           |                                        | $I_{OL} = 8 \text{ mA}$                                                                             |                        |      |      | 0.35                   | 0.5  |      |               |
| $I_I$     | Input current at maximum input voltage | A, B, C, D, $\overline{P}$ , U/ $\overline{D}$                                                      |                        |      | 0.1  |                        |      | 0.1  | mA            |
|           |                                        | Clock, $\overline{T}$                                                                               |                        |      | 0.1  |                        |      | 0.1  |               |
|           |                                        | LOAD                                                                                                |                        |      | 0.2  |                        |      | 0.2  |               |
| $I_{IH}$  | High-level input current               | A, B, C, D, $\overline{P}$ , U/ $\overline{D}$                                                      |                        |      | 20   |                        |      | 20   | $\mu\text{A}$ |
|           |                                        | Clock, $\overline{T}$                                                                               |                        |      | 20   |                        |      | 20   |               |
|           |                                        | LOAD                                                                                                |                        |      | 40   |                        |      | 40   |               |
| $I_{IL}$  | Low-level input current                | A, B, C, D, $\overline{P}$ , U/ $\overline{D}$                                                      |                        |      | -0.4 |                        |      | -0.4 | mA            |
|           |                                        | Clock, $\overline{T}$                                                                               |                        |      | -0.4 |                        |      | -0.4 |               |
|           |                                        | LOAD                                                                                                |                        |      | -0.8 |                        |      | -0.8 |               |
| $I_{OS}$  | Short-circuit output current §         | $V_{CC} = \text{MAX}$                                                                               | -20                    |      | -100 | -20                    |      | -100 | mA            |
| $I_{CC}$  | Supply current                         | $V_{CC} = \text{MAX}$ , See Note 2                                                                  |                        | 20   | 34   |                        | 20   | 34   | mA            |

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

‡ All typical values are at  $V_{CC} = 5 \text{ V}$ ,  $T_A = 25^\circ\text{C}$ .

§ Not more than one output should be shorted at a time, and duration of the short-circuit should not exceed one second.

NOTE 2:  $I_{CC}$  is measured after applying a momentary 4.5 V, then ground, to the clock input with all other inputs grounded and the outputs open.

switching characteristics,  $V_{CC} = 5 \text{ V}$ ,  $T_A = 25^\circ\text{C}$

| PARAMETER¶       | FROM (INPUT)      | TO (OUTPUT)      | TEST CONDITIONS                                                               | MIN | TYP | MAX | UNIT |
|------------------|-------------------|------------------|-------------------------------------------------------------------------------|-----|-----|-----|------|
| $f_{\text{max}}$ |                   |                  | $C_L = 15 \text{ pF}$ ,<br>$R_L = 2 \text{ k}\Omega$ ,<br>See Figures 2 and 3 | 25  | 32  |     | MHz  |
| $t_{PLH}$        | CLK               | $\overline{RCO}$ |                                                                               |     | 26  | 40  | ns   |
| $t_{PHL}$        |                   |                  |                                                                               |     | 40  | 60  |      |
| $t_{PLH}$        |                   | Any Q            |                                                                               |     | 18  | 27  |      |
| $t_{PHL}$        | $\overline{ENT}$  | $\overline{RCO}$ |                                                                               |     | 18  | 27  | ns   |
| $t_{PLH}$        |                   |                  |                                                                               |     | 11  | 17  |      |
| $t_{PHL}$        |                   |                  |                                                                               |     | 29  | 45  |      |
| $t_{PLH}^\#$     | U/ $\overline{D}$ | $\overline{RCO}$ |                                                                               |     | 22  | 35  | ns   |
| $t_{PHL}^\#$     |                   |                  |                                                                               |     | 26  | 40  |      |

¶  $f_{\text{max}}$  = Maximum clock frequency.

$t_{PLH}$  = propagation delay time, low-to-high-level output.

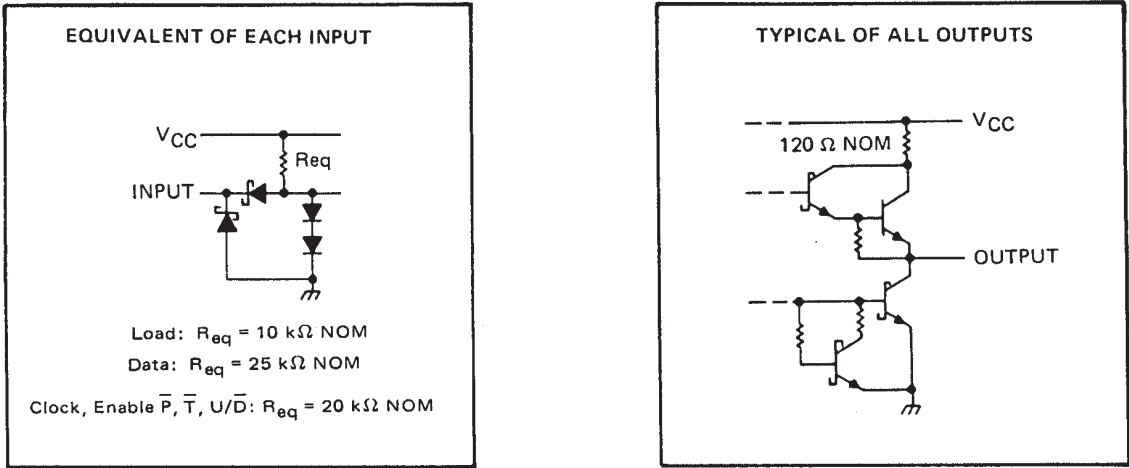
$t_{PHL}$  = propagation delay time, high-to-low-level output.

# Propagation delay time from up/down to ripple carry must be measured with the counter at either a minimum or a maximum count. As the logic level of the up/down input is changed, the ripple carry output will follow. If the count is minimum (0), the ripple carry output transition will be in phase. If the count is maximum (9 for 'LS668 or 15 for 'LS669), the ripple carry output will be out of phase.

SN54LS668, SN54LS669, SN74LS668, SN74LS669  
SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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schematics of inputs and outputs



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

|                                                            |                                                |
|------------------------------------------------------------|------------------------------------------------|
| Supply voltage, $V_{CC}$ (see Note 1)                      | 7 V                                            |
| Input voltage                                              | 7 V                                            |
| Operating free-air temperature range: SN54LS668, SN54LS669 | $-55^{\circ}\text{C}$ to $125^{\circ}\text{C}$ |
| SN74LS668, SN74LS669                                       | $0^{\circ}\text{C}$ to $70^{\circ}\text{C}$    |
| Storage temperature range                                  | $-65^{\circ}\text{C}$ to $150^{\circ}\text{C}$ |

NOTE 1: Voltage values are with respect to network ground terminal.

recommended operating conditions

|                                                                          |                                                    | SN54LS668<br>SN54LS669 |     |      | SN74LS668<br>SN74LS669 |     |      | UNIT               |
|--------------------------------------------------------------------------|----------------------------------------------------|------------------------|-----|------|------------------------|-----|------|--------------------|
|                                                                          |                                                    | MIN                    | NOM | MAX  | MIN                    | NOM | MAX  |                    |
| Supply voltage, $V_{CC}$                                                 |                                                    | 4.5                    | 5   | 5.5  | 4.75                   | 5   | 5.25 | V                  |
| High-level output current, $I_{OH}$                                      |                                                    |                        |     | -400 |                        |     | -400 | $\mu\text{A}$      |
| Low-level output current, $I_{OL}$                                       |                                                    |                        |     | 4    |                        |     | 8    | mA                 |
| Clock frequency, $f_{\text{clock}}$                                      |                                                    | 0                      |     | 25   | 0                      |     | 25   | MHz                |
| Width of clock pulse, $t_{W(\text{clock})}$ (high or low) (see Figure 1) |                                                    | 20                     |     |      | 20                     |     |      | ns                 |
| Setup time, $t_{su}$ (see Figure 1)                                      | Data inputs A, B, C, D                             | 25                     |     |      | 25                     |     |      | ns                 |
|                                                                          | $\overline{\text{ENP}}$ or $\overline{\text{ENT}}$ | 40                     |     |      | 40                     |     |      |                    |
|                                                                          | $\overline{\text{LOAD}}$                           | 30                     |     |      | 30                     |     |      |                    |
|                                                                          | $\overline{\text{U/D}}$                            | 45                     |     |      | 45                     |     |      |                    |
| Hold time at any input with respect to clock, $t_h$ (see Figure 1)       |                                                    | 0                      |     |      | 0                      |     |      | ns                 |
| Operating free-air temperature, $T_A$                                    |                                                    | -55                    |     | 125  | 0                      |     | 70   | $^{\circ}\text{C}$ |

# SN54LS668, SN54LS669, SN74LS668, SN74LS669

## SYNCHRONOUS 4-BIT UP/DOWN COUNTERS

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electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

| PARAMETER |                                        | TEST CONDITIONS†                                                                                    | SN54LS668<br>SN54LS669 |      |      | SN74LS668<br>SN74LS669 |      |      | UNIT          |
|-----------|----------------------------------------|-----------------------------------------------------------------------------------------------------|------------------------|------|------|------------------------|------|------|---------------|
|           |                                        |                                                                                                     | MIN                    | TYP‡ | MAX  | MIN                    | TYP‡ | MAX  |               |
| $V_{IH}$  | High-level input voltage               |                                                                                                     | 2                      |      |      | 2                      |      |      | V             |
| $V_{IL}$  | Low-level input voltage                |                                                                                                     |                        |      | 0.7  |                        |      | 0.8  | V             |
| $V_{IK}$  | Input clamp voltage                    | $V_{CC} = \text{MIN}, I_I = -18 \text{ mA}$                                                         |                        |      | -1.5 |                        |      | -1.5 | V             |
| $V_{OH}$  | High-level output voltage              | $V_{CC} = \text{MIN}, V_{IH} = 2 \text{ V}, V_{IL} = V_{IL \text{ max}}, I_{OH} = -400 \mu\text{A}$ | 2.5                    | 3.4  |      | 2.7                    | 3.4  |      | V             |
| $V_{OL}$  | Low-level output voltage               | $V_{CC} = \text{MIN}, V_{IH} = 2 \text{ V}, V_{IL} = V_{IL \text{ max}}, I_{OL} = 4 \text{ mA}$     | 0.25                   | 0.4  |      | 0.25                   | 0.4  |      | V             |
|           |                                        | $I_{OL} = 8 \text{ mA}$                                                                             |                        |      |      | 0.35                   | 0.5  |      |               |
| $I_I$     | Input current at maximum input voltage | A, B, C, D, $\overline{P}$ , $\overline{U}/\overline{D}$                                            |                        |      | 0.1  |                        |      | 0.1  | mA            |
|           |                                        | Clock, $\overline{T}$                                                                               |                        |      | 0.1  |                        |      | 0.1  |               |
|           |                                        | $\overline{LOAD}$                                                                                   |                        |      | 0.2  |                        |      | 0.2  |               |
| $I_{IH}$  | High-level input current               | A, B, C, D, $\overline{P}$ , $\overline{U}/\overline{D}$                                            |                        |      | 20   |                        |      | 20   | $\mu\text{A}$ |
|           |                                        | Clock, $\overline{T}$                                                                               |                        |      | 20   |                        |      | 20   |               |
|           |                                        | $\overline{LOAD}$                                                                                   |                        |      | 40   |                        |      | 40   |               |
| $I_{IL}$  | Low-level input current                | A, B, C, D, $\overline{P}$ , $\overline{U}/\overline{D}$                                            |                        |      | -0.4 |                        |      | -0.4 | mA            |
|           |                                        | Clock, $\overline{T}$                                                                               |                        |      | -0.4 |                        |      | -0.4 |               |
|           |                                        | $\overline{LOAD}$                                                                                   |                        |      | -0.8 |                        |      | -0.8 |               |
| $I_{OS}$  | Short-circuit output current§          | $V_{CC} = \text{MAX}$                                                                               | -20                    |      | -100 | -20                    |      | -100 | mA            |
| $I_{CC}$  | Supply current                         | $V_{CC} = \text{MAX}$ , See Note 2                                                                  | 20                     | 34   |      | 20                     | 34   |      | mA            |

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

‡ All typical values are at  $V_{CC} = 5 \text{ V}$ ,  $T_A = 25^\circ\text{C}$ .

§ Not more than one output should be shorted at a time, and duration of the short-circuit should not exceed one second.

NOTE 2:  $I_{CC}$  is measured after applying a momentary 4.5 V, then ground, to the clock input with all other inputs grounded and the outputs open.

switching characteristics,  $V_{CC} = 5 \text{ V}$ ,  $T_A = 25^\circ\text{C}$

| PARAMETER¶ | FROM<br>(INPUT) | TO<br>(OUTPUT) | TEST CONDITIONS                                  | MIN | TYP | MAX | UNIT |
|------------|-----------------|----------------|--------------------------------------------------|-----|-----|-----|------|
| fmax       |                 |                | CL = 15 pF,<br>RL = 2 kΩ,<br>See Figures 2 and 3 | 25  | 32  |     | MHz  |
| tPLH       | CLK             | RCO            |                                                  |     | 26  | 40  | ns   |
| tPHL       |                 |                |                                                  |     | 40  | 60  |      |
| tPLH       | CLK             | Any<br>Q       |                                                  |     | 18  | 27  | ns   |
| tPHL       |                 |                |                                                  |     | 18  | 27  |      |
| tPLH       | ENT             | RCO            |                                                  |     | 11  | 17  | ns   |
| tPHL       |                 |                |                                                  |     | 29  | 45  |      |
| tPLH#      | U/D             | RCO            |                                                  |     | 22  | 35  | ns   |
| tPHL#      |                 |                |                                                  |     | 26  | 40  |      |

¶  $f_{\text{max}}$  = Maximum clock frequency.

$t_{PLH}$  = propagation delay time, low-to-high-level output.

$t_{PHL}$  = propagation delay time, high-to-low-level output.

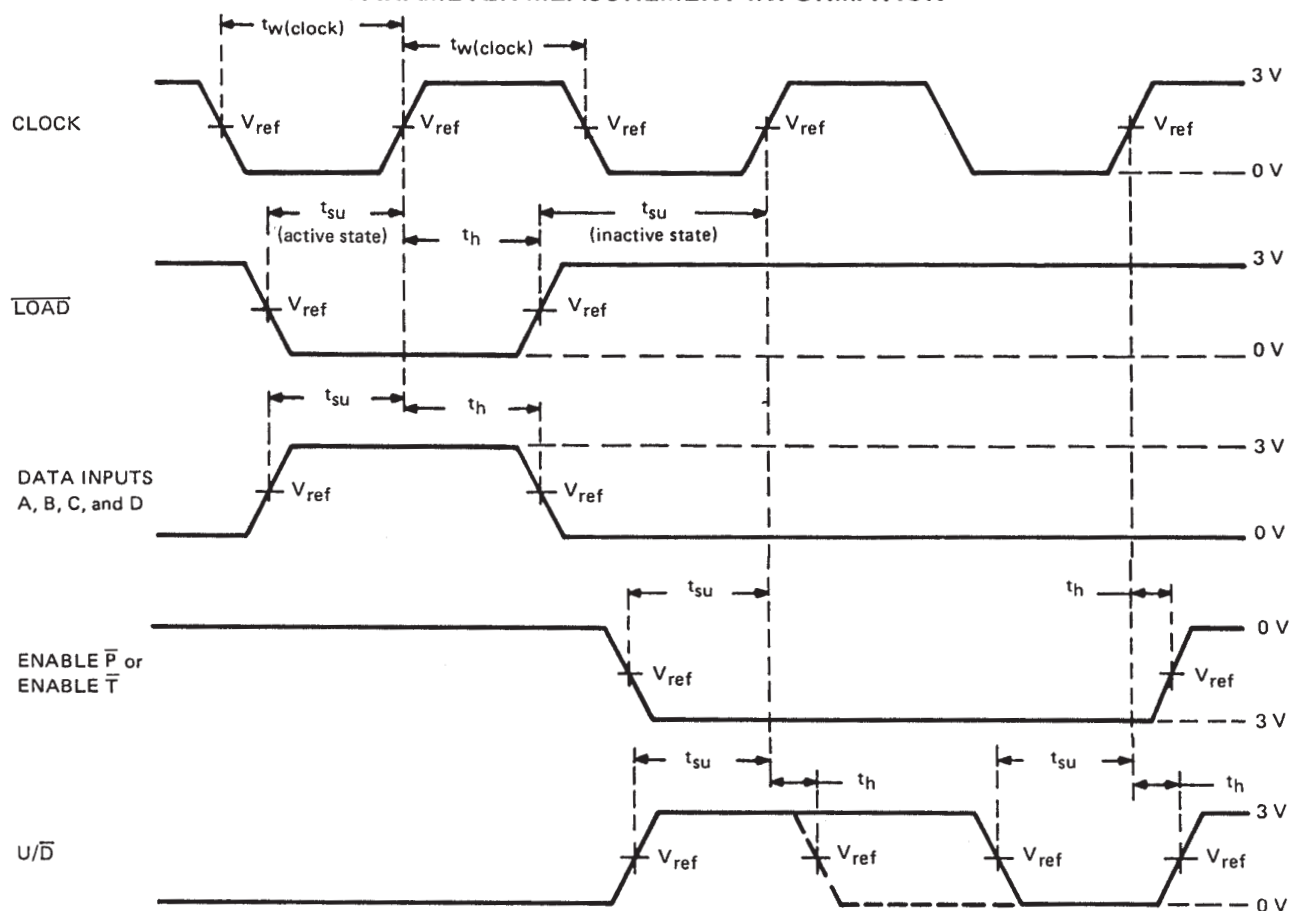
¶ Propagation delay time from up/down to ripple carry must be measured with the counter at either a minimum or a maximum count. As the logic level of the up/down input is changed, the ripple carry output will follow. If the count is minimum (0), the ripple carry output transition will be in phase. If the count is maximum (9 for 'LS668 or 15 for 'LS669), the ripple carry output will be out of phase.



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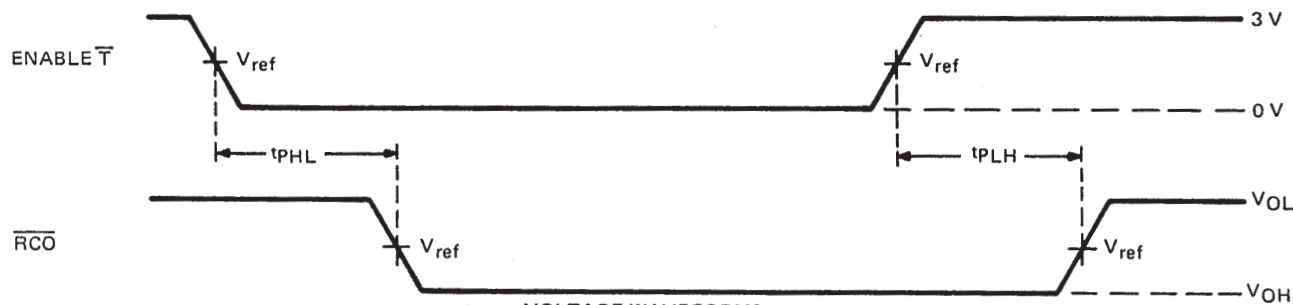
## PARAMETER MEASUREMENT INFORMATION



## VOLTAGE WAVEFORMS

- NOTES: A. The input pulses are supplied by a generator having the following characteristics:  $PRR \leq 1 \text{ MHz}$ , duty cycle  $\leq 50\%$ ,  $Z_{out} \approx 50 \Omega$ ;  $t_r \leq 15 \text{ ns}$ ,  $t_f \leq 6 \text{ ns}$ .  
B.  $V_{ref} = 1.3 \text{ V}$ .

FIGURE 1—PULSE WIDTHS, SETUP TIMES, HOLD TIMES



## VOLTAGE WAVEFORMS

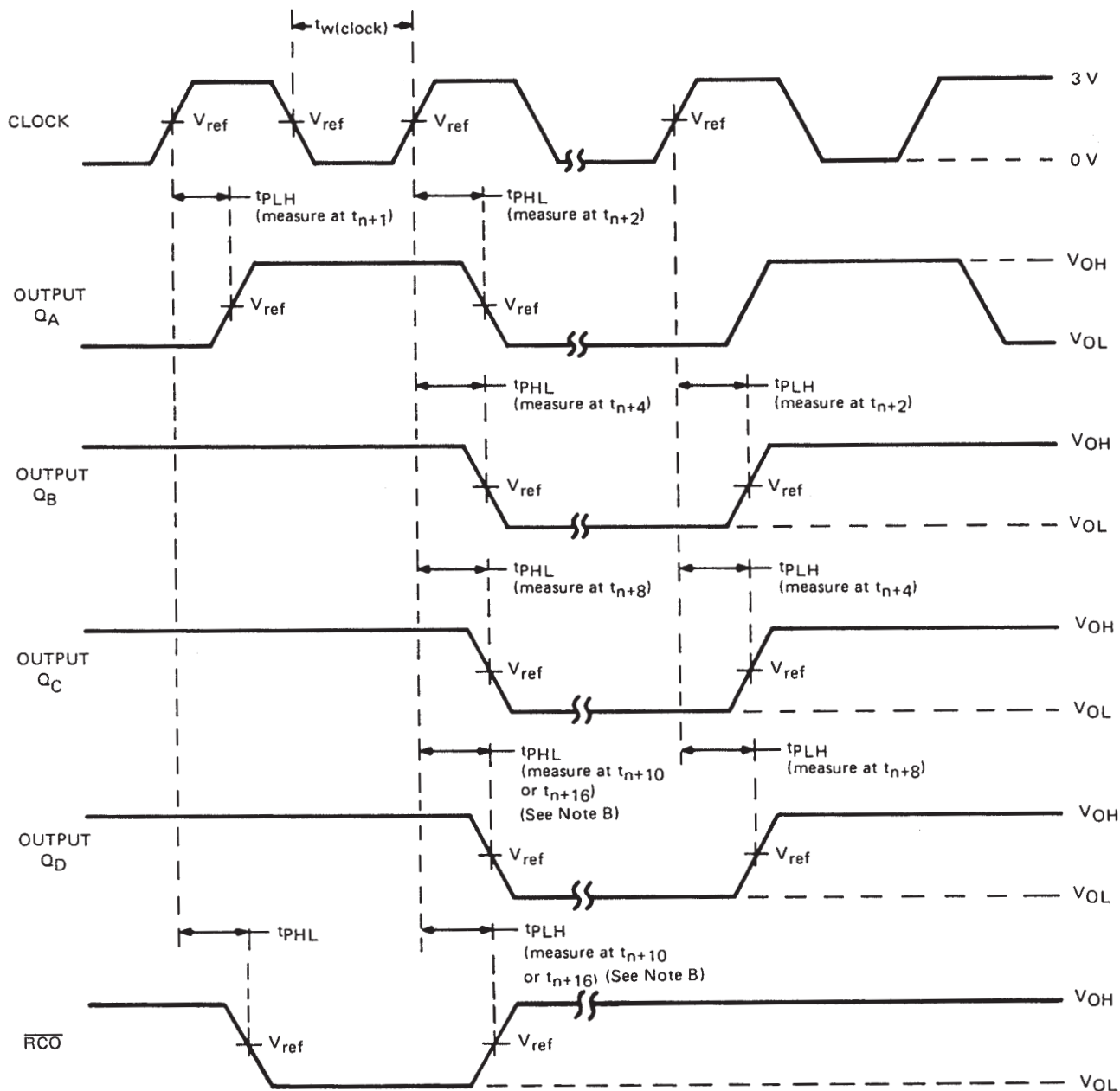
- NOTES: A. The input pulse is supplied by a generator having the following characteristics:  $PRR \leq 1 \text{ MHz}$ , duty cycle  $\leq 50\%$ ,  $Z_{out} \approx 50 \Omega$ ;  $t_r \leq 15 \text{ ns}$ ,  $t_f \leq 6 \text{ ns}$ .  
B.  $t_{PLH}$  and  $t_{PHL}$  from enable  $\bar{T}$  input to ripple carry output assume that the counter is at the maximum count ( $Q_A$  and  $Q_D$  high for 'LS668, all Q outputs high for 'LS669).  
C.  $V_{ref} = 1.3 \text{ V}$ .  
D. Propagation delay time from up/down to ripple carry must be measured with the counter at either a minimum or a maximum count. As the logic level of the up/down input is changed, the ripple carry output will follow. If the count is minimum (0) the ripple carry output transition will be in phase. If the count is maximum (9 for 'LS668, or 15 for 'LS669) the ripple carry output will be out of phase.

FIGURE 2—PROPAGATION DELAY TIMES TO CARRY OUTPUT



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PARAMETER MEASUREMENT INFORMATION



UP-COUNT VOLTAGE WAVEFORMS

- NOTES: A. The input pulses are supplied by a generator having the following characteristics:  $PRR \leq 1 \text{ MHz}$ , duty cycle  $\leq 50\%$ ,  $Z_{out} \approx 50 \Omega$ ,  $t_r \leq 15 \text{ ns}$ ,  $t_f \leq 6 \text{ ns}$ . Vary PRR to measure  $f_{max}$ .
- B. Outputs  $Q_D$  and carry are tested at  $t_{n+10}$  for the 'LS668, and at  $t_{n+16}$  for the 'LS669, where  $t_n$  is the bit-time when all outputs are low.
- C.  $V_{ref} = 1.3 \text{ V}$ .

FIGURE 3—PROPAGATION DELAY TIMES FROM CLOCK

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