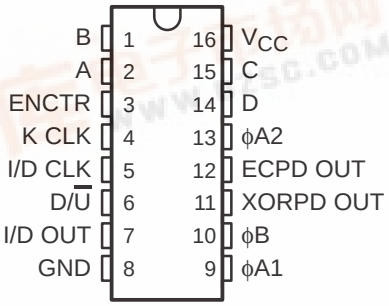
CD74ACT297
DIGITAL PHASE-LOCKED LOOP

SCHS297A – AUGUST 1998 – REVISED SEPTEMBER 1999

- **Digital Design Avoids Analog Compensation Errors**
- **Easily Cascadable for Hlgher Order Loops**
- **Useful Frequency Range**
  - **DC to 110 MHz Typical (K CLK)**
  - **DC to 70 MHz Typical (I/D CLK)**
- **Dynamically Variable Bandwidth**
- **Very Narrow Bandwidth Attainable**
- **Power-On Reset**
- **Output Capability**
  - **Standand: XORPD OUT, ECPD OUT**
  - **Bus Drlver: I/D OUT**
- **SCR Latch-Up-Resistant CMOS Process and Circuit Design**
- **Speed of Bipolar FAST™/AS/S with Significantly Reduced Power Consumption**
- **Balanced Propagation Delays**
- **ESD Protectlon Exceeds 2000 V per MIL-STD-883, Method 3015**
- **Packaged in Small-Outline Integrated Circuit Package**

M PACKAGE
(TOP VIEW)



description

The CD74ACT297 device is designed to provide a simple, cost-effective solution to high-accuracy, digital, phase-locked-loop applications. These devices contain all the necessary circuits, with the exception of the divide-by-N counter, to build first-order phase-locked loops as described in Figure 1.

Both exclusive-OR (XORPD) and edge-controlled (ECPD) phase detectors are provided for maximum flexibility.

Proper partitioning of the loop function, with many of the building blocks external to the package, makes it easy for the designer to incorporate ripple cancellation or to cascade to higher order phase-locked loops.

The length of the up/down K counter is digitally programmable according to the K-counter function table. With A, B, C, and D all low, the K counter is disabled. With A high and B, C, and D low, the K counter is only three stages long, which widens the bandwidth or capture range and shortens the lock time of the loop. When A, B, C, and D are programmed high, the K counter becomes 17 stages long, which narrows the bandwidth or capture range and lengthens the lock time. Real-time control of loop bandwidth by manipulating the A-through-D inputs can maximize the overall performance of the digital phase-locked loop.

This device performs the classic first-order phase-locked-loop function without using analog components. The accuracy of the digital phase-locked loop (DPLL) is not affected by V_{CC} and temperature variations, but depends solely on accuracies of the K clock, I/D clock, and loop propagation delays. The I/D clock frequency and the divide-by-N modulos determine the center frequency of the DPLL. The center frequency is defined by the relationship f_c = I/D clock/2N (Hz).

The CD74ACT297 is characterized for operation from –40°C to 85°C.

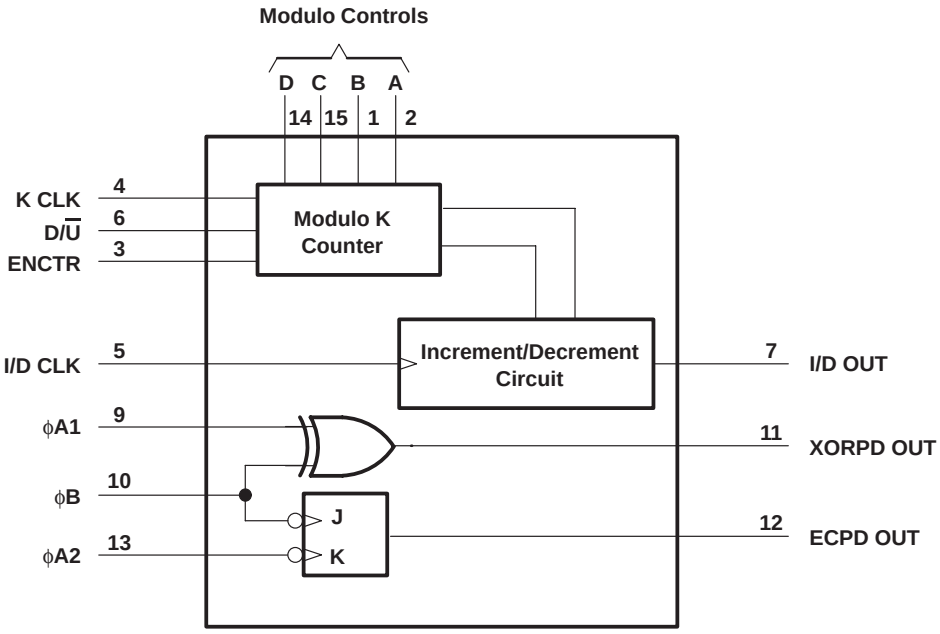


Figure 1. Simplifed Block Diagram

Function Tables

**K COUNTER
(DIGITAL CONTROL)**

D	C	B	A	MODULO (K)
L	L	L	L	Inhibited
L	L	L	H	2^3
L	L	H	L	2^4
L	L	H	H	2^5
L	H	L	L	2^6
L	H	L	H	2^7
L	H	H	L	2^8
L	H	H	H	2^9
H	L	L	L	2^{10}
H	L	L	H	2^{11}
H	L	H	L	2^{12}
H	L	H	H	21^3
H	H	L	L	2^{14}
H	H	L	H	2^{15}
H	H	H	L	2^{16}
H	H	H	H	2^{17}

EXCLUSIVE-OR PHASE DETECTOR

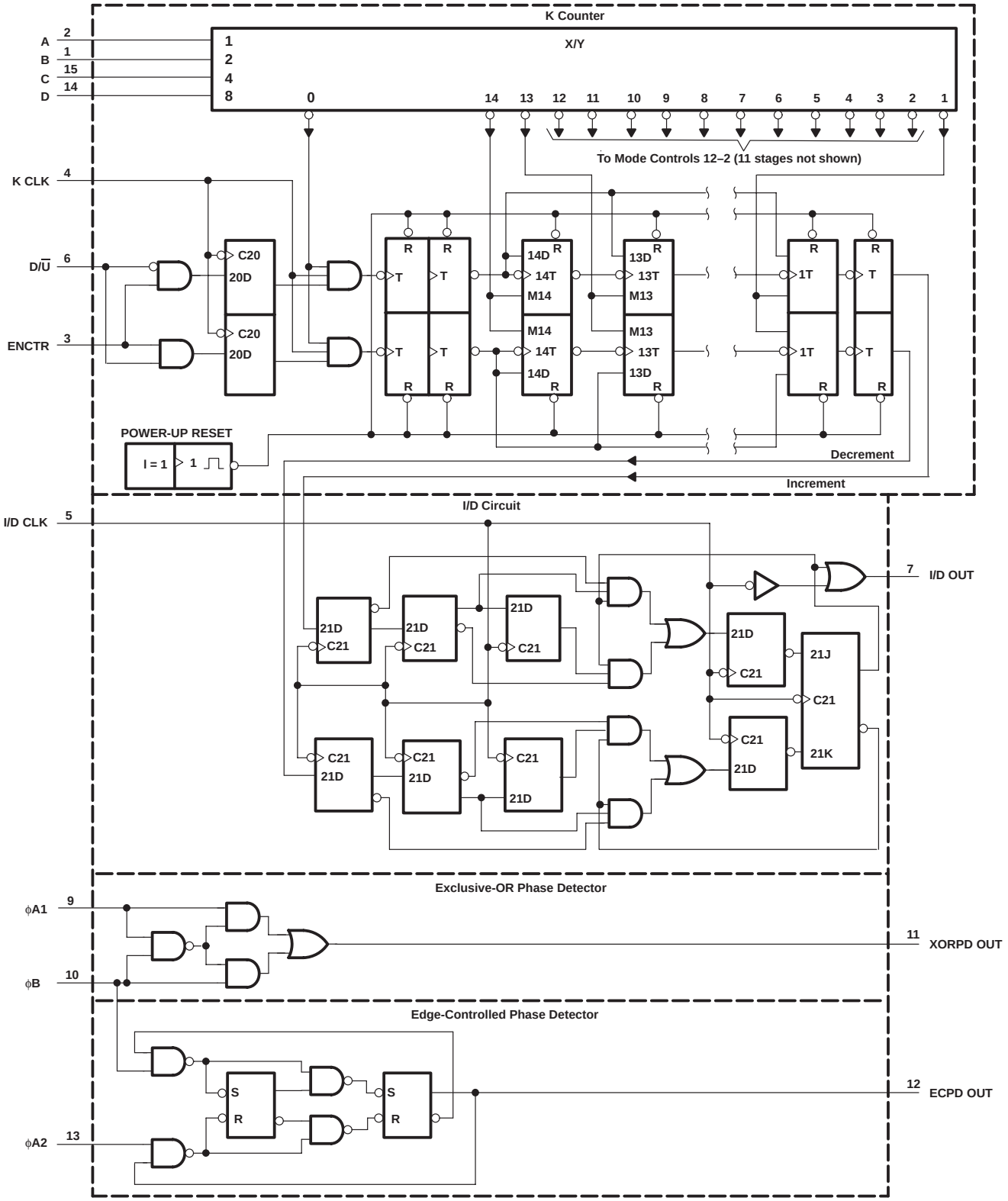
ϕA1	ϕB	XORPD OUT
L	L	L
L	H	H
H	L	H
H	H	L

EDGE-CONTROLLED PHASE DETECTOR

ϕA2	ϕB	ECPD OUT
H or L	↓	H
↓	H or L	L
H or L	↑	No change
↑	H or L	No change

H = steady-state high level
L = steady-state low level
↓ = transition from high to low
↑ = transition from low to high

functional block diagram



The phase detector generates an error-signal waveform that, at zero phase error, is a 50% duty-cycle square wave. At the limits of linear operation, the phase-detector output will be either high or low all of the time, depending on the direction of the phase error ($\phi_{in} - \phi_{out}$). Within these limits, the phase-detector output varies linearly with the input phase error according to the gain k_d, which is expressed in terms of phase-detector output per cycle of phase error. The phase-detector output can be varied between ±1 according to the relation:

$$\text{Phase-detector output} = \frac{\%\ \text{high} - \%\ \text{low}}{100} \quad (1)$$

The output of the phase detector will be $k_d\ \phi_e$, where the phase error $\phi_e = \phi_{in} - \phi_{out}$.

Exclusive-OR phase detectors (XORPD) and edge-controlled phase detectors (ECPD) are commonly used digital types. The ECPD is more complex than the XORPD logic function, but can be described generally as a circuit that changes states on one of the transitions of its inputs. For an XORPD, k_d is 4 because its output remains high (PD output = 1) for a phase error of 1/4 cycle. Similarly, for the ECPD, k_d is 2 because its output remains high for a phase error of 1/2 cycle. The type of phase detector will determine the zero-phase-error point, i.e., the phase separation of the phase-detector inputs for ϕ_e defined to be zero. For the basic DPLL system of Figure 2, $\phi_e = 0$ when the phase-detector output is a square wave. The XORPD inputs are 1/4 cycle out of phase for zero phase error. For the ECPD, $\phi_e = 0$ when the inputs are 1/2 cycle out of phase.

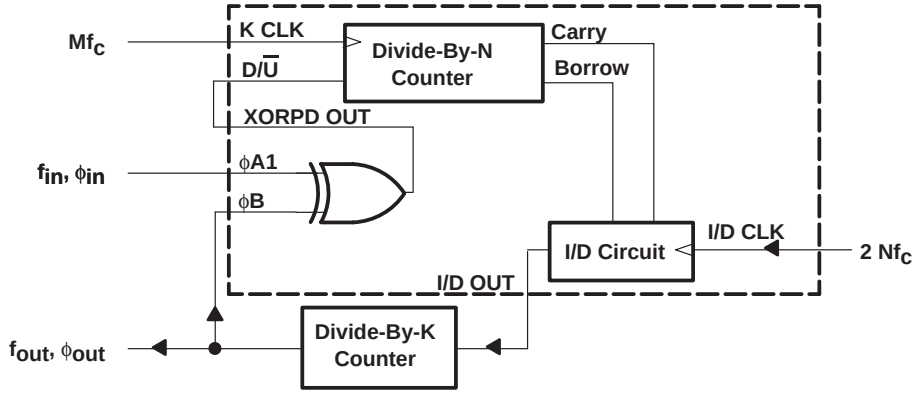


Figure 2. DPLL Using Exclusive-OR Phase Detection

The phase-detector output controls the up/down input to the K counter. The counter is clocked by input frequency Mf_c, which is a multiple M of the loop center frequency f_c. When the K counter recycles up, it generates a carry pulse. Recycling while counting down generates a borrow pulse. If the carry and borrow outputs are conceptually combined into one output that is positive for a carry and negative for a borrow, and if the K counter is considered as a frequency divider with the ratio Mf_c/K, the output of the K counter will equal the input frequency multiplied by the division ratio. Thus, the output from the K counter is $(k_d\phi_e Mf_c)K$.

The carry and borrow pulses go to the increment/decrement (I/D) circuit, which, in the absence of any carry or borrow pulse, has an output that is one half of the input clock (I/D CLK). The input clock is just a multiple, 2N, of the loop center frequency. In response to a carry or borrow pulse, the I/D circuit will either add or delete a pulse at I/D OUT. Thus, the output of the I/D circuit will be Nf_c 4 $(k_d\phi_e Mf_c)/2K$.

The output of the N counter (or the output of the phase-locked loop) is:

$$f_o = f_c + (k_d\phi_e Mf_c)/2KN \quad (2)$$

When this result is compared to the equation for a first-order analog phase-locked loop, the digital equivalent of the gain of the VCO is just $Mf_c/2KN$ or f_c/K for M = 2N.

Thus, the simple first-order phase-locked loop with an adjustable K counter is the equivalent of an analog phase-locked loop with a programmable VCO gain.

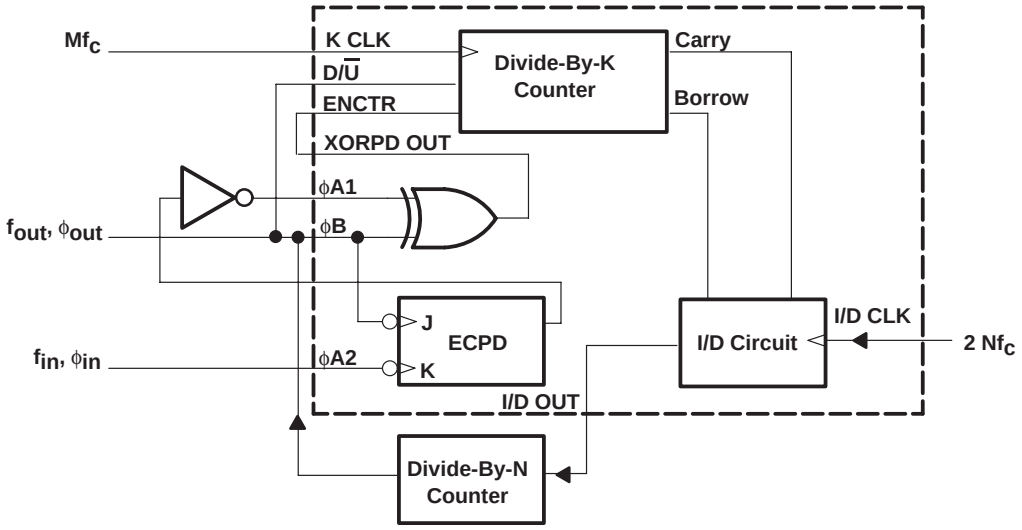


Figure 3. DPLL Using Both Phase Detectors in a Ripple-Cancellation Scheme

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

Supply voltage range, V_{CC} . . . . . –0.5 V to 6 V
DC input diode current, I_{IK} (V_I < –0.5 V or V_I > V_{CC} + 0.5 V) . . . . . ±20 mA
DC input diode current, I_{OK} (V_O < –0.5 V or V_O > V_{CC} + 0.5 V) . . . . . ±50 mA
DC output source or sink current per output pin, I_O (V_O > –0.5 V or V_O < V_{CC} + 0.5 V) . . . . . ±50 mA
Continuous current through V_{CC} or GND (Note 1) . . . . . ±100 mA
Package thermal impedance,θ_{JA} (see Note 2) . . . . . 73°C/W
Storage temperature range, T_{stg} . . . . . –65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. For up to four outputs per device, add ±25 mA for each additional output.
2. The package thermal impedance is calculated in accordance with JESD 51.

recommended operating conditions

		MIN	MAX	UNIT
V_{CC}	Supply voltage	4.5	5.5	V
V_{IH}	High-level input voltage	2		V
V_{IL}	Low-level input voltage		0.8	V
V_I	Input voltage	0	V_{CC}	V
V_O	Output voltage	0	V_{CC}	V
dt/dv	Input rise and fall slew rate		10	ns
T_A	Operating free-air temperature range	–40	85	°C

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

PARAMETER	TEST CONDITIONS		V_{CC}	T_A = 25°C		MIN	MAX	UNIT
				MIN	MAX			
V_{OH}	V_I = V_{IH} or V_{IL}	I_O = –50 μA	4.5 V	4.4		4.4		V
		I_O = –24 mA	4.5 V	3.94		3.8		
		I_O = –75 mA	5.5 V			3.85		
V_{OL}	V_I =V_{IH} or V_{IL}	I_O = 50 μA	4.5 V		0.1		0.1	V
		I_O = 24 mA	4.5 V		0.36		0.44	
		I_O = 75 mA†	5.5 V				1.65	
I_I	V_I = V_{CC} or GND		5.5 V		±0.1		±1	μA
I_{CC} (MSI)	V_I = V_{CC} or GND		5.5 V		8		80	μA
I_{CC} (SSI/FF)	V_I = V_{CC} or GND		5.5 V		4		40	μA
ΔI_{CC}	V_I = V_{CC} –2.1 V		4.5 V to 5.5 V		2.4		2.8	mA

† Test one output at a time for a 1-second maximum duration. Measurement is made by forcing current and measuring voltage to minimize power dissipation. Test verifies a minimum 50-Ω transmission-line drive capability at 85°C.

ACT Input Load Table

INPUT	UNIT LOAD
ENCTR, $D/\overline{U}$	0.1
A, B, C, D, K CLK, ϕA2	0.2
I/O CLK, ϕA1, ϕB	0.5

NOTE: Unit Load is ΔI_{CC} limit specified in electrical characteristics table (e.g., 2.4 mA at 25°C).

timing requirements over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

PARAMETER			T_A = 25°C		MIN	MAX	UNIT
			MIN	MAX			
f_{clock}	Clock frequency	K CLK		55		45	MHz
		I/D CLK		40		35	
t_w	Pulse duration	K CLK	6		8		ns
		I/D CLK	7		9		
t_{su}	Setup time before K CLK↑	D/$\overline{U}$	13		17		ns
		ENCTR	12		16		
t_h	Hold time after K CLK↑	D/$\overline{U}$	3		7		ns
		ENCTR	2		6		

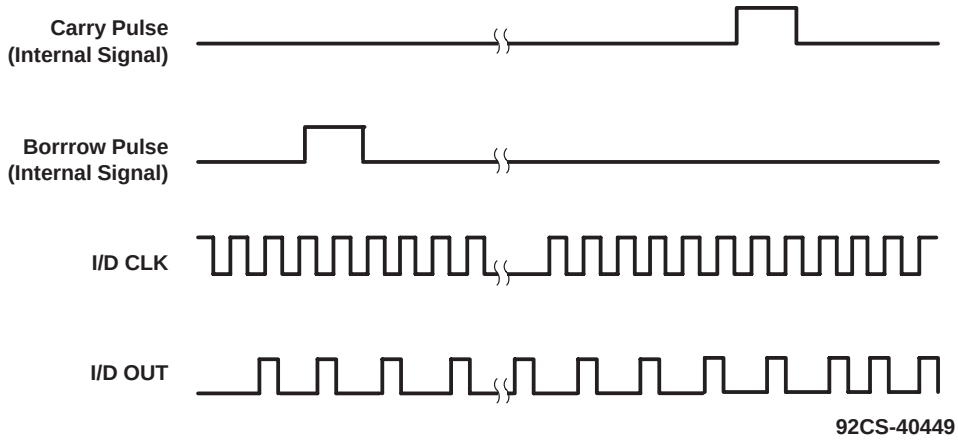


Figure 4. I/D OUT In Lock Condition

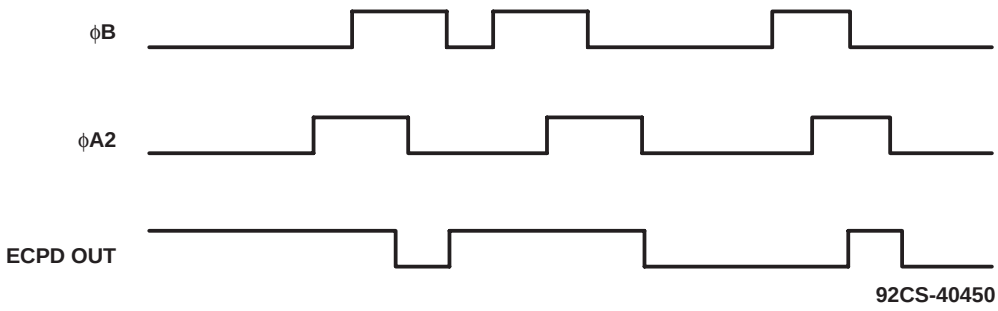


Figure 5. Edge-Controlled Phase-Comparator Waveforms

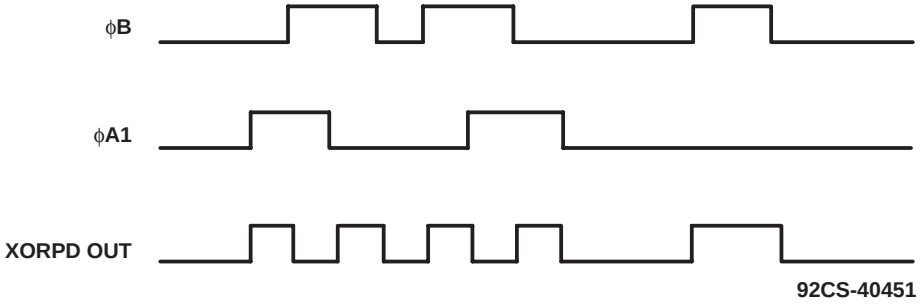


Figure 6. Exclusive-OR Phase-Detector Waveforms

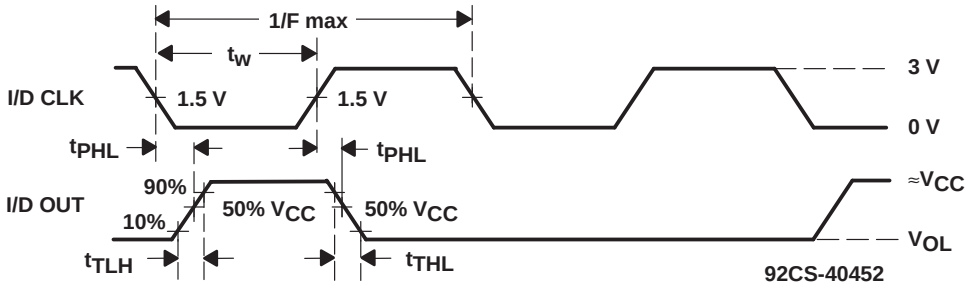


Figure 7. Waveforms Showing Clock (ID CLK) to Output (ID OUT) Propagation Delays, Clock Pulse Duration, and Maximum Clock Pulse Frequency

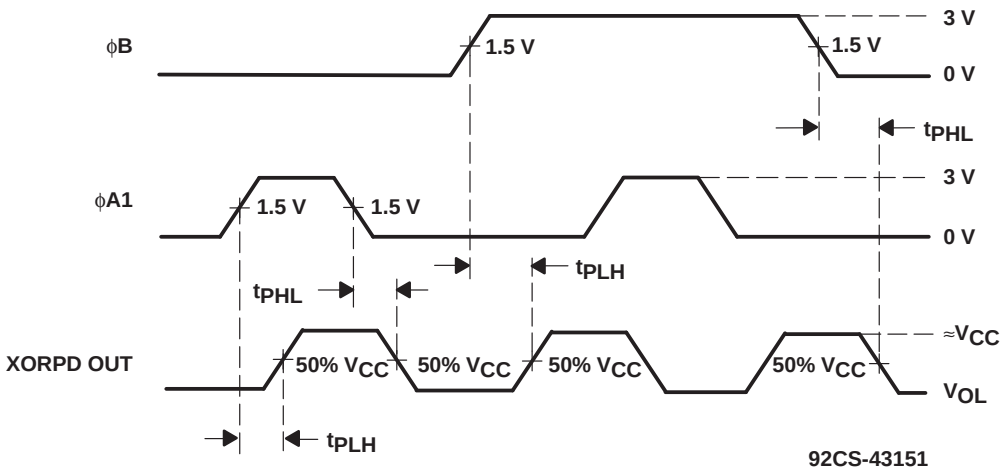


Figure 8. Waveforms Showing Phase Input (φB, φA2) to Output (XORPD OUT) Propagation Delays

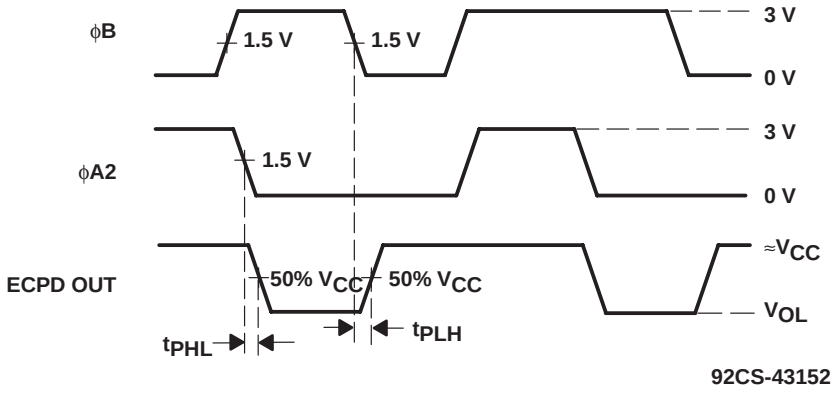
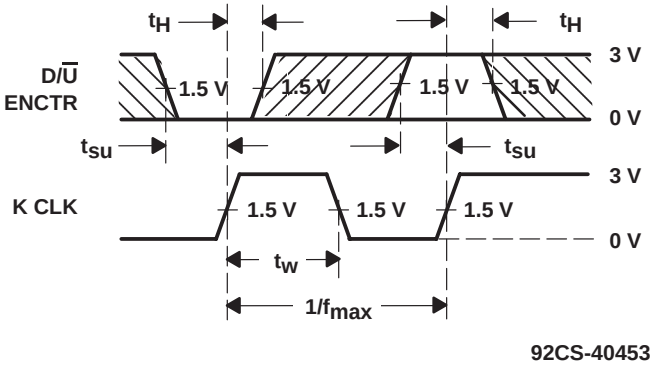


Figure 9. Waveforms Showing Phase Input (φB, φA2) to Output (ECPD OUT) Propagation Delays



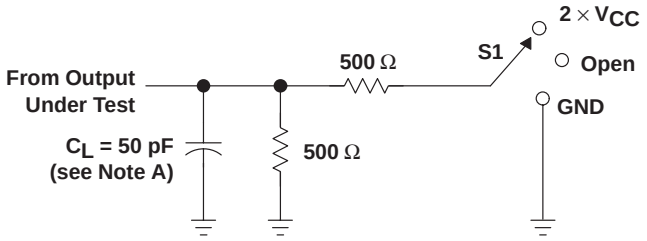
NOTE A: Shaded areas indicate when the input is permitted to change for predictable output performance.

Figure 10. Waveforms Showing Clock (K CLK) Pulse Duration and Maximum Clock Pulse Frequency, and Inputs (D/U, ENCTR) to Clock (K CLK) Setup and Hold Times.

switching characteristics over recommended operating free-air temperature range, C_L = 50 pF, (unless otherwise noted)

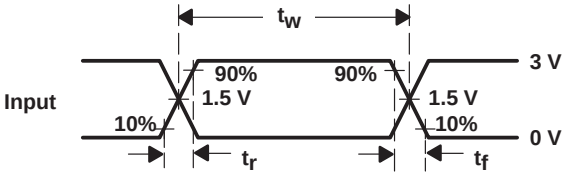
PARAMETER	FROM (INPUT)	TO (OUTPUT)	T_A = 25°C			MIN	MAX	UNIT
			MIN	TYP	MAX			
f_{max}	K CLK	I/D OUT	55			45		MHz
	I/D CLK		40			35		
t_{PLH}	I/D CLK	I/D OUT			19		24	ns
t_{PHL}					19		24	
t_{PHL}	ϕA_2	ECPD OUT			24		30	ns
t_{PLH}	ϕA_1	XORPD OUT			17		22	ns
t_{PHL}					17		22	
t_{PLH}	φB	XORPD OUT			17		22	ns
t_{PHL}					17		22	
t_{PLH}	φB	ECPD OUT			24		30	ns

PARAMETER MEASUREMENT INFORMATION

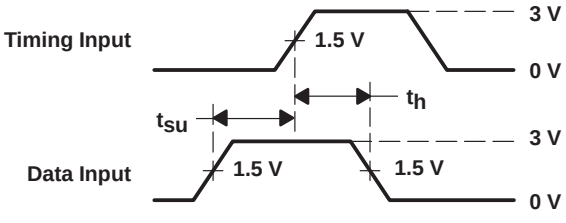


TEST	S1
t_{PLH}/t_{PHL}	Open
t_{PLZ}/t_{PZL}	2 × V_{CC}
t_{PHZ}/t_{PZH}	GND

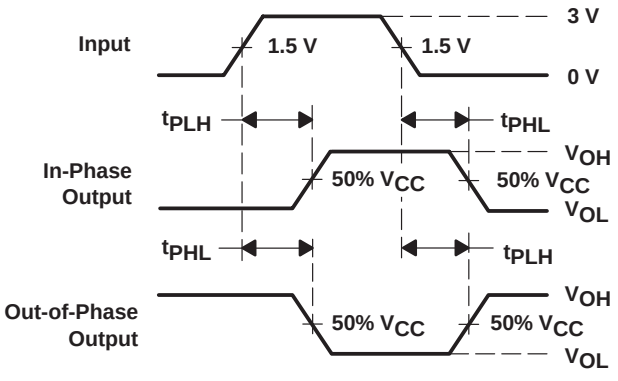
LOAD CIRCUIT



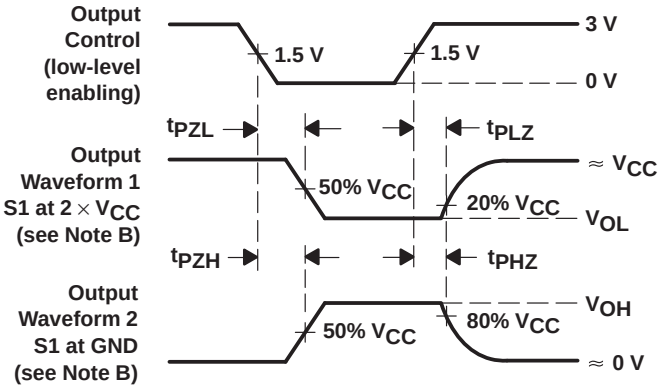
VOLTAGE WAVEFORMS
INPUT RISE AND FALL TIMES AND PULSE DURATION



VOLTAGE WAVEFORMS
SETUP AND HOLD TIMES



VOLTAGE WAVEFORMS
PROPAGATION DELAY TIMES



VOLTAGE WAVEFORMS
ENABLE AND DISABLE TIMES

NOTES: A. C_L includes probe and jig capacitance.
B. Waveform 1 is for an output with internal conditions such that the output is low except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is high except when disabled by the output control.
C. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, Z_O = 50 Ω, t_r = 3 ns, t_f = 3 ns.
D. The outputs are measured one at a time with one input transition per measurement.

Figure 11. Load Circuit and Voltage Waveforms

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