

# 74HC4046A-Q100

Phase-locked loop with VCO

Rev. 1 — 27 November 2019

Product data sheet

## 1. General description

The 74HC4046A-Q100 is a high-speed Si-gate CMOS device. It is specified in compliance with JEDEC standard no 7A.

This product has been qualified to the Automotive Electronics Council (AEC) standard Q100 (Grade 1) and is suitable for use in automotive applications.

## 2. Features and benefits

- Automotive product qualification in accordance with AEC-Q100 (Grade 1)
  - Specified from -40 °C to +85 °C and from -40 °C to +125 °C
- Low power consumption
- VCO-Inhibit control for ON/OFF keying and for low standby power consumption
- Center frequency up to 17 MHz (typical) at  $V_{CC} = 4.5$  V
- Choice of three phase comparators:
  - PC1: EXCLUSIVE-OR
  - PC2: Edge-triggered J-K flip-flop
  - PC3: Edge-triggered RS flip-flop
- Excellent Voltage Controlled Oscillator (VCO) linearity
- Low frequency drift with supply voltage and temperature variations
- Operating power supply voltage range:
  - VCO section 3.0 V to 6.0 V
  - Digital section 2.0 V to 6.0 V
- Zero voltage offset due to operational amplifier buffering
- ESD protection:
  - HBM JESD22-A114F exceeds 2000 V
  - MM JESD22-A115-A exceeds 200 V

## 3. Applications

- FM modulation and demodulation
- Frequency synthesis and multiplication
- Frequency discrimination
- Tone decoding
- Data synchronization and conditioning
- Voltage-to-frequency conversion
- Motor-speed control

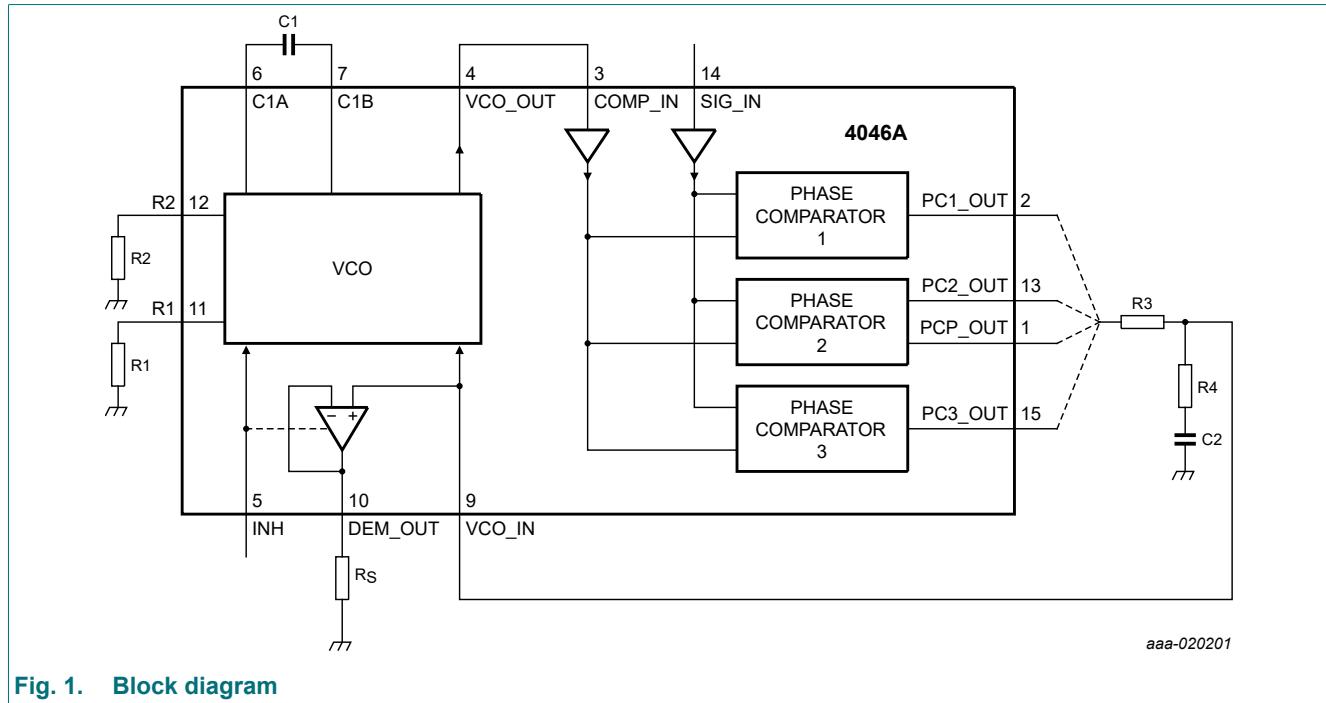
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## 4. Ordering information

Table 1. Ordering information

Type number	Package		
	Name	Description	Version
74HC4046APW-Q100	TSSOP16	plastic thin shrink small outline package; 16 leads; body width 4.4 mm	SOT403-1

## 5. Block diagram



## 6. Functional diagram

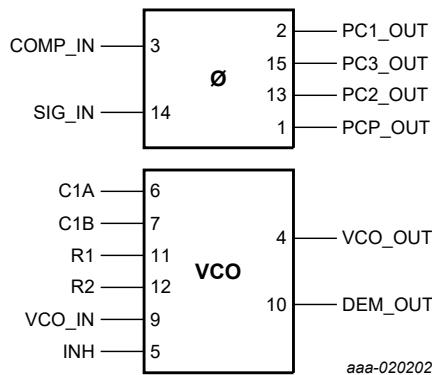


Fig. 2. Logic symbol

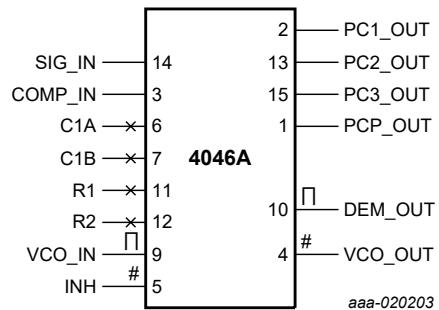


Fig. 3. IEC logic symbol

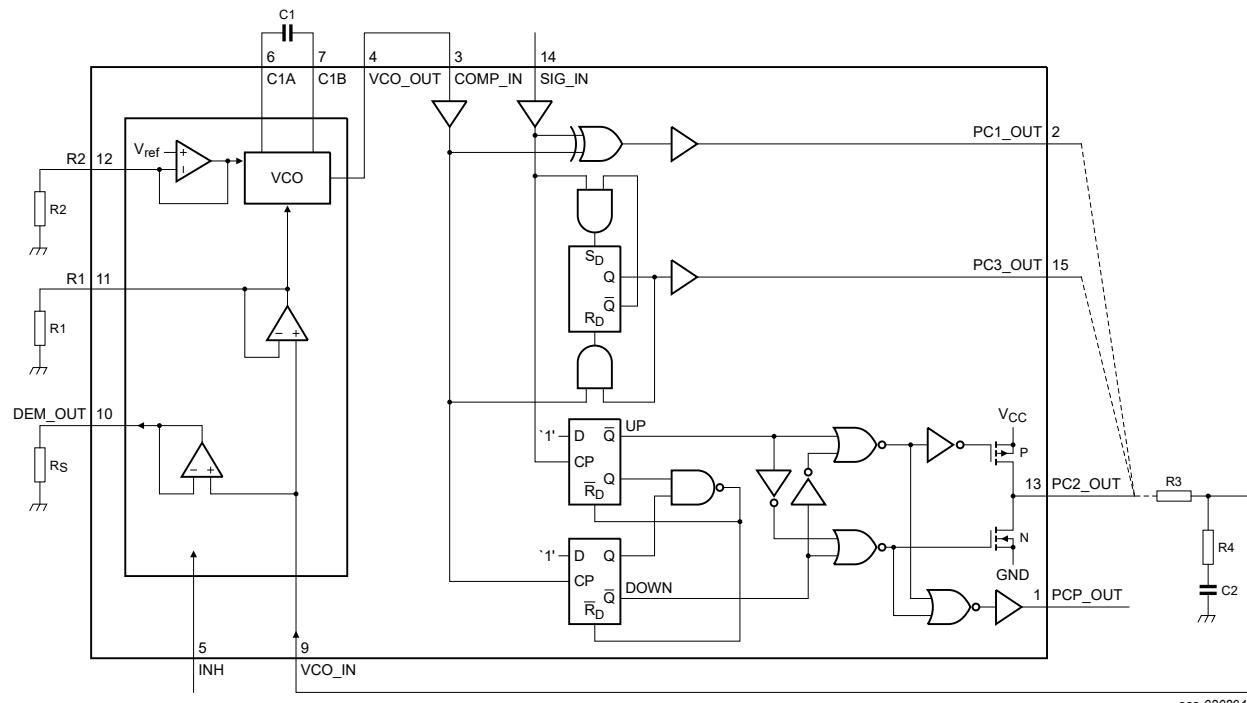


Fig. 4. Logic diagram

## 7. Pinning information

### 7.1. Pinning

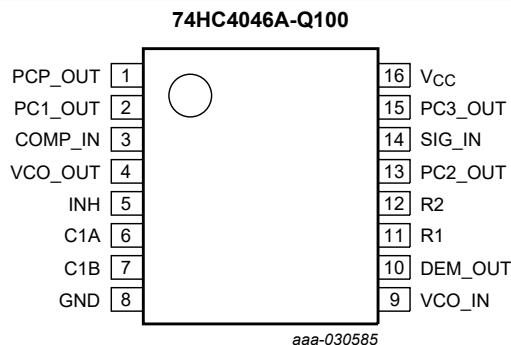


Fig. 5. Pin configuration SOT403-1 (TSSOP16)

### 7.2. Pin description

Table 2. Pin description

Symbol	Pin	Description
PCP_OUT	1	phase comparator pulse output
PC1_OUT	2	phase comparator 1 output
COMP_IN	3	comparator input
VCO_OUT	4	VCO output
INH	5	inhibit input
C1A	6	capacitor C1 connection A
C1B	7	capacitor C1 connection B
GND	8	ground (0 V)
VCO_IN	9	VCO input
DEM_OUT	10	demodulator output
R1	11	resistor R1 connection
R2	12	resistor R2 connection
PC2_OUT	13	phase comparator 2 output
SIG_IN	14	signal input
PC3_OUT	15	phase comparator 3 output
V <sub>CC</sub>	16	supply voltage

## 8. Functional description

The 74HC4046A-Q100 is a phase-locked-loop circuit that comprises a linear VCO and three different phase comparators (PC1, PC2 and PC3). It has a common signal input amplifier and a common comparator input (see [Fig. 1](#)). The signal input can be directly coupled to a large voltage signal, or indirectly coupled (with a series capacitor) to a small voltage signal. A self-bias input circuit keeps small voltage signals within the linear region of the input amplifiers. With a passive low-pass filter, the 74HC4046A-Q100 forms a second-order loop PLL. The excellent VCO linearity is achieved by the use of linear op amp techniques.

### 8.1. VCO

The VCO requires one external capacitor C1 (between pins C1A and C1B) and one external resistor R1 (between pins R1 and GND). Alternatively, it requires two external resistors R1 and R2 (between pins R1 and GND, and R2 and GND). Resistor R1 and capacitor C1 determine the frequency range of the VCO. Resistor R2 enables the VCO to have a frequency offset if necessary (see [Fig. 4](#)).

The high input impedance of the VCO simplifies the design of the low-pass filters by giving the designer a wide choice of resistor/capacitor ranges. In order not to load the low-pass filter, a demodulator output of the VCO input voltage is provided at pin DEM\_OUT. In contrast to conventional techniques, where the DEM\_OUT voltage is one threshold voltage lower than the VCO input voltage, the DEM\_OUT voltage equals the VCO input. If DEM\_OUT is used, a series resistor ( $R_s$ ) should be connected from pin DEM\_OUT to GND. If unused, DEM\_OUT should be left open. The VCO output (pin VCO\_OUT) can be connected directly to the comparator input (pin COMP\_IN) or connected via a frequency divider. When the VCO input DC level is held constant, the VCO output signal has a duty cycle of 50 % (maximum expected deviation 1 %). A LOW-level at the inhibit input (pin INH) enables the VCO and demodulator, while a HIGH-level turns off both to minimize standby power consumption.

### 8.2. Phase comparators

The input signal can be coupled to the self-biasing amplifier at pin SIG\_IN, when the signal swing is between the standard HC family input logic levels. Capacitive coupling is required for signals with smaller swings.

#### 8.2.1. Phase Comparator 1 (PC1)

This circuit is an EXCLUSIVE-OR network. The signal and comparator input frequencies ( $f_i$ ) must have a 50 % duty cycle to obtain the maximum locking range. The transfer characteristic of PC1, assuming ripple ( $f_r = 2f_i$ ) is suppressed, is:

$$V_{DEM\_OUT} = \frac{V_{CC}}{\pi} (\Phi_{SIG\_IN} - \Phi_{COMP\_IN})$$

where:

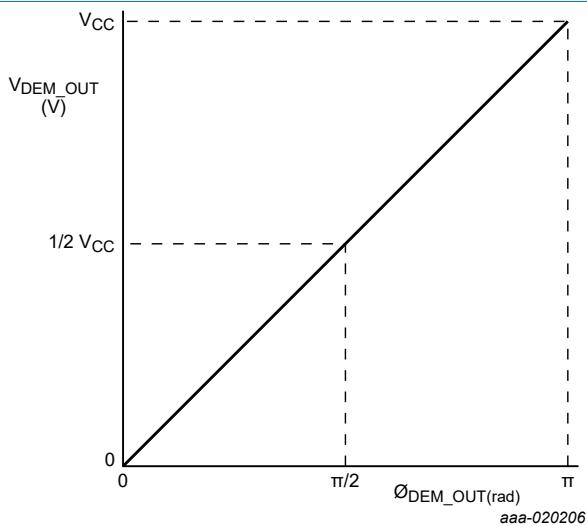
- $V_{DEM\_OUT}$  is the demodulator output at pin DEM\_OUT
- $V_{DEM\_OUT} = V_{PC1\_OUT}$  (via low-pass filter)

The phase comparator gain is:  $K_p = \frac{V_{CC}}{\pi} (V/\text{rad})$

PC1 is fed to the VCO input via the low-pass filter and provided at the demodulator output at pin DEM\_OUT ( $V_{DEM\_OUT}$ ). The average output voltage from PC1 is the result of the phase differences of signals (SIG\_IN) and the comparator input (COMP\_IN). These phase differences are shown in [Fig. 6](#). The average of  $V_{DEM\_OUT}$  is equal to  $0.5V_{CC}$  when no signal or noise is present at SIG\_IN. Using this input, the VCO oscillates at the center frequency ( $f_0$ ). Typical waveforms for the PC1 loop locked at  $f_0$  are shown in [Fig. 7](#).

The frequency capture range ( $2f_c$ ) is defined as the frequency range of input signals on which the PLL locks when it was initially out-of-lock. The frequency lock range ( $2f_L$ ) is the frequency range of the input signals on which the loop stays locked when it was initially in lock. The capture range is smaller or equal to the lock range.

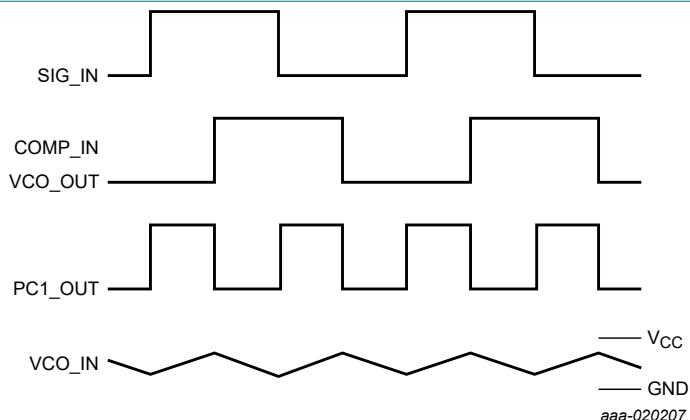
With PC1, the capture range depends on the low-pass filter characteristics and can be made as large as the lock range. This configuration remains locked even with very noisy input signals. Typical behavior of this type of phase comparator is that it can lock to input frequencies close to the harmonics of the VCO center frequency.



$$V_{DEM\_OUT} = V_{PC1\_OUT} = \frac{V_{CC}}{\pi} (\Phi_{SIG\_IN} - \Phi_{COMP\_IN})$$

$$\Phi_{DEM\_OUT} = (\Phi_{SIG\_IN} - \Phi_{COMP\_IN})$$

**Fig. 6. Phase comparator 1; average output voltage as a function of input phase difference**



**Fig. 7. Typical waveforms for PLL using phase comparator 1; loop-locked at  $f_0$**

### 8.2.2. Phase Comparator 2 (PC2)

PC2 is a positive edge-triggered phase and frequency detector. When the PLL uses this comparator, positive signal transitions control the loop and the duty cycles of SIG\_IN and COMP\_IN are not important. PC2 comprises two D-type flip-flops, control gating and a 3-state output stage. The circuit functions as an up-down counter (see [Fig. 4](#)) where SIG\_IN causes an up-count and COMP\_IN a down count. The transfer function of PC2, assuming ripple ( $f_r = f_i$ ) is suppressed, is:

$$V_{DEM\_OUT} = \frac{V_{CC}}{4\pi} (\Phi_{SIG\_IN} - \Phi_{COMP\_IN})$$

where:

- $V_{DEM\_OUT}$  is the demodulator output at pin DEM\_OUT
- $V_{DEM\_OUT} = V_{PC2\_OUT}$  (via low-pass filter)

$$\text{The phase comparator gain is: } K_p = \frac{V_{CC}}{4\pi} (\text{V/rad})$$

$V_{DEM\_OUT}$  is the resultant of the initial phase differences of SIG\_IN and COMP\_IN as shown in [Fig. 8](#). Typical waveforms for the PC2 loop locked at  $f_o$  are shown in [Fig. 9](#).

When the SIG\_IN and COMP\_IN frequencies are equal but the phase of SIG\_IN leads that of COMP\_IN, the p-type output driver at PC2\_OUT is held 'ON'. The time that it is held 'ON' corresponds with the phase difference ( $\Phi_{DEM\_OUT}$ ). When the phase of SIG\_IN lags that of COMP\_IN, the n-type driver is held 'ON'.

When the SIG\_IN frequency is higher than the COMP\_IN frequency, the p-type output driver is held 'ON' for most of the input signal cycle time. For the remainder of the cycle time, both n- and p-type drivers are 'OFF' (3-state). If the SIG\_IN frequency is lower than the COMP\_IN frequency, the n-type driver is held 'ON' for most of the cycle. The voltage at capacitor (C2) of the low-pass filter, connected to PC2\_OUT, varies until the phase and frequency of the signal and comparator inputs are equal. At this stable point, the voltage on C2 remains constant as the PC2 output is in 3-state and the VCO\_IN input is in a high-impedance state. In this condition, the signal at the phase comparator pulse output (PCP\_OUT) is a HIGH level and can be used for indicating a locked condition.

Thus for PC2 no phase difference exists between SIG\_IN and COMP\_IN over the full frequency range of the VCO. The power dissipation due to the low-pass filter is reduced because both n- and p-type output drivers are 'OFF' for most of the signal input cycle. The PLL lock range for this type of phase comparator is equal to the capture range and is independent of the low-pass filter. With no signal present at SIG\_IN the VCO adjust, via PC2, to its lowest frequency.

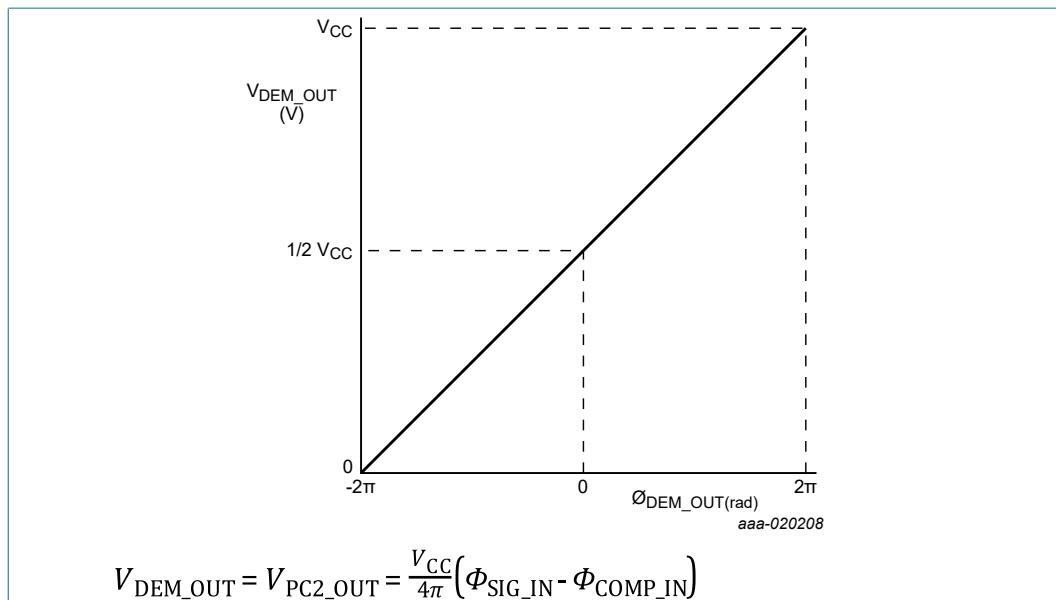


Fig. 8. Phase comparator 2; average output voltage as a function of input phase difference

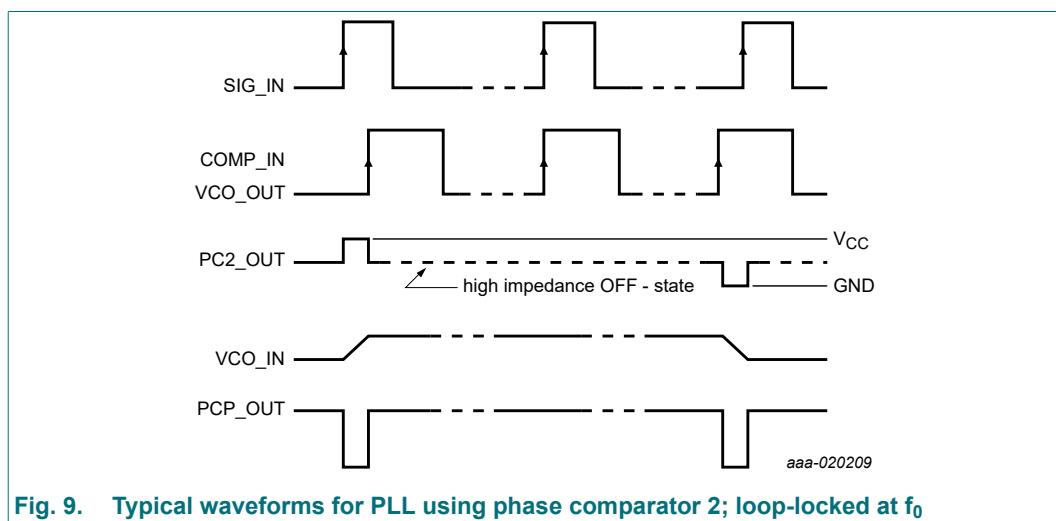


Fig. 9. Typical waveforms for PLL using phase comparator 2; loop-locked at  $f_0$

### 8.2.3. Phase Comparator 3 (PC3)

PC3 is a positive edge-triggered sequential phase detector using an RS-type flip-flop. When the PLL is using this comparator, positive signal transitions control the loop and the duty factors of SIG\_IN and COMP\_IN are not important. The transfer characteristic of PC3, assuming ripple ( $f_r = f_i$ ) is suppressed, is:

$$V_{DEM\_OUT} = \frac{V_{CC}}{2\pi} (\Phi_{SIG\_IN} - \Phi_{COMP\_IN})$$

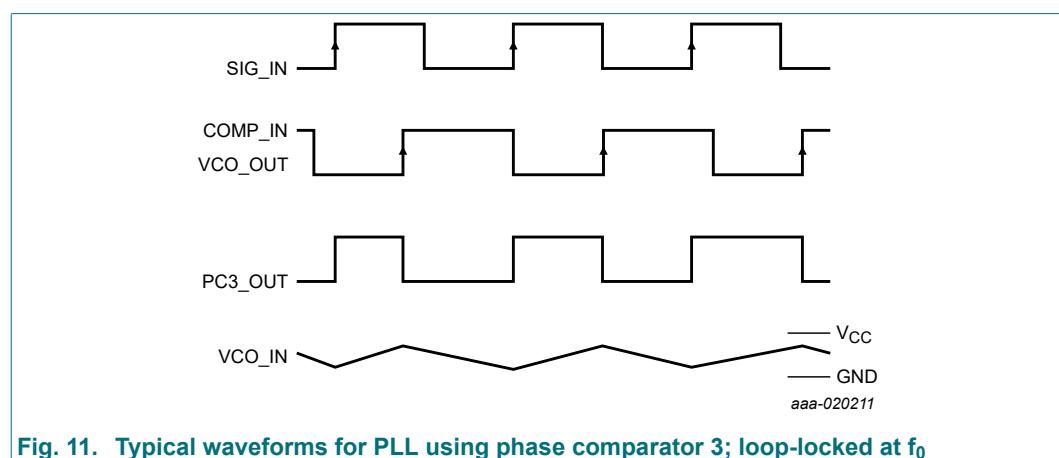
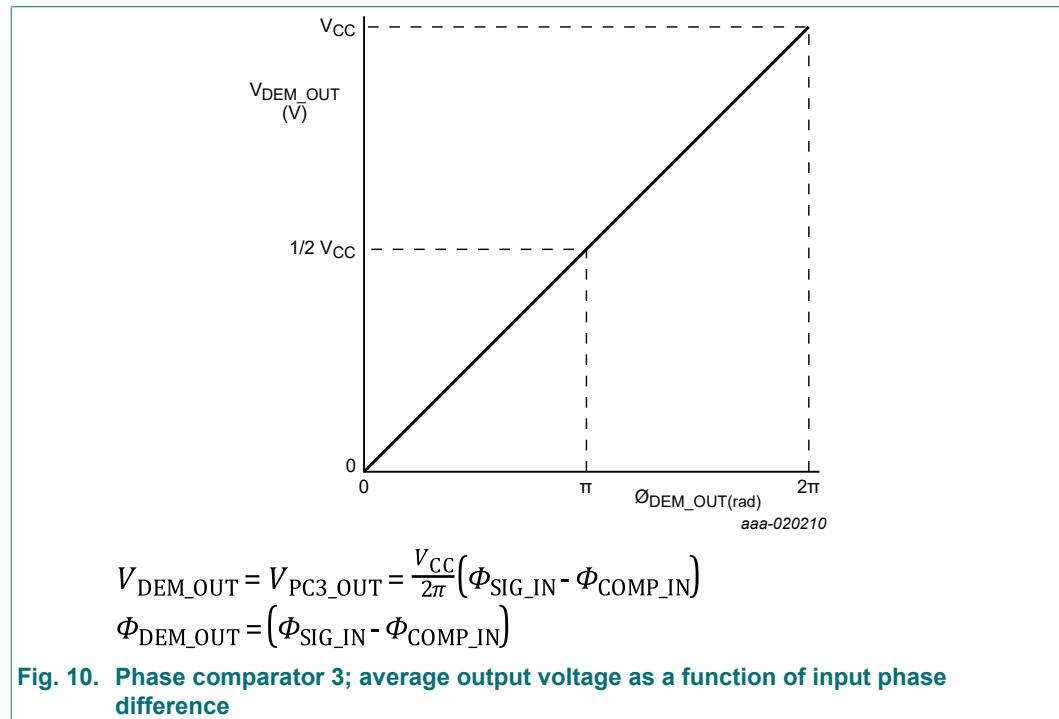
where:

- $V_{DEM\_OUT}$  is the demodulator output at pin DEM\_OUT
- $V_{DEM\_OUT} = V_{PC3\_OUT}$  (via low-pass filter)

The phase comparator gain is:  $K_p = \frac{V_{CC}}{2\pi} (V/rad)$

PC3 is fed to the VCO via the low-pass filter and present at the demodulator output at pin DEM\_OUT. The average output from PC3 is the resultant of the phase differences of SIG\_IN and COMP\_IN, see Fig. 10. Typical waveforms for the PC3 loop locked at  $f_0$  are shown in Fig. 11.

The phase-to-output response characteristic of PC3 (Fig. 10) differs from PC2 in that the phase angle between SIG\_IN and COMP\_IN varies between 0° and 360°. It is 180° at the center frequency. Also PC3 gives a greater voltage swing than PC2 for input phase differences. As a result, the ripple content of the VCO input signal is higher. The PLL lock range for this type of phase comparator and the capture range are dependent on the low-pass filter. With no signal present at SIG\_IN, the VCO adjusts to its lowest frequency via PC3.



## 9. Limiting values

**Table 3. Limiting values**

In accordance with the Absolute Maximum Rating System (IEC 60134). Voltages are referenced to GND (ground = 0 V).

Symbol	Parameter	Conditions	Min	Max	Unit
$V_{CC}$	supply voltage		-0.5	+7	V
$I_{IK}$	input clamping current	$V_I < -0.5 \text{ V}$ or $V_I > V_{CC} + 0.5 \text{ V}$	-	$\pm 20$	mA
$I_{OK}$	output clamping current	$V_O < -0.5 \text{ V}$ or $V_O > V_{CC} + 0.5 \text{ V}$	-	$\pm 20$	mA
$I_O$	output current	$-0.5 \text{ V} < V_O < V_{CC} + 0.5 \text{ V}$	-	$\pm 25$	mA
$I_{CC}$	supply current		-	$+50$	mA
$I_{GND}$	ground current		-50	-	mA
$T_{stg}$	storage temperature		-65	$+150$	$^{\circ}\text{C}$
$P_{tot}$	total power dissipation	$T_{amb} = -40 \text{ }^{\circ}\text{C}$ to $+125 \text{ }^{\circ}\text{C}$	[1]	-	500 mW

[1] For SOT403-1 (TSSOP16) packages:  $P_{tot}$  derates linearly with 8.5 mW/K above 91  $^{\circ}\text{C}$ .

## 10. Recommended operating conditions

**Table 4. Recommended operating conditions**

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$V_{CC}$	supply voltage		3.0	5.0	6.0	V
		when VCO is not used	2.0	5.0	6.0	V
$V_I$	input voltage		0	-	$V_{CC}$	V
$V_O$	output voltage		0	-	$V_{CC}$	V
$\Delta t/\Delta V$	input transition rise and fall rate	pin INH				
		$V_{CC} = 2.0 \text{ V}$	-	-	625	ns/V
		$V_{CC} = 4.5 \text{ V}$	-	1.67	139	ns/V
		$V_{CC} = 6.0 \text{ V}$	-	-	83	ns/V
$T_{amb}$	ambient temperature		-40	+25	$+125$	$^{\circ}\text{C}$

## 11. Static characteristics

**Table 5. Static characteristics**

At recommended operating conditions; voltages are referenced to GND (ground = 0 V).

Symbol	Parameter	Conditions	25 °C			-40 °C to +85 °C		-40 °C to +125 °C		Unit
			Min	Typ	Max	Min	Max	Min	Max	
<b>Phase comparator section</b>										
V <sub>IH</sub>	HIGH-level input voltage	SIG_IN, COMP_IN; DC coupled								
		V <sub>CC</sub> = 2.0 V	1.5	1.2	-	1.5	-	1.5	-	V
		V <sub>CC</sub> = 4.5 V	3.15	2.4	-	3.15	-	3.15	-	V
		V <sub>CC</sub> = 6.0 V	4.2	3.2	-	4.2	-	4.2	-	V
V <sub>IL</sub>	LOW-level input voltage	SIG_IN, COMP_IN; DC coupled								
		V <sub>CC</sub> = 2.0 V	-	0.8	0.5	-	0.5	-	0.5	V
		V <sub>CC</sub> = 4.5 V	-	2.1	1.35	-	1.35	-	1.35	V
		V <sub>CC</sub> = 6.0 V	-	2.8	1.8	-	1.8	-	1.8	V
V <sub>OH</sub>	HIGH-level output voltage	PCP_OUT, PCn_OUT; V <sub>I</sub> = V <sub>IH</sub> or V <sub>IL</sub>								
		I <sub>O</sub> = -20 µA; V <sub>CC</sub> = 2.0 V	1.9	2.0	-	1.9	-	1.9	-	V
		I <sub>O</sub> = -20 µA; V <sub>CC</sub> = 4.5 V	4.4	4.5	-	4.4	-	4.4	-	V
		I <sub>O</sub> = -20 µA; V <sub>CC</sub> = 6.0 V	5.9	6.0	-	5.9	-	5.9	-	V
		I <sub>O</sub> = -4 mA; V <sub>CC</sub> = 4.5 V	3.98	4.32	-	3.84	-	3.7	-	V
		I <sub>O</sub> = -5.2 mA; V <sub>CC</sub> = 6.0 V	5.48	5.81	-	5.34	-	5.2	-	V
V <sub>OL</sub>	LOW-level output voltage	PCP_OUT, PCn_OUT; V <sub>I</sub> = V <sub>IH</sub> or V <sub>IL</sub>								
		I <sub>O</sub> = 20 µA; V <sub>CC</sub> = 2.0 V	-	0	0.1	-	0.1	-	0.1	V
		I <sub>O</sub> = 20 µA; V <sub>CC</sub> = 4.5 V	-	0	0.1	-	0.1	-	0.1	V
		I <sub>O</sub> = 20 µA; V <sub>CC</sub> = 6.0 V	-	0	0.1	-	0.1	-	0.1	V
		I <sub>O</sub> = 4 mA; V <sub>CC</sub> = 4.5 V	-	0.15	0.26	-	0.33	-	0.4	V
		I <sub>O</sub> = 5.2 mA; V <sub>CC</sub> = 6.0 V	-	0.16	0.26	-	0.33	-	0.4	V
I <sub>I</sub>	input leakage current	SIG_IN, COMP_IN; V <sub>I</sub> = V <sub>CC</sub> or GND								
		V <sub>CC</sub> = 2.0 V	-	-	±3	-	±4	-	±5	µA
		V <sub>CC</sub> = 3.0 V	-	-	±7	-	±9	-	±11	µA
		V <sub>CC</sub> = 4.5 V	-	-	±18	-	±23	-	±27	µA
		V <sub>CC</sub> = 6.0 V	-	-	±30	-	±38	-	±45	µA
I <sub>OZ</sub>	OFF-state output current	PC2_OUT; V <sub>I</sub> = V <sub>IH</sub> or V <sub>IL</sub> ; V <sub>O</sub> = V <sub>CC</sub> or GND								
		V <sub>CC</sub> = 6.0 V	-	-	±0.5	-	±5	-	±10	µA
R <sub>I</sub>	input resistance	SIG_IN, COMP_IN; V <sub>I</sub> at self-bias operating point; $\Delta V_I = 0.5$ V; see Fig. 12, Fig. 13 and Fig. 14								
		V <sub>CC</sub> = 3.0 V	-	800	-	-	-	-	-	kΩ
		V <sub>CC</sub> = 4.5 V	-	250	-	-	-	-	-	kΩ
		V <sub>CC</sub> = 6.0 V	-	150	-	-	-	-	-	kΩ

Symbol	Parameter	Conditions	25 °C			-40 °C to +85 °C		-40 °C to +125 °C		Unit
			Min	Typ	Max	Min	Max	Min	Max	
<b>VCO section</b>										
V <sub>IH</sub>	HIGH-level input voltage	INH								
		V <sub>CC</sub> = 3.0 V	2.1	1.7	-	2.1	-	2.1	-	V
		V <sub>CC</sub> = 4.5 V	3.15	2.4	-	3.15	-	3.15	-	V
		V <sub>CC</sub> = 6.0 V	4.2	3.2	-	4.2	-	4.2	-	V
V <sub>IL</sub>	LOW-level input voltage	INH								
		V <sub>CC</sub> = 3.0 V	-	1.3	0.9	-	0.9	-	0.9	V
		V <sub>CC</sub> = 4.5 V	-	2.1	1.35	-	1.35	-	1.35	V
		V <sub>CC</sub> = 6.0 V	-	2.8	1.8	-	1.8	-	1.8	V
V <sub>OH</sub>	HIGH-level output voltage	VCO_OUT; V <sub>I</sub> = V <sub>IH</sub> or V <sub>IL</sub>								
		I <sub>O</sub> = -20 μA; V <sub>CC</sub> = 3.0 V	2.9	3.0	-	2.9	-	2.9	-	V
		I <sub>O</sub> = -20 μA; V <sub>CC</sub> = 4.5 V	4.4	4.5	-	4.4	-	4.4	-	V
		I <sub>O</sub> = -20 μA; V <sub>CC</sub> = 6.0 V	5.9	6.0	-	5.9	-	5.9	-	V
		I <sub>O</sub> = -4 mA; V <sub>CC</sub> = 4.5 V	3.98	4.32	-	3.84	-	3.7	-	V
		I <sub>O</sub> = -5.2 mA; V <sub>CC</sub> = 6.0 V	5.48	5.81	-	5.34	-	5.2	-	V
V <sub>OL</sub>	LOW-level output voltage	VCO_OUT; V <sub>I</sub> = V <sub>IH</sub> or V <sub>IL</sub>								
		I <sub>O</sub> = 20 μA; V <sub>CC</sub> = 3.0 V	-	0	0.1	-	0.1	-	0.1	V
		I <sub>O</sub> = 20 μA; V <sub>CC</sub> = 4.5 V	-	0	0.1	-	0.1	-	0.1	V
		I <sub>O</sub> = 20 μA; V <sub>CC</sub> = 6.0 V	-	0	0.1	-	0.1	-	0.1	V
		I <sub>O</sub> = 4 mA; V <sub>CC</sub> = 4.5 V	-	0.15	0.26	-	0.33	-	0.4	V
		I <sub>O</sub> = 5.2 mA; V <sub>CC</sub> = 6.0 V	-	0.16	0.26	-	0.33	-	0.4	V
		C1A, C1B; V <sub>I</sub> = V <sub>IH</sub> or V <sub>IL</sub>								
		I <sub>O</sub> = 4 mA; V <sub>CC</sub> = 4.5 V	-	-	0.40	-	0.47	-	0.54	V
		I <sub>O</sub> = 5.2 mA; V <sub>CC</sub> = 6.0 V	-	-	0.40	-	0.47	-	0.54	V
I <sub>I</sub>	input leakage current	INH, VCO_IN; V <sub>I</sub> = V <sub>CC</sub> or GND								
		V <sub>CC</sub> = 6.0 V	-	-	±0.1	-	±1	-	±1	μA
R1	resistor 1	V <sub>CC</sub> = 3.0 V to 6.0 V	[1]	3	-	300	-	-	-	kΩ
R2	resistor 2	V <sub>CC</sub> = 3.0 V to 6.0 V	[1]	3	-	300	-	-	-	kΩ
C1	capacitor 1	V <sub>CC</sub> = 3.0 V to 6.0 V		40	-	no limit	-	-	-	pF
V <sub>VCO_IN</sub>	input voltage on pin VCO_IN	VCO_IN; over the range specified for R1; for linearity see <a href="#">Fig. 22</a> and <a href="#">Fig. 23</a>								
		V <sub>CC</sub> = 3.0 V	1.1	-	1.9	-	-	-	-	V
		V <sub>CC</sub> = 4.5 V	1.1	-	3.4	-	-	-	-	V
		V <sub>CC</sub> = 6.0 V	1.1	-	4.9	-	-	-	-	V

Symbol	Parameter	Conditions	25 °C			-40 °C to +85 °C		-40 °C to +125 °C		Unit
			Min	Typ	Max	Min	Max	Min	Max	
<b>Demodulator section</b>										
$R_s$	series resistance	at $R_s > 300 \text{ k}\Omega$ , the leakage current can influence $V_{DEM\_OUT}$								
		$V_{CC} = 3.0 \text{ V to } 6.0 \text{ V}$	50	-	300	-	-	-	-	$\text{k}\Omega$
$V_{offset}$	offset voltage	$V_{CO\_IN}$ to $DEM\_OUT$ ; $V_1 = V_{VCO\_IN} = 0.5V_{CC}$ ; values taken over $R_s$ range; see <a href="#">Fig. 15</a>								
		$V_{CC} = 3.0 \text{ V}$	-	$\pm 30$	-	-	-	-	-	$\text{mV}$
		$V_{CC} = 4.5 \text{ V}$	-	$\pm 20$	-	-	-	-	-	$\text{mV}$
		$V_{CC} = 6.0 \text{ V}$	-	$\pm 10$	-	-	-	-	-	$\text{mV}$
$R_{dyn}$	dynamic resistance	$DEM\_OUT$ ; $V_{DEM\_OUT} = 0.5V_{CC}$								
		$V_{CC} = 3.0 \text{ V to } 6.0 \text{ V}$	-	25	-	-	-	-	-	$\Omega$
<b>General</b>										
$I_{CC}$	supply current	VCO disabled; $COMP\_IN$ , $INH$ and $SIG\_IN$ at $V_{CC}$ ; $VCO\_IN$ at $GND$ ; $I_i$ at pins $COMP\_IN$ and $SIG\_IN$ to be excluded								
		$V_{CC} = 6.0 \text{ V}$	-	-	8	-	80	-	160	$\mu\text{A}$
$C_I$	input capacitance	INH	-	3.5	-	-	-	-	-	$\text{pF}$

[1] The parallel value of  $R1$  and  $R2$  should be more than  $2.7 \text{ k}\Omega$ . Optimum performance is achieved when  $R1$  and/or  $R2$  are/is  $> 10 \text{ k}\Omega$ .

## 11.1. Graphs

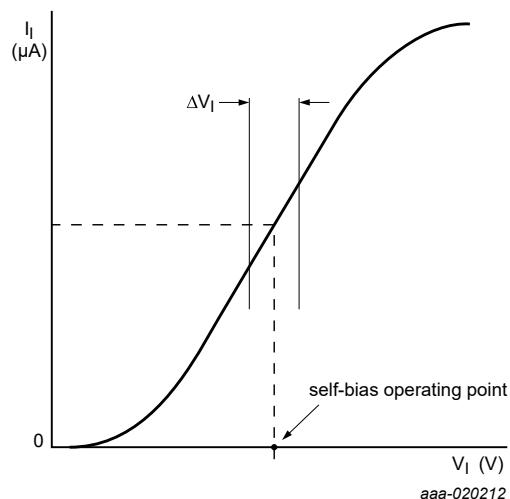


Fig. 12. Typical input resistance curve at SIG\_IN and COMP\_IN

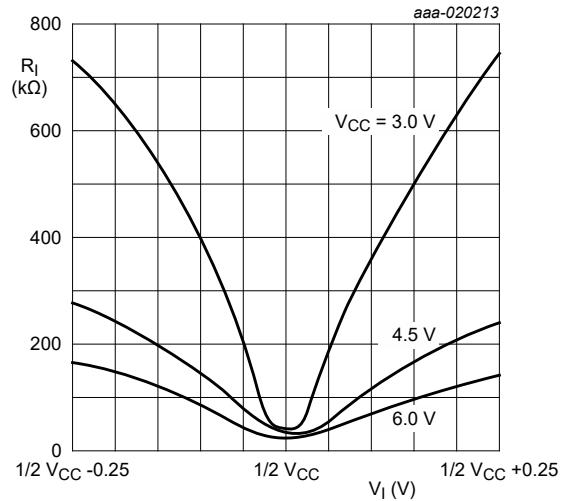


Fig. 13. Input resistance at SIG\_IN, COMP\_IN with  $\Delta V_I = 0.5$  V at self-bias point

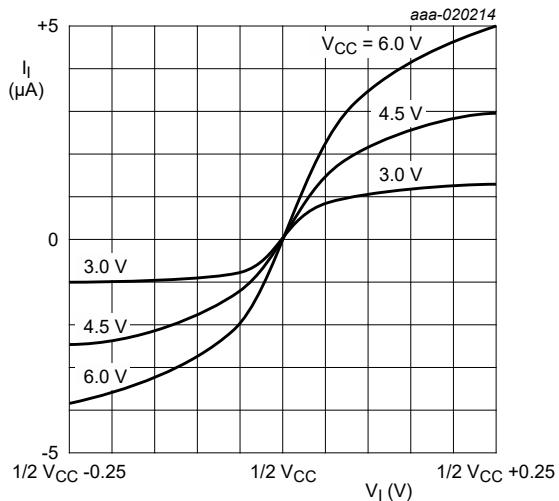


Fig. 14. Input current at SIG\_IN, COMP\_IN with  $\Delta V_I = 0.5$  V at self-bias point

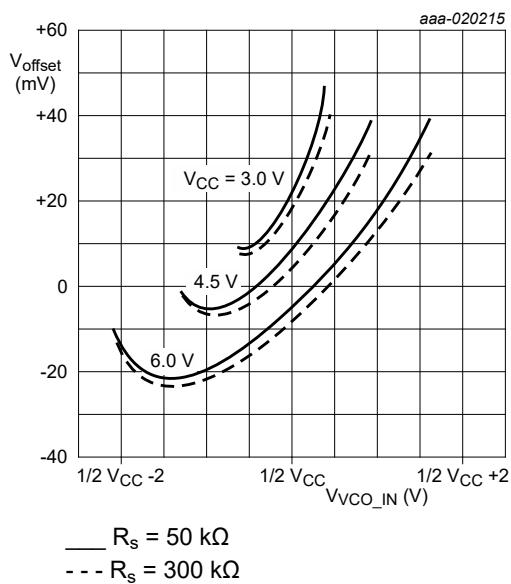


Fig. 15. Offset voltage at demodulator output as a function of  $V_{VCO\_IN}$  and  $R_s$

## 12. Dynamic characteristics

**Table 6. Dynamic characteristics**

$GND = 0 \text{ V}$ ;  $t_r = t_f = 6 \text{ ns}$ ;  $C_L = 50 \text{ pF}$ .

Symbol	Parameter	Conditions	25 °C			-40 °C to +85 °C			-40 °C to +125 °C		Unit
			Min	Typ	Max	Min	Typ	Max	Min	Max	
<b>Phase comparator section</b>											
$t_{pd}$	propagation delay	SIG_IN, COMP_IN to PC1_OUT; see Fig. 16	[1]								
		$V_{CC} = 2.0 \text{ V}$	-	63	200	-	-	250	-	300	ns
		$V_{CC} = 4.5 \text{ V}$	-	23	40	-	-	50	-	60	ns
		$V_{CC} = 6.0 \text{ V}$	-	18	34	-	-	43	-	51	ns
		SIG_IN, COMP_IN to PCP_OUT; see Fig. 16	[1]								
		$V_{CC} = 2.0 \text{ V}$	-	96	340	-	-	425	-	510	ns
		$V_{CC} = 4.5 \text{ V}$	-	35	68	-	-	85	-	102	ns
		$V_{CC} = 6.0 \text{ V}$	-	28	58	-	-	72	-	87	ns
		SIG_IN, COMP_IN to PC3_OUT; see Fig. 16	[1]								
		$V_{CC} = 2.0 \text{ V}$	-	77	270	-	-	340	-	405	ns
		$V_{CC} = 4.5 \text{ V}$	-	28	54	-	-	68	-	81	ns
		$V_{CC} = 6.0 \text{ V}$	-	22	46	-	-	58	-	69	ns
$t_{en}$	enable time	SIG_IN, COMP_IN to PC2_OUT; see Fig. 17	[1]								
		$V_{CC} = 2.0 \text{ V}$	-	83	280	-	-	350	-	420	ns
		$V_{CC} = 4.5 \text{ V}$	-	30	56	-	-	70	-	84	ns
		$V_{CC} = 6.0 \text{ V}$	-	24	48	-	-	60	-	71	ns
$t_{dis}$	disable time	SIG_IN, COMP_IN to PC2_OUT; see Fig. 17	[1]								
		$V_{CC} = 2.0 \text{ V}$	-	99	325	-	-	405	-	490	ns
		$V_{CC} = 4.5 \text{ V}$	-	36	65	-	-	81	-	98	ns
		$V_{CC} = 6.0 \text{ V}$	-	29	55	-	-	69	-	83	ns
$t_t$	transition time	PC1_OUT, PC3_OUT, PCP_OUT; see Fig. 16	[1]								
		$V_{CC} = 2.0 \text{ V}$	-	19	75	-	-	95	-	110	ns
		$V_{CC} = 4.5 \text{ V}$	-	7	15	-	-	19	-	22	ns
		$V_{CC} = 6.0 \text{ V}$	-	6	13	-	-	16	-	19	ns
$V_{i(p-p)}$	peak-to-peak input voltage	SIGN_IN, COMP_IN; AC coupled; $f_i = 1 \text{ MHz}$									
		$V_{CC} = 2.0 \text{ V}$	-	9	-	-	-	-	-	-	mV
		$V_{CC} = 3.0 \text{ V}$	-	11	-	-	-	-	-	-	mV
		$V_{CC} = 4.5 \text{ V}$	-	15	-	-	-	-	-	-	mV
		$V_{CC} = 6.0 \text{ V}$	-	33	-	-	-	-	-	-	mV

Symbol	Parameter	Conditions	25 °C			-40 °C to +85 °C			-40 °C to +125 °C			Unit
			Min	Typ	Max	Min	Typ	Max	Min	Max		
<b>VCO section</b>												
f <sub>0</sub>	center frequency	V <sub>VCO_IN</sub> = 0.5V <sub>CC</sub> ; duty cycle = 50 %; R <sub>1</sub> = 3 kΩ; R <sub>2</sub> = ∞ Ω; C <sub>1</sub> = 40 pF; see <a href="#">Fig. 20</a> and <a href="#">Fig. 21</a>										
		V <sub>CC</sub> = 3.0 V	7.0	10.0	-	-	-	-	-	-	MHz	
		V <sub>CC</sub> = 4.5 V	11.0	17.0	-	-	-	-	-	-	MHz	
		V <sub>CC</sub> = 5.0 V	-	19.0	-	-	-	-	-	-	MHz	
		V <sub>CC</sub> = 6.0 V	13.0	21.0	-	-	-	-	-	-	MHz	
Δf/f	relative frequency variation	R <sub>1</sub> = 100 kΩ; R <sub>2</sub> = ∞ Ω; C <sub>1</sub> = 100 pF; see <a href="#">Fig. 22</a> and <a href="#">Fig. 23</a>										
		V <sub>CC</sub> = 3.0 V	-	1.0	-	-	-	-	-	-	%	
		V <sub>CC</sub> = 4.5 V	-	0.4	-	-	-	-	-	-	%	
		V <sub>CC</sub> = 6.0 V	-	0.3	-	-	-	-	-	-	%	
Δf/ΔT	frequency variation with temperature	V <sub>VCO_IN</sub> = 0.5V <sub>CC</sub> ; R <sub>1</sub> = 100 kΩ; R <sub>2</sub> = ∞ Ω; C <sub>1</sub> = 100 pF; see <a href="#">Fig. 18</a> and <a href="#">Fig. 19</a>										
		V <sub>CC</sub> = 3.0 V	-	-	-	-	0.20	-	-	-	%/K	
		V <sub>CC</sub> = 4.5 V	-	-	-	-	0.15	-	-	-	%/K	
		V <sub>CC</sub> = 6.0 V	-	-	-	-	0.14	-	-	-	%/K	
δ	duty cycle	VCO_OUT; V <sub>CC</sub> = 3.0 V to 6.0 V	-	50	-	-	-	-	-	-	%	
<b>General</b>												
C <sub>PD</sub>	power dissipation capacitance		[2][3]	-	24	-	-	-	-	-	pF	

[1] t<sub>pd</sub> is the same as t<sub>PLH</sub> and t<sub>PHL</sub>. t<sub>dis</sub> is the same as t<sub>PZL</sub> and t<sub>PZH</sub>. t<sub>en</sub> is the same as t<sub>PZL</sub> and t<sub>PZH</sub>. t<sub>t</sub> is the same as t<sub>TLH</sub> and t<sub>THL</sub>.

[2] Applies to the phase comparator section only (VCO disabled). For power dissipation of the VCO and demodulator sections, see [Fig. 24](#), [Fig. 25](#) and [Fig. 26](#)

[3] C<sub>PD</sub> is used to determine the dynamic power dissipation (P<sub>D</sub> in μW).

$$P_D = C_{PD} \times V_{CC}^2 \times f_i \times N + \sum(C_L \times V_{CC}^2 \times f_o)$$

f<sub>i</sub> = input frequency in MHz;

f<sub>o</sub> = output frequency in MHz;

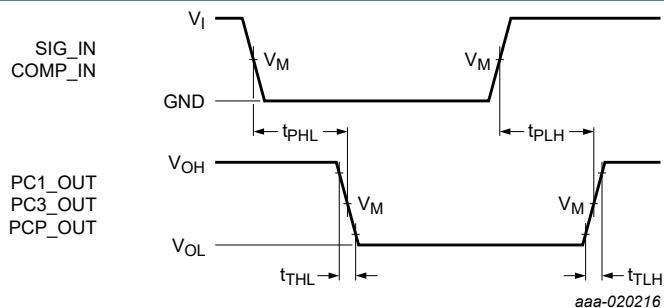
C<sub>L</sub> = output load capacitance in pF;

V<sub>CC</sub> = supply voltage in V;

N = total load switching outputs;

$\sum(C_L \times V_{CC}^2 \times f_o)$  = sum of outputs.

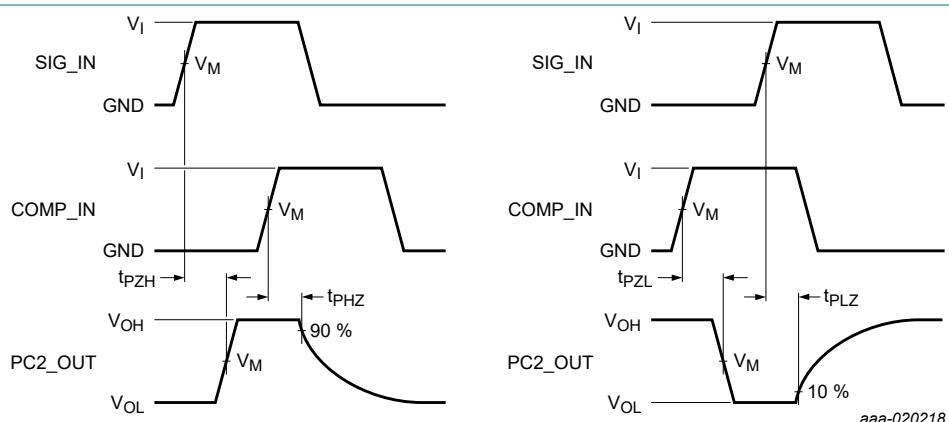
## 12.1. Waveforms and graphs



$V_M = 0.5V_{CC}$ ;  $V_I = \text{GND to } V_{CC}$ .

$V_{OL}$  and  $V_{OH}$  are typical voltage output levels that occur with the output load.

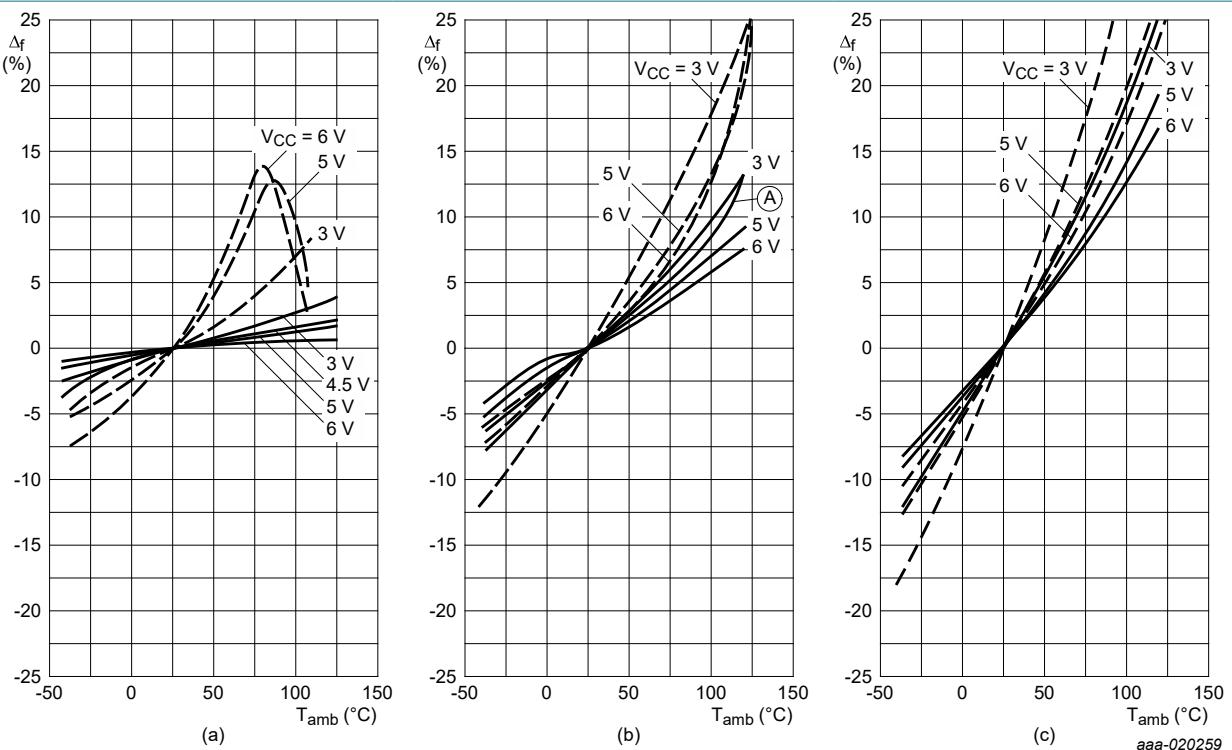
**Fig. 16. Waveforms showing input (SIG\_IN, COMP\_IN) to output (PC1\_OUT, PC3\_OUT, PCP\_OUT) propagation delays and the output transition times**



$V_M = 0.5V_{CC}$ ;  $V_I = \text{GND to } V_{CC}$ .

$V_{OL}$  and  $V_{OH}$  are typical voltage output levels that occur with the output load.

**Fig. 17. Waveforms showing the enable and disable times for PC2\_OUT**



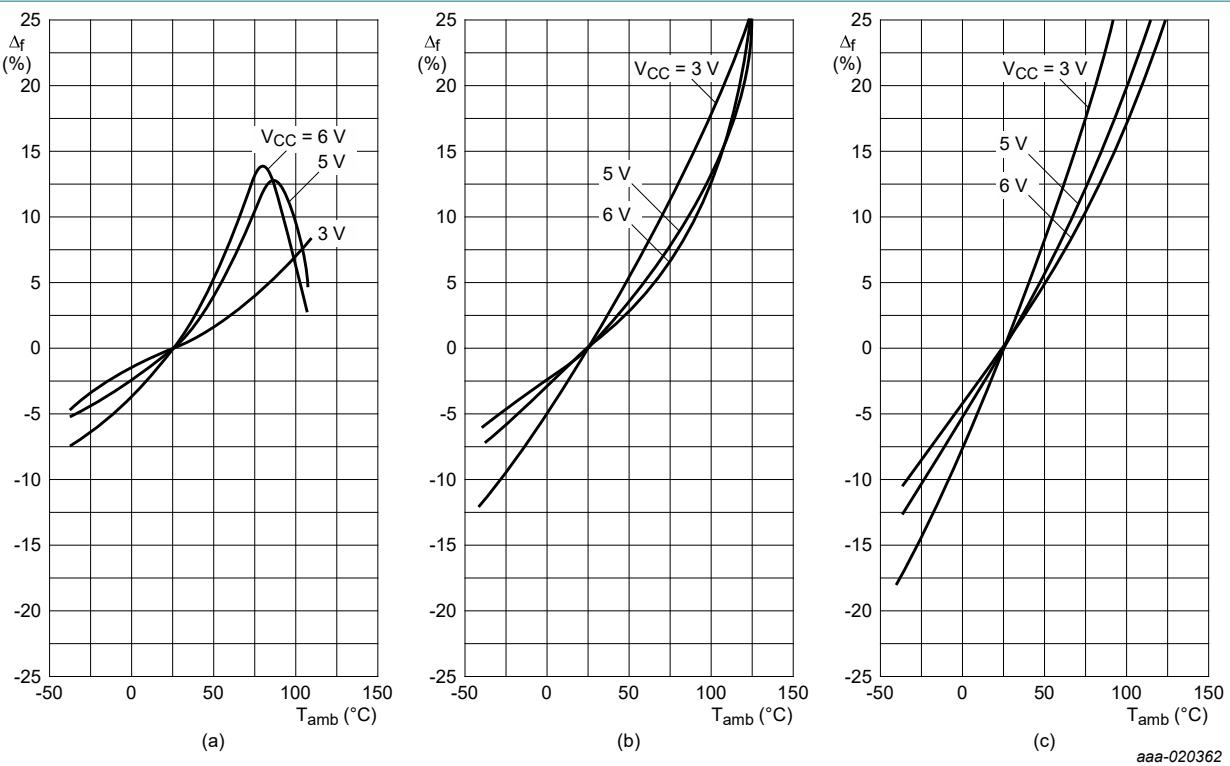
To obtain optimum temperature stability, C1 must be as small as possible but larger than 100 pF.

In (b), the frequency stability for  $R1 = R2 = 10 k\Omega$  at 5 V is also given (curve A). The total VCO bias current sets this curve, and is not simply the addition of the two  $10 k\Omega$  stability curves.  $C1 = 100 \text{ pF}$ ;  $V_{VCO\_IN} = 0.5V_{CC}$ ; This curve is set as follows:

— Without offset  $R2 = \infty \Omega$ : (a)  $R1 = 3 k\Omega$ ; (b)  $R1 = 10 k\Omega$ ; (c)  $R1 = 300 k\Omega$ .

- - - With offset  $R1 = \infty \Omega$ : (a)  $R2 = 3 k\Omega$ ; (b)  $R2 = 10 k\Omega$ ; (c)  $R2 = 300 k\Omega$ .

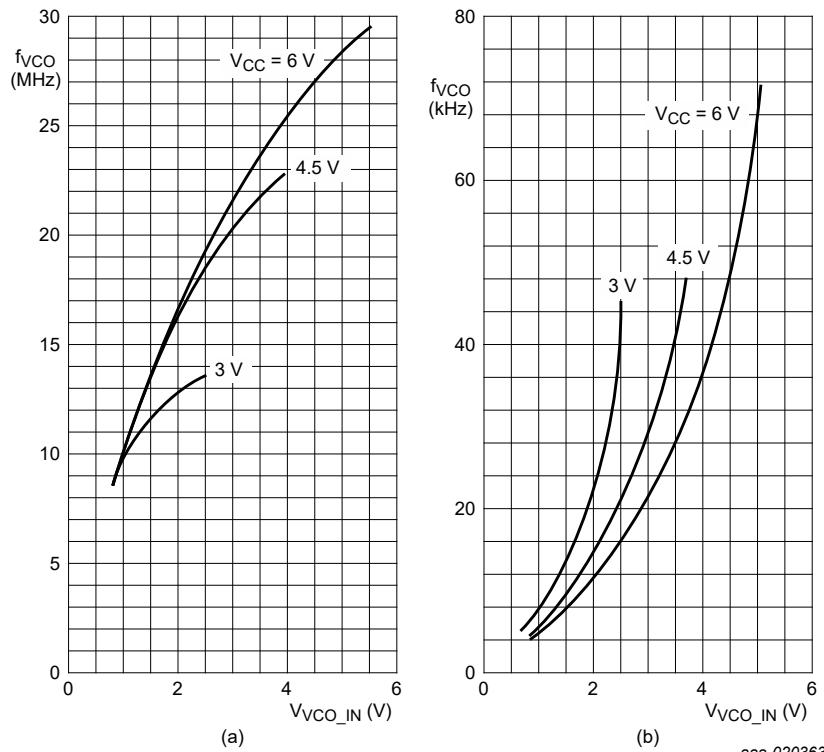
**Fig. 18. Frequency stability of the VCO as a function of ambient temperature**



To obtain optimum temperature stability,  $C_1$  must be as small as possible but larger than 100 pF.

— With offset;  $R_1 = \infty \Omega$ : (a)  $R_2 = 3\text{ k}\Omega$ ; (b)  $R_2 = 10\text{ k}\Omega$ ; (c)  $R_2 = 300\text{ k}\Omega$ .

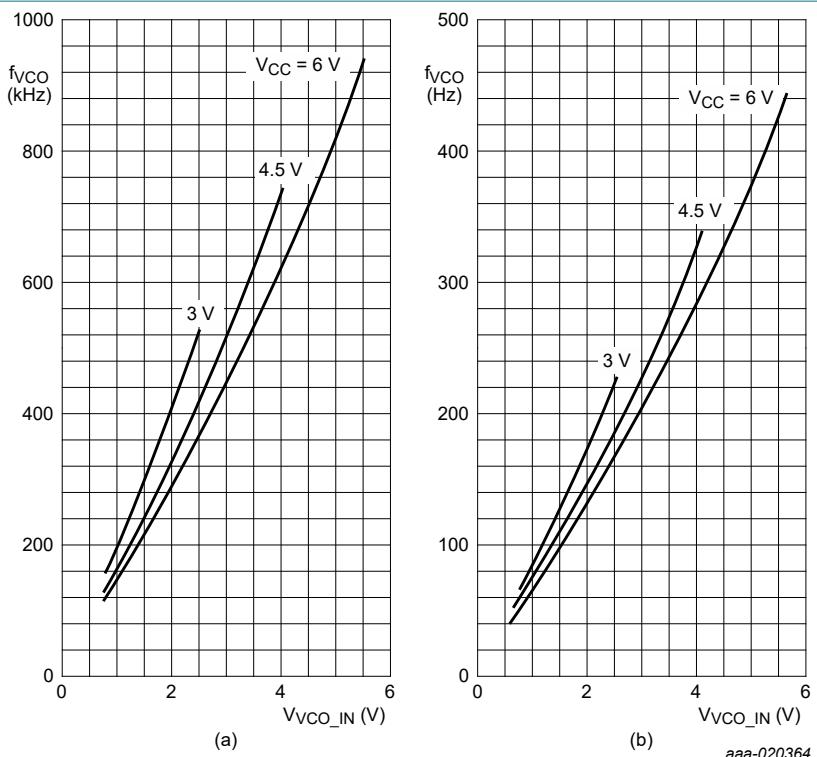
**Fig. 19. Frequency stability of the VCO as a function of ambient temperature**



To obtain optimum temperature stability,  $C_1$  must be as small as possible but larger than 100 pF.

(a)  $R_1 = 3\text{ k}\Omega$ ;  $C_1 = 40\text{ pF}$  (b)  $R_1 = 3\text{ k}\Omega$ ;  $C_1 = 100\text{ nF}$

**Fig. 20. Graphs showing VCO frequency as a function of the VCO input voltage**



To obtain optimum temperature stability,  $C1$  must be as small as possible but larger than 100 pF.

(a)  $R1 = 300$  k $\Omega$ ;  $C1 = 40$  pF (b)  $R1 = 300$  k $\Omega$ ;  $C1 = 100$  nF

Fig. 21. Graphs showing VCO frequency as a function of the VCO input voltage

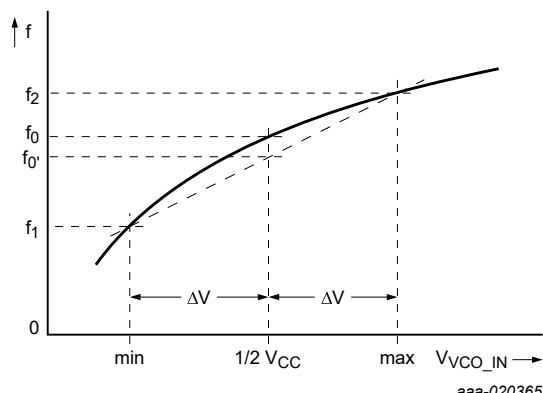


Fig. 22. Definition of VCO frequency linearity

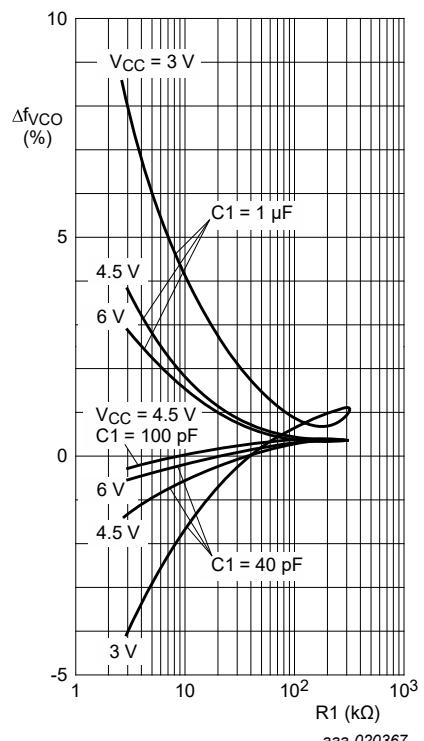
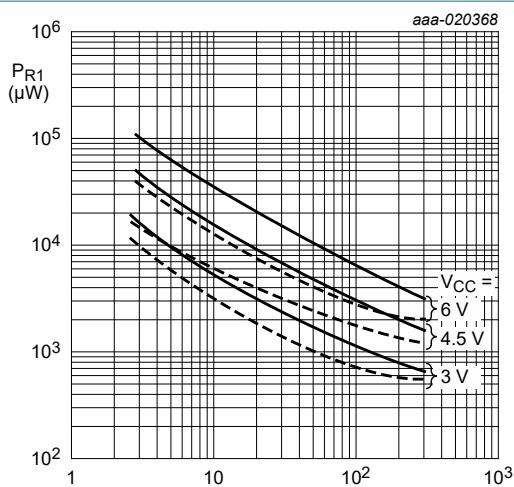
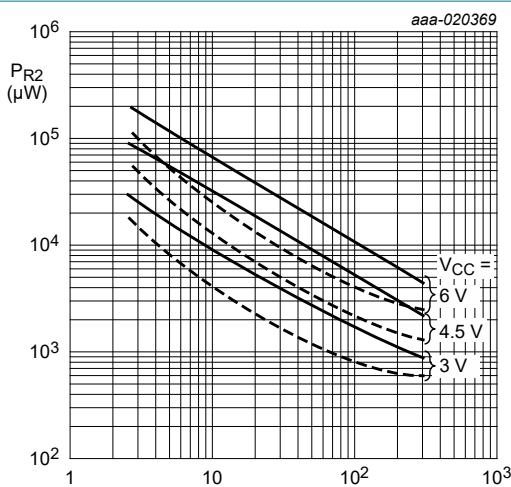


Fig. 23. Frequency linearity as a function of  $R1$ ,  $C1$



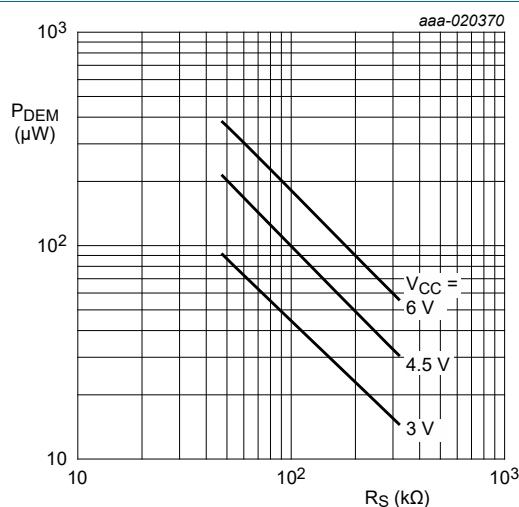
$R2 = \infty \Omega$ ;  $C_L = 50 \text{ pF}$ ;  $V_{VCO\_IN} = 0.5V_{CC}$ ;  
 $T_{amb} = 25^\circ\text{C}$   
 —  $C1 = 40 \text{ pF}$ ; - - -  $C1 = 1 \mu\text{F}$

Fig. 24. Power dissipation as a function of R1



$R1 = \infty \Omega$ ;  $C_L = 50 \text{ pF}$ ;  $V_{VCO\_IN} = \text{GND}$ ;  
 $T_{amb} = 25^\circ\text{C}$   
 —  $C1 = 40 \text{ pF}$ ; - - -  $C1 = 1 \mu\text{F}$

Fig. 25. Power dissipation as a function of R2



$R1 = R2 = \infty \Omega$ ;  $V_{VCO\_IN} = 0.5V_{CC}$ ;  $T_{amb} = 25^\circ\text{C}$

Fig. 26. Typical power dissipation of demodulator sections as a function of  $R_s$ 

## 13. Application information

This information is a guide for the approximation of values of external components to be used with the 74HC4046A-Q100 in a phase-locked-loop system.

References should be made to [Fig. 30](#), [Fig. 31](#) and [Fig. 32](#) as indicated in [Table 8](#).

Values of the selected components should be within the ranges shown in [Table 7](#).

Table 7. Survey of components

Component	Value
R1	between 3 kΩ and 300 kΩ
R2	between 3 kΩ and 300 kΩ
R1 + R2	parallel value > 2.7 kΩ
C1	> 40 pF

Table 8. Design considerations for VCO section

Subject	Phase comparator	Design consideration
VCO frequency without extra offset	PC1, PC2 or PC3	VCO frequency characteristic. With $R2 = \infty \Omega$ and $R1$ within the range $3 \text{ k}\Omega < R1 < 300 \text{ k}\Omega$ , the characteristics of the VCO operation is as shown in <a href="#">Fig. 27a</a> . (Due to $R1$ , $C1$ time constant a small offset remains when $R2 = \infty \Omega$ ).
	PC1	Selection of $R1$ and $C1$ . Given $f_0$ , determine the values of $R1$ and $C1$ using <a href="#">Fig. 30</a> .
	PC2 or PC3	Given $f_{\max}$ and $f_0$ , determine the values of $R1$ and $C1$ using <a href="#">Fig. 30</a> ; use <a href="#">Fig. 32</a> to obtain $2f_L$ and then use it to calculate $f_{\min}$ .
VCO frequency with extra offset	PC1, PC2 or PC3	VCO frequency characteristic. With $R1$ and $R2$ within the ranges $3 \text{ k}\Omega < R1 < 300 \text{ k}\Omega$ and $3 \text{ k}\Omega < R2 < 300 \text{ k}\Omega$ . The characteristics of the VCO operation are as shown in <a href="#">Fig. 27b</a> .
	PC1, PC2 or PC3	Selection of $R1$ , $R2$ and $C1$ . Given $f_0$ and $f_L$ determine the value of product $R1C1$ by using <a href="#">Fig. 32</a> . Calculate $f_{\text{off}}$ from the equation $f_{\text{off}} = f_0 - 1.6f_L$ . Obtain the values of $C1$ and $R2$ by using <a href="#">Fig. 31</a> . Calculate the value of $R1$ from the value of $C1$ and the product $R1C1$ .
PLL conditions no signal at pin SIG_IN	PC1	VCO adjusts to $f_0$ with $\Phi_{\text{DEM\_OUT}} = 90^\circ$ and $V_{\text{VCO\_IN}} = 0.5V_{\text{CC}}$ , see <a href="#">Fig. 6</a>
	PC2	VCO adjusts to $f_0$ with $\Phi_{\text{DEM\_OUT}} = -360^\circ$ and $V_{\text{VCO\_IN}} = \text{minimum}$ , see <a href="#">Fig. 8</a>
	PC3	VCO adjusts to $f_0$ with $\Phi_{\text{DEM\_OUT}} = -360^\circ$ and $V_{\text{VCO\_IN}} = \text{minimum}$ , see <a href="#">Fig. 10</a>

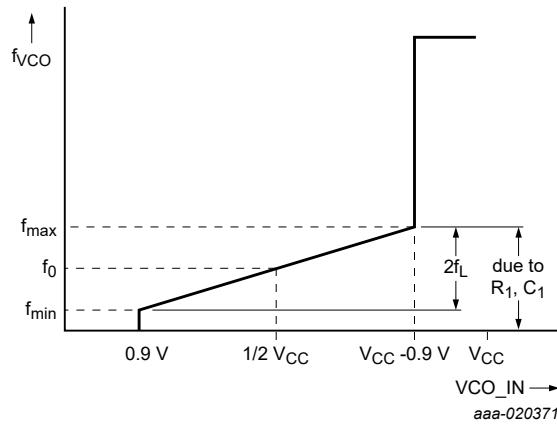
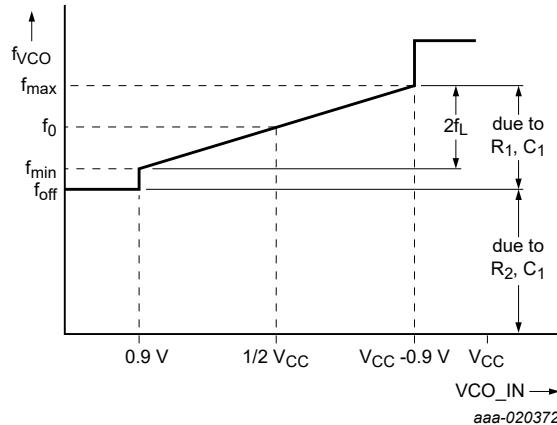
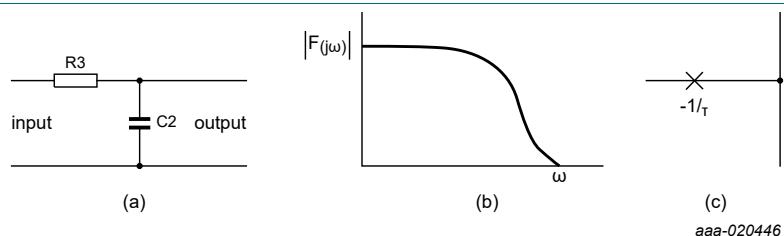
a. Operating without offset;  $f_0$  = center frequency;  $2f_L$  = frequency lock range.b. Operating with offset;  $f_0$  = center frequency;  $2f_L$  = frequency lock range.

Fig. 27. Frequency characteristic of VCO

**Table 9. General design considerations**

Subject	Phase comparator	Design consideration
PLL frequency capture range	PC1, PC2 or PC3	Loop filter component selection, see <a href="#">Fig. 28</a> and <a href="#">Fig. 29</a>
PLL locks on harmonics at center frequency	PC1 or PC3	yes
	PC2	no
Noise rejection at signal input	PC1	high
	PC2 or PC3	low
AC ripple content when PLL is locked	PC1	$f_r = 2f_i$ ; large ripple content at $\Phi_{DEM\_OUT} = 90^\circ$
	PC2	$f_r = f_i$ ; small ripple content at $\Phi_{DEM\_OUT} = 0^\circ$
	PC3	$f_r = f_i$ ; large ripple content at $\Phi_{DEM\_OUT} = 180^\circ$

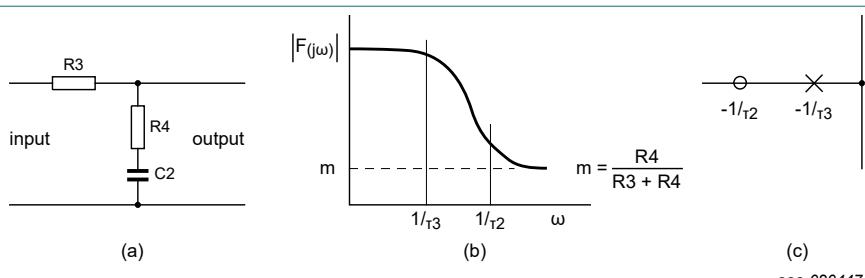


$$R_3 \geq 500 \Omega.$$

A small capture range ( $2f_c$ ) is obtained if  $2f_c \approx \frac{1}{\pi} \sqrt{2\pi f_L / \tau}$

- (a)  $\tau_1 = R3 \times C2$
- (b) amplitude characteristics
- (c) pole-zero diagram

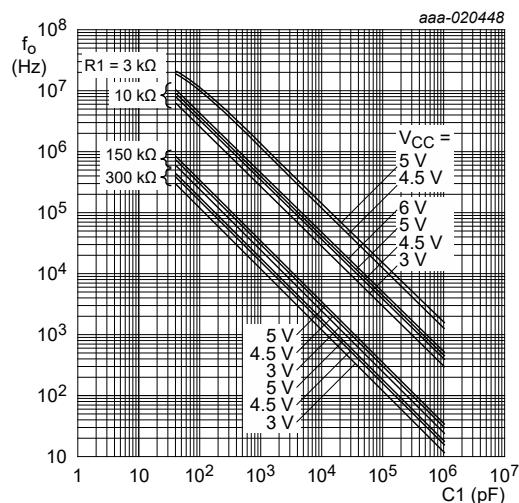
**Fig. 28. Simple loop filter for PLL without offset**



$$R_3 + R_4 \geq 500 \Omega.$$

(a)  $\tau_1 = R3 \times C2$ ;  $\tau_2 = R4 \times C2$ ;  $\tau_3 = (R3 + R4) \times C2$ ;  
 (b) amplitude characteristics  
 (c) pole-zero diagram

Fig. 29. Simple loop filter for PLL with offset

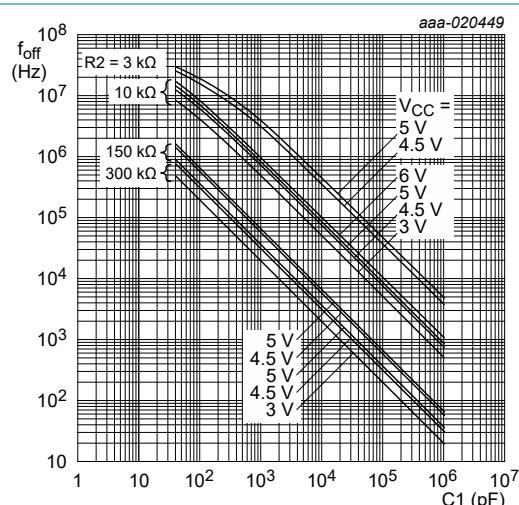


To obtain optimum VCO performance, C1 must be as small as possible but larger than 100 pF.

Interpolation for various values of R1 can be easily calculated because a constant R1C1 product produces almost the same VCO output frequency.

R2 =  $\infty$  Ω; V<sub>VCO\_IN</sub> = 0.5V<sub>CC</sub>; INH = GND; T<sub>amb</sub> = 25 °C.

**Fig. 30. Typical value of VCO center frequency (f₀) as a function of C1**

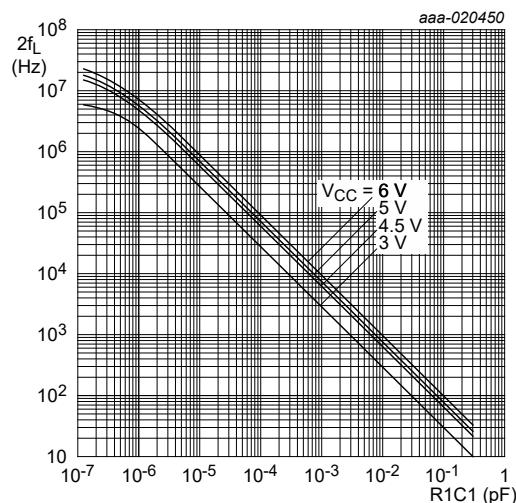


To obtain optimum VCO performance, C1 must be as small as possible but larger than 100 pF.

Interpolation for various values of R2 can be easily calculated because a constant R2C1 product produces almost the same VCO output frequency.

R1 =  $\infty$  Ω; V<sub>VCO\_IN</sub> = 0.5V<sub>CC</sub>; INH = GND; T<sub>amb</sub> = 25 °C.

**Fig. 31. Typical value of frequency offset as a function of C1**



$V_{VCO\_IN} = 0.9\text{ V}$  to  $(V_{CC} - 0.9)\text{ V}$ ;  $R2 = \infty\text{ }\Omega$ .

VCO gain:  $K_V = \frac{2f_L}{V_{VCO\_IN} \text{ range}} 2\pi$  (rad/s/V)

Fig. 32. Typical frequency lock range ( $2f_L$ ) as a function of the product  $R1C1$

### 13.1. PLL design example

The frequency synthesizer used in the design example shown in [Fig. 33](#) has the following parameters:

- Output frequency: 2 MHz to 3 MHz
- Frequency steps: 100 kHz
- Settling time: 1 ms
- Overshoot: < 20 %

The open loop gain is:

$$H(s) \times G(s) = K_p(s) \times K_f(s) \times K_o(s) \times K_n$$

where:

- $K_p(s)$  = phase comparator gain
- $K_f(s)$  = low-pass filter transfer gain
- $K_o(s) = K_v/s$  VCO gain
- $K_n = 1/n$  divider ratio

The programmable counter ratio  $K_n$  can be found as follows:

$$N_{\min} = \frac{f_{\text{OUT}}}{f_{\text{step}}} = \frac{2 \text{ MHz}}{100 \text{ kHz}} = 20$$

$$N_{\max} = \frac{f_{\text{OUT}}}{f_{\text{step}}} = \frac{3 \text{ MHz}}{100 \text{ kHz}} = 30$$

The values of R1, R2 and C1; R2 = 10 kΩ (adjustable) set the VCO.

The values can be determined using the information in [Table 8](#) and [Table 9](#).

With  $f_0 = 2.5$  MHz and  $f_L = 500$  kHz, the following values ( $V_{CC} = 5.0$  V) are given:

- R1 = 10 kΩ
- R2 = 10 kΩ
- C1 = 500 pF

The VCO gain is:

$$K_v = \frac{2f_L \times 2\pi}{0.9 - (V_{CC} - 0.9)} = \frac{1 \text{ MHz}}{3.2} \times 2\pi \approx 2 \times 10^6 \text{ rad/s/V}$$

The gain of the phase comparator is:

$$K_p = \frac{V_{CC}}{4\pi} = 0.4 \text{ V/rad}$$

The transfer gain of the filter is calculated as follows:

$$K_f(s) = \frac{1 + \tau_2(s)}{1 + (\tau_1 + \tau_2)(s)}$$

Where:

$$\tau_1 = R3 \times C2$$

$$\tau_2 = R4 \times C2$$

The characteristic equation is:  $1 + H(s) \times G(s) = 0$

It results in:

$$S^2 + \frac{1 + K_p \times K_v \times K_n \times \tau_2}{(\tau_1 + \tau_2)} \times S + \frac{K_p \times K_v \times K_n}{(\tau_1 + \tau_2)} = 0$$

The natural frequency  $\omega_n$  is defined as:

$$\omega_n = \sqrt{\frac{K_p \times K_v \times K_n}{(\tau_1 + \tau_2)}}$$

and the damping value ( $\zeta$ ) given as:  $\zeta = \frac{1}{2\omega_n} \times \frac{1 + K_p \times K_v \times K_n \times \tau_2}{(\tau_1 + \tau_2)}$

In [Fig. 34](#), the output frequency response to a step of input frequency is shown.

The overshoot and settling time percentages are now used to determine  $\omega_n$ . [Fig. 34](#) shows that the damping ratio  $\zeta = 0.45$  produces an overshoot of less than 20 % and settle to within 5 % at  $\omega_n t = 5$ . The required settling time is 1 ms. It results in:

$$\omega_n = \frac{5}{t} = \frac{5}{0.001} = 5 \times 10^3 \text{ rad/s}$$

Rewriting the equation for natural frequency results in:

$$(\tau_1 + \tau_2) = \frac{K_p \times K_v \times K_n}{(\omega_n)^2}$$

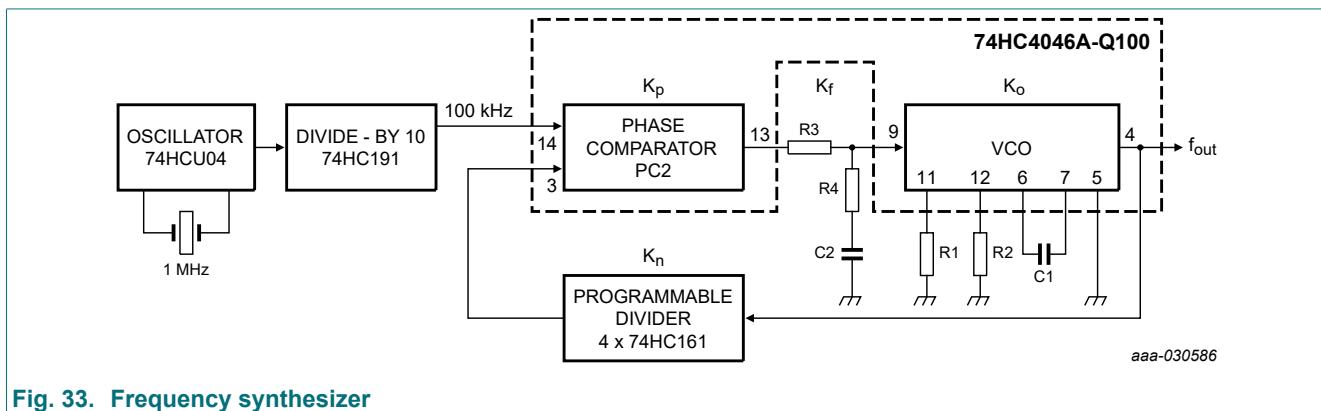
The maximum overshoot occurs at  $N_{\max}$ :

$$(\tau_1 + \tau_2) = \frac{0.4 \times 2 \times 10^6}{5000^2 \times 30} = 0.0011 \text{ s}$$

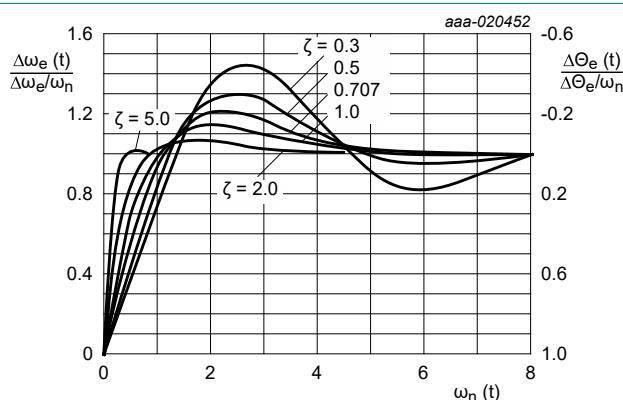
When  $C_2 = 470 \text{ nF}$ , then:

$$R4 = \frac{(\tau_1 + \tau_2) \times 2 \times \omega_n \times \zeta - 1}{K_p \times K_v \times K_n \times C_2} = 315 \Omega$$

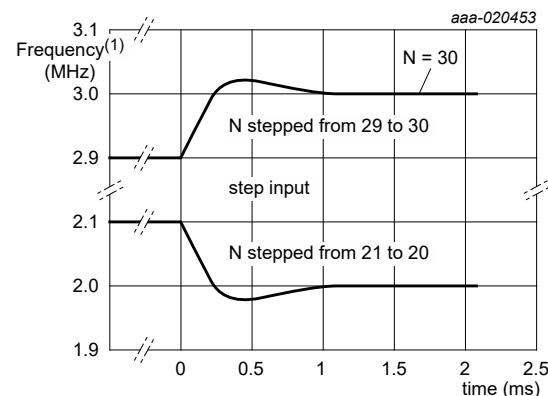
$R3$  can be calculated:  $R3 = \frac{\tau_1}{C_2} - R4 = 2 \text{ k}\Omega$



**Fig. 33. Frequency synthesizer**



**Fig. 34. Type 2, second order frequency step response**



The output frequency is proportional to the VCO control voltage. As a result, the PLL frequency response can be observed with an oscilloscope by monitoring pin VCO\_IN of the VCO. The average frequency response, as calculated by the Laplace method, is found experimentally by smoothing this voltage at pin VCO\_IN using a simple RC filter. The filter has a long time constant when compared with the phase detector sampling rate, but short when compared with the PLL response time.

Fig. 35. Frequency compared to the time response

## 14. Package outline

TSSOP16: plastic thin shrink small outline package; 16 leads; body width 4.4 mm

SOT403-1

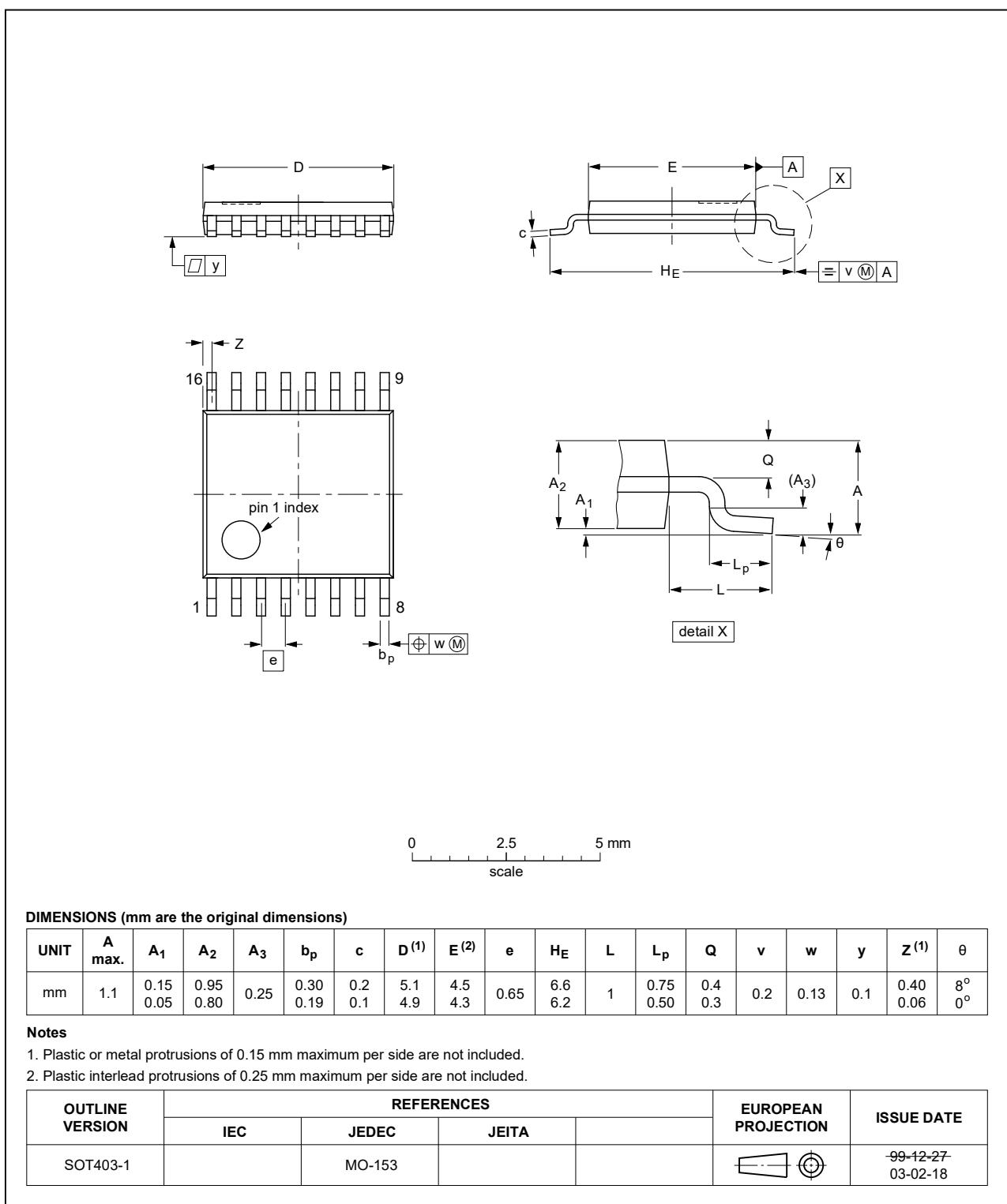


Fig. 36. Package outline SOT403-1 (TSSOP16)

## 15. Abbreviations

**Table 10. Abbreviations**

Acronym	Description
CMOS	Complementary Metal Oxide Semiconductors
DUT	Device Under Test
ESD	ElectroStatic Discharge
HBM	Human Body Model
MM	Machine Model
PLL	Phase-Locked Loop
VCO	Voltage Controlled Oscillator

## 16. Revision history

**Table 11. Revision history**

Document ID	Release date	Data sheet status	Change notice	Supersedes
74HC4046A_Q100 v.1	20191127	Product data sheet	-	-

## 17. Legal information

### Data sheet status

Document status [1][2]	Product status [3]	Definition
Objective [short] data sheet	Development	This document contains data from the objective specification for product development.
Preliminary [short] data sheet	Qualification	This document contains data from the preliminary specification.
Product [short] data sheet	Production	This document contains the product specification.

- [1] Please consult the most recently issued document before initiating or completing a design.
- [2] The term 'short data sheet' is explained in section "Definitions".
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