Numerically Controlled Oscillator Megafunction

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Target Applications:
Communications
Digital Signal Processing

Family: FLEX 10K

Vendor:

NOVA ENGINEERING

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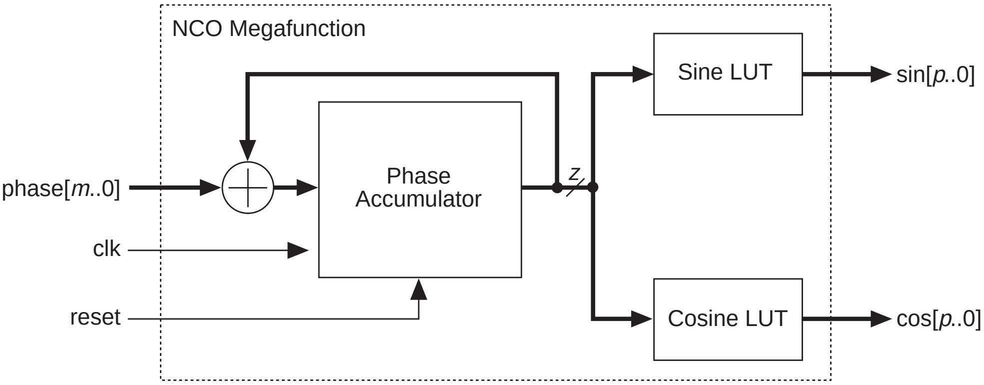
Features

- Simultaneous quadrature outputs
- Parameterized phase accumulator width and output data width
- Optimized for the FLEX® 10K device architecture
- Ideal for the following functions:
  - Direct digital synthesizers
  - Frequency hopping systems
  - Discrete Fourier transforms
  - Modulators / demodulators
  - Polar-to-rectangular conversion

General Description

The numerically controlled oscillator (NCO) megafunction from Nova Engineering generates digital sine and cosine waveforms at a programmable periodic rate. The sine and cosine outputs can be adjusted over a wide range of frequencies with a high degree of resolution. Nova Engineering can customize the input and output data width to meet user specifications. See Figure 1.

Figure 1. Numerically Controlled Oscillator Megafunction Block Diagram



Functional Description

The NCO megafunction contains sine and cosine look-up tables (LUTs) that perform the following functions:

$$\sin(n) = \sin(2\pi n / N)$$
$$\cos(n) = \cos(2\pi n / N)$$

where: n = Address input to the LUT
N = Number of samples in the LUT
$\sin(n)$ = Amplitude of sine wave at $(2\pi n / N)$
$\cos(n)$ = Amplitude of cosine wave at $(2\pi n / N)$

Incrementing n from 0 to N causes the LUT to output one complete cycle of amplitude values for the sine and cosine functions. The value $2\pi n / N$ represents a fractional phase angle between 0 and 2π. The time (t) required to increment n from 0 to N is the period of the sine and cosine waveforms produced by the NCO megafunction.

The LUT address is incremented once each system clock cycle by an amount equal to the `phase[`m`..0]` input. The phase angle data is accumulated and stored in the phase accumulator register. The output of the phase accumulator register is used to address the LUTs.

The frequency (f) of the system clock (f_{CLK}) is fixed. Therefore, the frequency of the sine and cosine waves is:

$f = 1 / t = f_{CLK} \times$ `phase[`m`..0]` $/ 2^m$.

Ports

Table 1 describes the ports for the NCO megafunction. All internal and external operations of the megafunction are synchronized to the rising edge of the system clock, except `reset`.

Table 1. Numerically Controlled Oscillator Megafunction Ports

Name	Type	Width	Description
`phase[`m`..0]`	Input	8 to 32 bits	Incremental phase angle added to the phase accumulator register on each rising edge of the system clock. Two's complement format.
`clk`	Input	–	System clock.
`reset`	Input	–	Asynchronous reset, active high. Initializes the phase accumulator register to 0.
`sin[`p`..0]`	Output	4 to 10 bits	Amplitude of the sine function at the angle contained in the phase accumulator register. Two's complement format.
`cos[`p`..0]`	Output	4 to 10 bits	Amplitude of the cosine function at the angle contained in the phase accumulator register. Two's complement format.

Parameters

Table 2 describes the parameters that Nova Engineering can customize to meet user specifications.

Table 2. Numerically Controlled Oscillator Megafunction Parameters

Parameter	Typical Value	Description
Input data width	8 to 32 bits	Specifies the width of the `phase[`m`..0]` input and the phase accumulator register. Determines the frequency range (f_{MIN} to f_{MAX}) of the NCO megafunction.
Output data width	4 to 10 bits	Specifies the bit width and amplitude resolution of the `sin[`p`..0]` and `cos[`p`..0]` outputs.

The width of the `phase[`m`..0]` input determines the minimum frequency of the megafunction, which occurs when `phase[`m`..0]` is set to 1. If the width of `phase[`m`..0]` is w bits, then 2π radians are divided into 2^w parts. By substituting $2^w = 2\pi$ and setting `phase[`m`..0]` to 1, the minimum frequency of the megafunction is $f_{CLK} / 2^w$.

The maximum frequency is theoretically limited to $f_{CLK} / 2$ by the Nyquist sampling theory. However, the practical maximum operating frequency is generally determined by the application.

The angular resolution is determined by the number of address bits (z), and the number of address bits is determined by the specified width of the output data. For example, if a 10-bit output is specified, the amplitude of the sine wave must be accurate to within 1 part in 1,024 (i.e., 2^{10}). This amplitude resolution can be achieved by using an angular resolution of 1 part in 4,096, which can be determined by evaluating how angular changes affect amplitude changes in the sine wave. Because the sine wave amplitude is changing at its maximum rate near zero, the maximum amplitude change resulting from the smallest angular change can be calculated.

Device Utilization

The NCO megafunction requires one or more embedded array blocks (EABs) to implement the LUT. The NCO megafunction minimizes the use of EABs by taking advantage of the symmetry of the sine and cosine waveforms. Specifically, the sine and cosine amplitudes are symmetrical about $M\pi/2$ (where $M = 0, 1, 2,...$).

The NCO megafunction also conserves logic array block (LAB) resources, allowing the megafunction to be combined with complementary functions that require the use of logic resources, such as multipliers for modulation and demodulation.

Table 3 illustrates the typical device utilization and maximum clock frequency for the NCO megafunction. For this example, the frequency ranges from approximately 0.03 Hz to 10 MHz. The relationship between the sine and cosine frequencies, the system clock, and the `phase[m..0]` input is:

$$f = f_{CLK} \times \texttt{phase[}m\texttt{..0]} / 2^{w}$$

Table 3. Typical Device Utilization

Implementation	Clock (Max)	Logic Cells	EABs
Input data width = 30 bits Output data width = 8 bits	35 MHz	70	2

Contact Nova Engineering for more information on the NCO megafunction.

Applications

The NCO megafunction is useful for a variety of applications, including direct digital synthesis (DDS) and frequency shift keying (FSK).

Direct Digital Synthesis

DDS uses digital circuitry, such as an NCO megafunction, to generate or synthesize frequency references. Communication systems generally require a frequency reference that can be tuned or changed. For example, a transmitter may require multiple frequencies to transmit information on different channels or frequencies. Typically, the receiver requires a tunable frequency reference so it can be adjusted to match the transmitter frequency. The receiver must lock the transmitter frequency before the data can be correctly recovered.

A tunable analog reference frequency can be created by applying the output of the NCO megafunction to a digital-to-analog converter (DAC). The DAC transforms the digital outputs of the NCO megafunction into analog voltages. Generally, a low-pass analog filter follows the DAC to smooth the DAC transitions and to band limit the output.

Frequency Shift Keying

FSK is a type of digital modulation that permits the transmission of binary data. Two frequencies are used in FSK: one is transmitted for a binary 1, and another is transmitted for a binary 0. FSK can be designed using an NCO megafunction, two phase registers, and a digital multiplexer.

In the NCO megafunction, the two `phase[`*m*`..0]` inputs required to generate the two desired frequencies are stored in separate phase registers. The output of each phase register is fed into the multiplexer. The transmitted data controls the multiplexer select input. Each time a binary 1 is to be transmitted, the data input causes the multiplexer to select the phase register that induces the NCO megafunction to output the frequency for a binary 1. A binary 0 is transmitted when the multiplexer selects the other phase register.

Revision History

The information contained in *Solution Brief 5 (Numerically Controlled Oscillator Megafunction)* version 1.01 supersedes information published in *Solution Brief 5 (Numerically Controlled Oscillator)* version 1.0. Version 1.01 includes a corrected frequency equation on page 2.

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