A Numerically controlled oscillator for all Digital Phase Locked Loop

Anupama.Patil [#1] ;Dr P .H .Tandel[* 2]

#Research Associate Faculty of Electronics and Communication Engineering Pacific Academy of Higher Education and Research University ,Udaipur ,Rajasthan,India

**Professor and Director PG studies, Electronics and Communication (Retired) P IET Nimda Dist Vadodara,Gujarat,India*

Abstract :

Numerically Controlled Oscillator (NCO) is a digital oscillator signal generator. It generates a synchronous ,clocked, discrete waveform, usually sinusoidal [1]. NCOs are often used in combination with a digital to analog converter (DAC) at the output to create a direct digital synthesizer (DDS).NCOs are used in many communications systems which are completely digital or mixed signal, like arbitrary waveform synthesis, precoise control for phased array radar or SONAR systems, All digital PLLs, Digital Down/Up converters for Cellular and PCS base stations and drivers for optical or acoustic transmissions & multilevel FSK / PSK modulators or demodulators(modem)[2]. The NCO used in our ADPLL has been modeled using matlab simulink and realized on FPGA board for hardware Realization. The designs are tested on Xilinx Nexys 4 DDR Artix 7 FPGA Development Platform . A FPGA based Implementation method greatly improves the performance, reduces the development cycle and reduces cost. The basic NCO architecture is improved and enhanced with the minimum hardware in order to facilitate the complete system level support for different kinds of modulation with minimal FPGA resources. This paper presents the implementation of Siusoidal Wave Generation using NCO module which improves the performance, reduces the power & area requirement.

Keywords *— NCO, ADPLL, Sine Wave, Digital*

I INTRODUCTION

Numerically Controlled Oscillators (NCO) are also known as Direct Digital Synthesizers (DDS),They offer several advantages over other types of oscillators in terms of accuracy, stability and reliability. NCOs provide a flexible architecture that enables easy programmability such as on-the-fly frequency/phase. The NCOs better in terms of signal quality and stability compared to other methods (e.g., voltage controlled oscillators, VCO). A common method for digitally generating a complex or real valued sinusoid makes use of a lookup table in whichstores the samples of a sinusoid are stored.

A digital integrator is used to generate a suitable phase argument that is mapped by the lookup table to the desired output waveform [3].NCO makes use of a technology known as Frequency synthesis; It is developed the using third generation of Frequency synthesis technology. The technique of NCO to generate sinusoidal and modulated signals in digital systems is gaining popularity.[4]. Applications range from modern communication systems, including spread-spectrum and phase shift-keying modulation techniques, to measurement instrumentation. In this paper NCO module is used for Sine Wave Generation band the input is from digital low pas iir filter and output is the feedback signal to the phase detector of All Digital Phase Locked Loop(ADPLL) . The NCO module operates on the principle of DDS by repeatedly adding a fixed value to an accumulator which is used in place of voltage controlled oscillator of analog phase locked loop. The NCO module can operate in two modes: 1) fixed duty cycle PWM mode 2) frequency controlled pulse mode.

II LITERARY REVIEW

In 2001 hybrid NCOs bringing together in a hybrid scheme both ROM lookup tables (LUT) and hardware implementations of the iterative CORDIC algorithm for sine/cosine function generation were investigated.[7].

In 2003- Adding a small lookup table (LUT) to adjust the feedback in a second-order numerically controlled digital oscillator (NCDO) eliminated all of the stability problems created by roundoff error in digital oscillators. It used less hardware than any of the three major competing approaches: (1) sinusoidal look up table, (2) digital oscillators with roundoff compensation, and (3) CORDIC based designs[8].

In 2004 by using a fine phase tuner and a rounding processor for a numerically controlled oscillator (NCO), yielded into a reduced phase error in generating a digital sine waveform. By using the fine phase tuner when the ratio of the desired sine wave frequency to the clock frequency was expressed as a fraction, an accurate adjustment in representing the fractional value could be achieved with simple hardware[9].

In 2012 a new technique to the design of high spectral purity numerically controlled oscillator (NCO) was devised. In this work, a single look up table (LUT) with sine amplitudes at equally spaced samples was used to approximate the complete sine wave cycle. A simple computation process was conducted to evaluate the slope coefficients, thus the LUT for mapping those values was eliminated due to which the NCO structure was efficiently simplified and the memory reduction resulted in noticeable logic element (LE) saving[13].

In 2013 NCO was designed which had the advantages of that tuning resolution could be made arbitrarily small to satisfy almost any design specification. The phase and the frequency of the waveform was able to be controlled in one sample period, making phase modulation feasible without controlling the gain[10]

Another again in 2013 was designed and realized including sub modules like phase Accumulator and Look-Up Table. Area resources were optimized by using Coefficients for only quarter cycle of sinusoidal waveform and for remaining part the same had been flipped and for negative cycle it has been inverted[11].

In the same year Direct Digital Synthesizing was done at tuning frequency that was specified as normalized value relative to clock rate given. Since it was a dual Oscillator, it supported variable Width, Phase modulation inputs and user defined frequency resolution[12].

In 2015 Using the Numerically Controlled Oscillator (NCO) module is used to generate a sine wave at any desired frequency and thus its advantages over the conventional Pulse-Width Modulation (PWM) approach have also been covered[6].

III Overview of Numerically Controlled Oscillator(NCO) and ADPLL

3.1 Architecture of NCO

If seen basically Numerically Controlled Oscillator is constructed by a ROM with samples of a sine wave stored in it (sine look-up, LUT) [5]. Fig.1 shows the block diagram of a NCO system. The NCO produces sinusoidal signals whose frequency is decided by frequency setting word (FSW) or frequency control word(FCW).This determines the phase step. Once this digital word is set, it determines the frequency of the sine wave to be produced. A *phase accumulator* (PA), goes on adding the value held at its output a frequency control value at each clock sample. A *phase-to-amplitude converter* (PAC), uses the phase accumulator output word (phase word) usually as an index into a waveform look-up table (LUT) to provide a corresponding amplitude sample. Thus the phase accumulator continuously produces proper binary words at the output. This represents the instantaneous phase to the table look-up function[2].

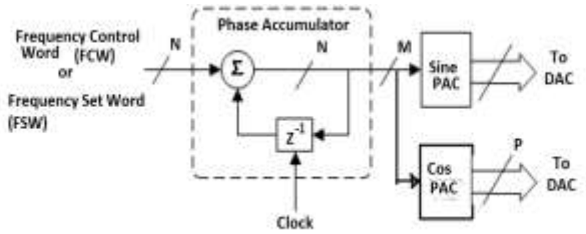

Figure 1 Block Diagram of NCO

The NCO is not limited to the generation of a sine wave. By using a proper filter with an appropriate cut off frequency, any desired wave shape can be rendered to the resultant output. . In the figure 1 N sets the NCO frequency resolution .It is normally much larger than the number of bits defining the memory space of the PAC look-up table. The PAC capacity is 2^M, means that, the Phase Accumulator(PA) output word must be truncated to M bits as shown in Figure 1. These truncated bits can be used for interpolation. The truncation of the phase output word does not affect the frequency accuracy but produces a time-varying periodic phase error his phase error is a primary source of spurious products. Another source is finite word length.

The NCO translates the resulting phase to a sinusoidal waveform via the look-up table, and converts the digital representation of the sine-wave to Analog form using a Digital-to-Analog converter followed by a low pass filter (LPF) as shown in figure 2.

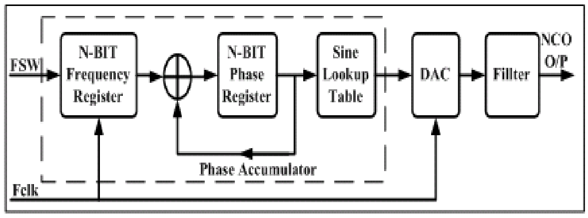

Figure 2 Block Diagram of NCO with DAC and Filter[1].

The Output frequency of the NCO is numerically controlled by using a binary word instead of voltage. That is the NCO generates an output signal whose frequency is proportional to the input control word. The frequency of the output signal for signal N-bit system is determined by following equation 1.

$$F_{out} = \frac{K \cdot F_{clk}}{2^N} \quad (1)$$

Where K is the FSW,N is the number of bits that the phase accumulator can handle ,F_{clk} is system clock.

3.2 All Digital Phase Locked Loop

The All -Digital PLL (ADPLL) , unlike analog PLLs is a pure digital circuit. In a analog PLL the loop filter occupies as much as 50% of the chip . A digital loop filter do not contain any large capacitors, resistors or coils and needs no large guard rings or high resistive substrates usually required for good isolation . It enables significant reductions in chip area . A pure digital circuit enables faster design turnaround cycles since automated tools can be used to a greater extent . Many parameters like frequency of oscillator can be set programmatically.

The need for an All-Digital PLL approach is rising as advanced deep-submicron CMOS processes make it extremely difficult to implement traditional analog circuits.

The basic block diagram of ADPLL consists of digital phase detector. It can be

1. Flipflop counter phase detector
2. Nyquist Rate phase detector
3. Zero crossing phase detector
4. Hilbert transform phase detector

One of the basic components of ADPLL is the Oscillator which gives the output based on the output of the filter in the circuit of the phase locked Figure 5 a Response of NCO for sinusoidal changes at its input
loop. Having a stable oscillator with least dependence on environmental parameters is very important.NCO is found be a better choice in ADPLL.

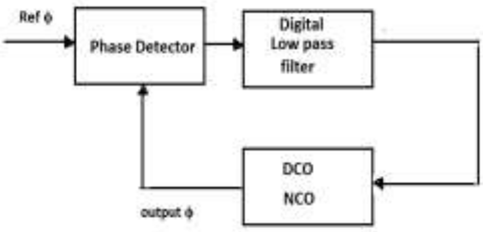

Figure 3 Block diagram of ADPLL

The basic structure of the NCO used in ADPLL that I have used is shown in figure 4.

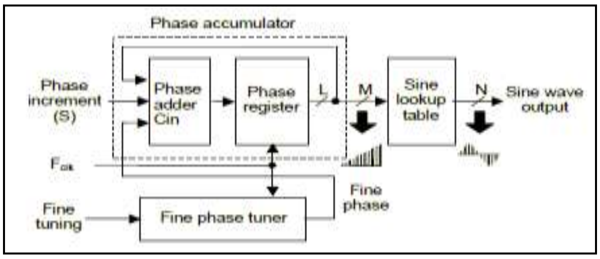

Figure 4 Basic structure of NCO using LUT

The output of Numerically controlled oscillator for various inputs were studied using MATLAB.The waveforms are given in the figures 5,6,7 and 8.

IV Response waveforms of NCO

The input and output wave forms of NCO for different inputs are shown below:

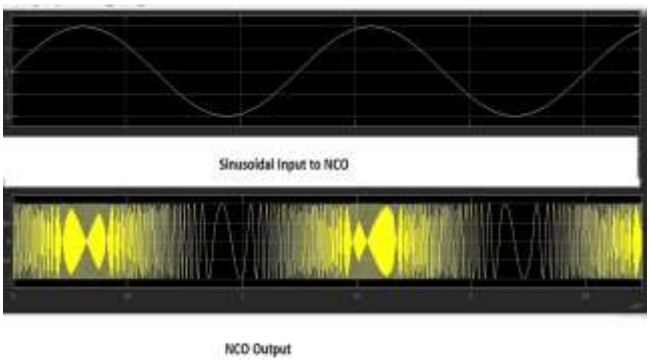

Figure 5 a Response of NCO for sinusoidal changes at its input

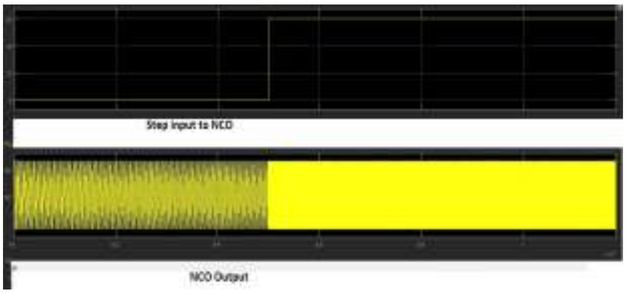

Figure 5 b Step response of the NCO

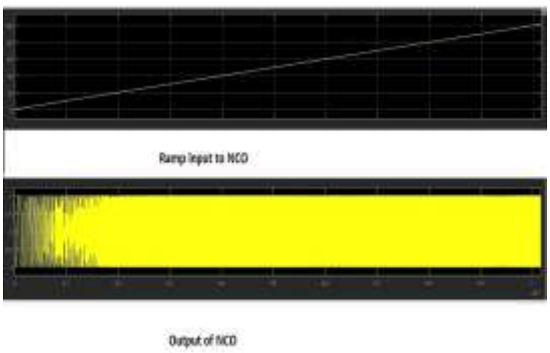

Figure 5c Ramp input to NCO and its output

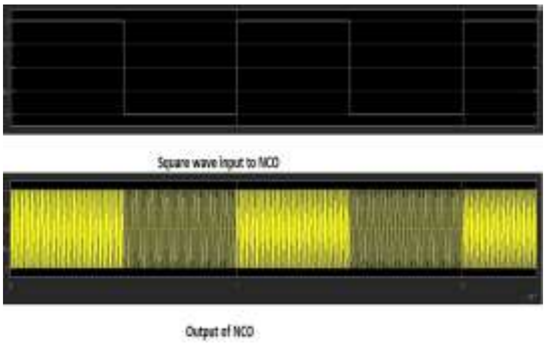

Figure 5d Response of NCO with square wave Input

It has been observed that sinusoidal signal is generated at the out put of the NCO in discrete time for different changes at the input. This can successfully utilized with ADPLL for the digital oscillator purpose.

V Conclusion

The experiments done with the NCO while utilizing it for the ADPLL has shown that a discrete sine wave is always possible to get at the output of the NCO.The input to the NCO is the out[pput of the filter which is also digital in nature .The output of the NCO when feds to to phase detector has given satisfactory phase locking.

References

[1] Jane Radatz, The IEEE Standard Dictionary of Electrical & Electronics Terms,IEEE Standards office, New York, NY, 1997

[2] Numerically Controlled Oscillator, Lattice Semiconductor Corporation, 2009

[3] Wenmiao Song, Qiongqiong Yao, "*Design and Implement of QPSK Modem Based on FPGA",*
North china Electric power University,Baoding, china IEEE, 2010.

[4] M.L. Welborn, "*Direct Waveform Synthesis for software Radios*," IEEE Wireless Communications and Networking Conference WCNC. 1999, vol. 1, pp.211-215, September 1999.

[5]. Gopal D. Ghiwala, Pinakin P. Thaker, GireejaD.Amin, "Realization of FPGA based
numerically Controlled Oscillator", IOSR Journal of VLSI and Signal Processing (IOSR-JVSP) ISSN: 2319 – 4200, ISBN No. : 2319 – 4197 Volume 1, Issue 5, PP 07-11, (Jan. - Feb 2013).

[6] Priyankap. Chopda, Kavita S. Tated&Jayant J. Chopade, "Sine Wave Generation Using
Numerically Controlled Oscillator Module",BEST: International Journal of Management, Information Technology and Engineering (BEST: IJMITE) ISSN(P): 2348-0513;ISSN(E):2454-471X Vol. 3, Issue 7 , 35-40, Jul 2015.

[7] I.Janiszewski;F M Darmstadt,Germany;B.Hoppe;H Meuth, "Precision and performance of numerically controlled oscillators with hybrid function generators", 2001 IEEE International Frequency Control Symposium and FDA Exhibition, page no.744-752.

[8] S. Menon;Sch of Eletr and Comp Engg,Oklohoma State Univ; Stillwater,OK,USA; G Cho; M Soderstrand,"An Improved Numerically Controlled Digital Oscillator" Communications computers and signal processing,2003 PACRIM, 2003 IEEE Pacific RIM Conference Print ISBN**:**0-7803-7978-0 pages 1040-1044.

[9] In Gi Lim and When-Woo Kim ,"A Numerically Controlled Oscillator with a Fine Phase Tuner and a Rounding Processor,ETRF Journal p-ISSN -1225 6463 e-ISSN-2223 7326

[10] Gaurav Gupta, Monika Kapoor, "An Improved Analog Waveforms Generation Technique using Direct Digital Synthesizer", International Journal of Computer Applications (0975 – 8887) Volume 78 – No.5, September 2013.

[11]. Gopal D. Ghiwala, Pinakin P. Thaker, GireejaD.Amin, "Realization of FPGA based numerically Controlled Oscillator", IOSR Journal of VLSI and Signal Processing (IOSR-JVSP) ISSN: 2319 – 4200, ISBN No. : 2319 – 4197 Volume 1, Issue 5, PP 07-11, (Jan. - Feb 2013).

[12]. SnehalGaikwad, KunalDekate, "Design and Implementation of Feasible Direct Digital Synthesizer to Eliminate Manual Tweaking", IOSR Journal of VLSI and Signal Processing (IOSR-JVSP) Volume 2, Issue 4, , PP 53-56e-ISSN: 2319 – 4200, p-ISSN No. : 2319 – 4197,(May. – Jun. 2013).

[13] Q. K. Omran, M.T. Islam, N. Misran, "Design and Simulation of High Spectral Purity Numerically Controlled Oscillator", Applied Mechanics and Materials, Vols. 229-231, pp. 2117-2121, 2012