Understanding Direct Digital Synthesis (DDS)

Overview

National Instruments signal generators utilize a technology known as direct digital synthesis (DDS) to generate signals at precise frequencies and implement phase-continuous sweeping. This whitepaper describes the fundamental operation of DDS.

This tutorial is part of the National Instruments Signal Generator Fundamentals series. Each tutorial in this series will teach basic concepts about the architecture, features, or applications of signal generators.
Introduction

National Instruments function generators are able to achieve 0.355 µHz of frequency precision using a technology called direct digital synthesis (DDS). DDS works by first storing a large repetitive waveform in onboard memory. For National Instruments products, any single cycle of a waveform (sine, triangle, square, arbitrary) can be represented by exactly 16,384 points and stored into memory. Once the waveform is stored into memory, it can be generated at very precise frequencies.

Note, also learn about this topic in a multimedia tutorial at the following link: Signal Generators Fundamentals: Introduction to Direct Digital Synthesis.

DDS Memory Utilization

Function generators utilize DDS to generate periodic signals at precise frequencies by choosing samples from memory rather than generating all samples of a waveform.   By contrast, arbitrary waveform generators (AWGs) generate each sample of a waveform that is stored into memory. While AWGs allow a user to precisely define the waveform that is being generated, they are limited in the frequency precision they can achieve, particularly at high frequencies.   By contrast, we illustrate how a function generator is able to generate a 21 MHz sinusoid, even though its frequency is not a direct multiple of the sample rate.   This is illustrated this in the graph below:
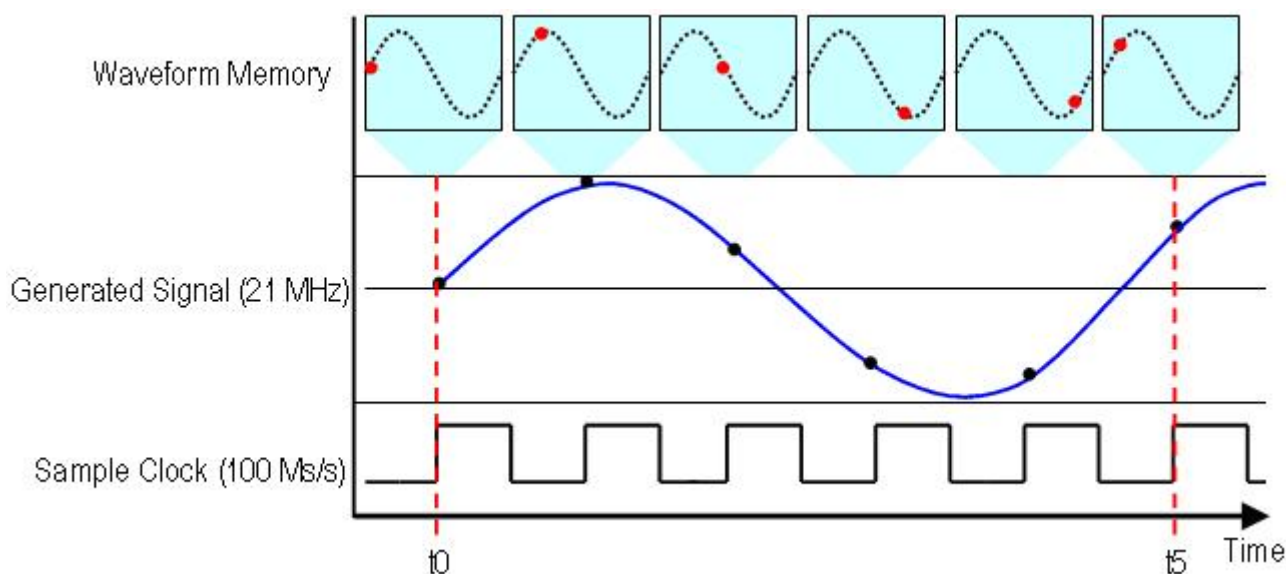

Figure 1: 21 MHz Sine Generation using DDS

From the figure above, we ne notice from the figure above that the frequency of the sinusoid is not a divisor of the sampling rate. As a result, generating a 21 MHz sinusoid would be difficult with an AWG sampling at 100 MS/s. Function generators, on the other hand, use DDS to store a 16,384 sample waveform in memory.   With each clock cycle, the appropriate sample is chosen from a lookup table and then generated.   As a result, we are able to generate signals at precise frequencies while supplying the digital-to-analog converter (DAC) with a constant 100 MHz clock.

Functional Overview

The actual implementation of DDS requires a look-up table to determine the phase output signal at any point in time. The following figure shows the building blocks for direct digital synthesis-based waveform generation.
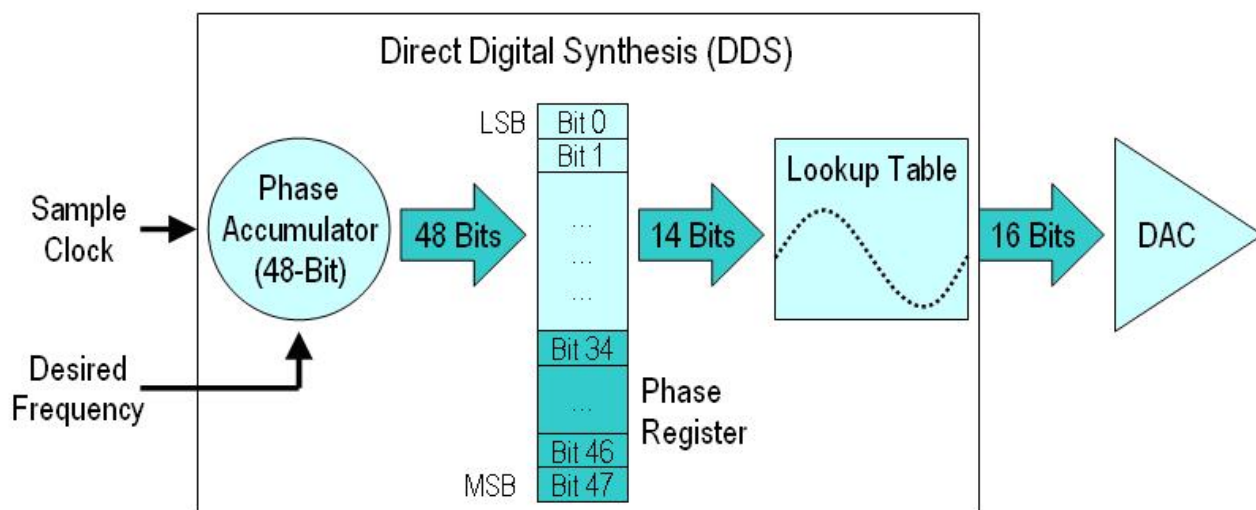

Figure 2: Direct Digital Synthesis Block Diagram

As the figure above illustrates, a phase accumulator compares the sample clock and desired frequency to increment a phase register. Again, the fundamental idea is that we can generate signals with precise frequencies by generating an appropriate sample based on the phase of that frequency at any point in time. In addition, by representing our waveform with 2^{14} (16,384) points, we are able to represent exactly 16,384 phase increments with our lookup table.

The phase accumulator uses simple arithmetic operations to calculate the lookup table address for each generated sample. It does this by dividing the desired frequency by the sample clock and multiplying the result by 2^{48}. This number is based on the bit resolution of the phase register. For NI signal generators, a 48-bit phase register is used for maximum precision. Of these, 34 bits are used to store the remainder phase, and 14 bits are used to choose a sample from the lookup table.

Thus, the phase accumulator produces a 14-bit address that corresponds to the exact phase of the signal.   For example, an address of '00000000000000' corresponds to 0°. On the other hand, an address of '11111111111111' corresponds to 359.978°. Thus, the signal generator can use this address to control the phase of the signal at any point in time. This is shown below:
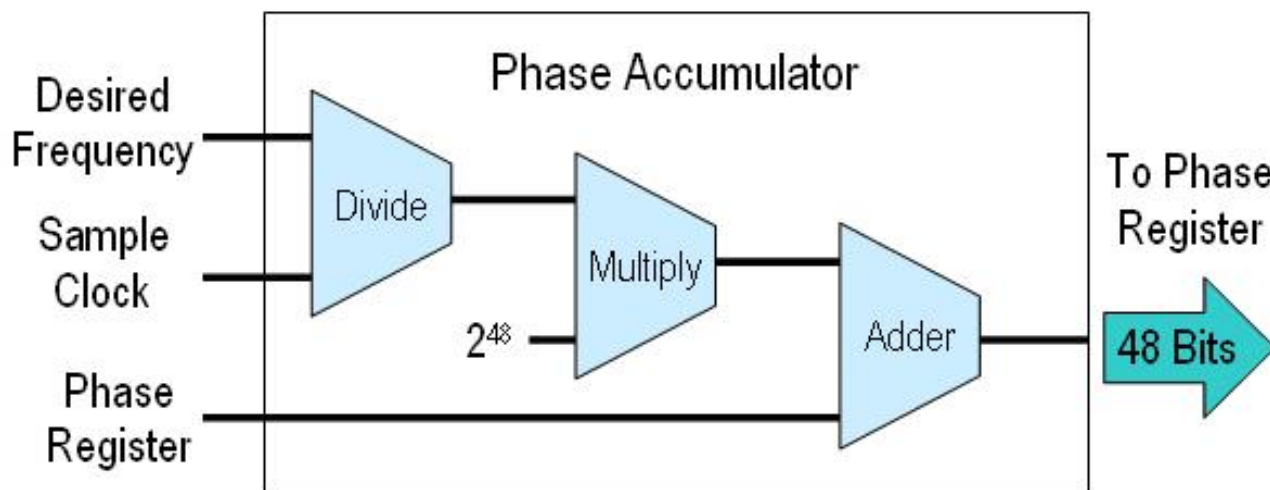
Figure 3: Computation of the Phase Register

As the diagram suggests, the phase accumulator is able to represent the phase of the generated signal with 2^{48} points of precision. However, because we only have 2^{14} available points in our waveform, only the 14 most significant bits of the phase register are used in the lookup table. The remaining 34 bits are used to store the remainder of the phase increment. This remainder enables the DDS precision by ensuring that the lookup table will return the appropriate phase information after the phase register rolls over (once per period of the waveform).

Applications

Because direct digital synthesis enables generation of periodic signals at very precise frequencies, it is useful for applications required phase-continuous frequency sweeping. One common application is filter characterization. A block diagram of a typical system setup is shown below:
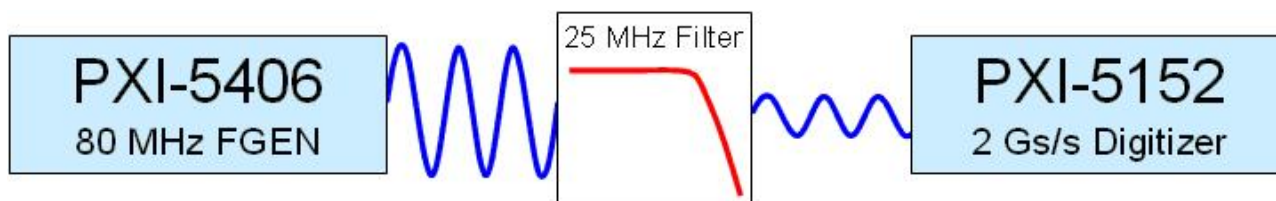

Figure 4: Block Diagram of Lowpass Filter Characterization

In this application, a function generator is used to sweep a sinusoid across a wide frequency range in discrete frequency steps. Using direct digital synthesis, we are able to ensure that the signal generated at each step in the frequency sweep is accurate to within 0.355 µHz. As a result, you are able to more accurately characterize the analog filter by generating a wider range of frequencies.
Related Topics

To view a webcast on the same topic, view the multimedia webcast: Signal Generators Fundamentals: Introduction to Direct Digital Synthesis.

This tutorial is part of the National Instruments Signal Generator Tutorial series. Each tutorial in this series, will teach you a specific topic of common measurement applications, by explaining the theory and giving practical examples. This tutorial includes descriptions of signal generator terminology and specifications.

For additional signal generator concepts, refer to the Signal Generator Fundamentals main page.
Related Links
- ni.com/signalgenerators
- ni.com/modularinstruments

Related Products
- PXI-5406, 40 MHz Function Generator
- PXI-5652, 6.6 GHz RF CW Source