A Small Form Factor 3-9 GHz Synthesizer Module for Use in Synthetic Instrumentation Applications

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A novel 3-9 GHz fast switching frequency synthesizer module has been developed. The synthesizer employs a multi-loop VCO-based design that delivers +15 to +19 dBm output power across the band. A built-in DDS provides sub-Hz frequency resolution with excellent spurious and phase noise characteristics. The developed module employs a "brick" form factor and can be used in a variety of synthetic instrumentation applications and platforms. The module's construction and measurement results are presented.

Introduction

Synthetic instrumentation is an emerging technology that offers a cost-effective modular approach for building complex test and measurement equipment. It enables the emulation of various traditional benchtop instruments employed in automatic test systems using a reconfigurable combination of core hardware and software components [1], [2].

The performance of synthetic instruments primarily depends on technical characteristics of their core modules. The need for a low-cost, high-performance frequency synthesizer as a key component of virtually any test and measurement system is recognized throughout the microwave community [3]-[5]. The industry feels persistent pressure to deliver higher performance, higher functionality, smaller size, lower power consumption, and lower-cost synthesizer designs. A key market demand is faster frequency tuning speed, as dictated by the ongoing increase of the data rates of modern microwave systems [6]. Addressing these needs, we introduce a novel, 3-9 GHz, VCO-based, fast-switching frequency synthesizer module compacted into a "brick" form factor (approximately 4" x 6" x 1.5"), which can be used in a variety of small form factor (VXI, PXI, LXI) synthetic instrumentation applications. The module's construction and measurement results are discussed below in the context of PXI as the target platform.

Synthesizer Design

The module consists of two major parts: the microwave synthesizer and the reference block, as shown in Figure 1. The reference block is based on a 100 MHz highly stable ovenized crystal oscillator (OCXO) that serves as a reference for the microwave synthesizer. The reference block also includes a divide-by-10 divider to get a 10 MHz reference signal; both 10 MHz and 100 MHz outputs are provided on the front panel of the module. The internal OCXO can drive the module itself or can be automatically locked to an external 10 MHz reference if required. The module constantly monitors the presence of the external reference and frequency lock.

The microwave portion is based on a 5-10 GHz, fundamental, solid-state, voltage-controlled oscillator (VCO) with an output that is split into two sub-bands, as depicted in Figure 2. The upper branch utilizes a portion of the available bandwidth (5 to 9 GHz) that allows the use of a 9 GHz

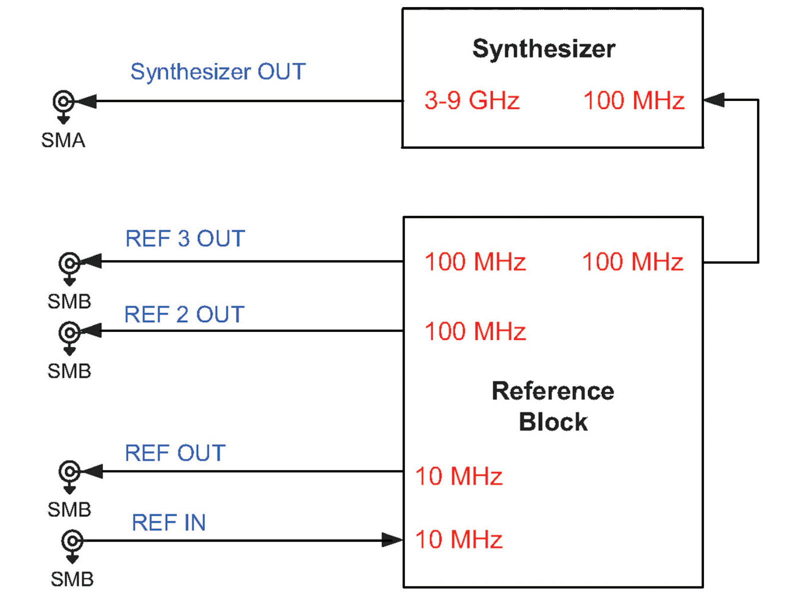

Figure 1: Module Block Diagram

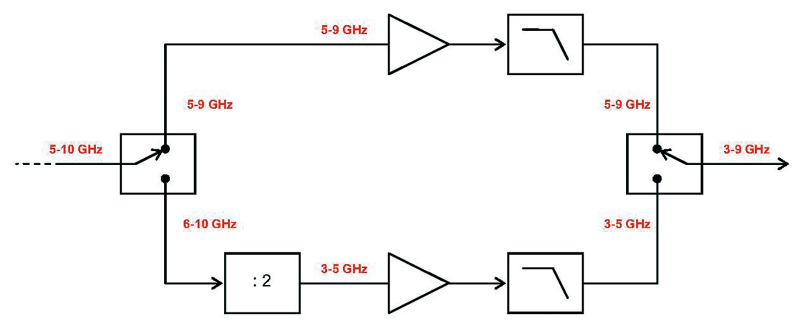

Figure 2: Block Diagram of the Synthesizer Output

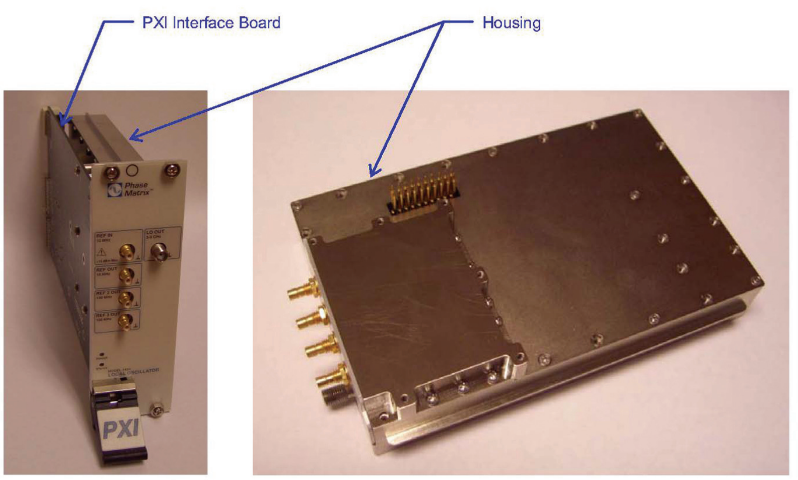

Figure 3: Prototype PXI Synthesizer Assembly

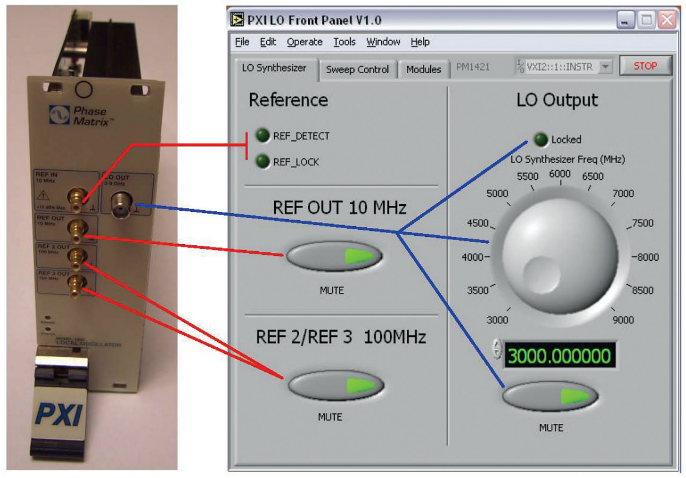

Figure 4: Synthesizer Control

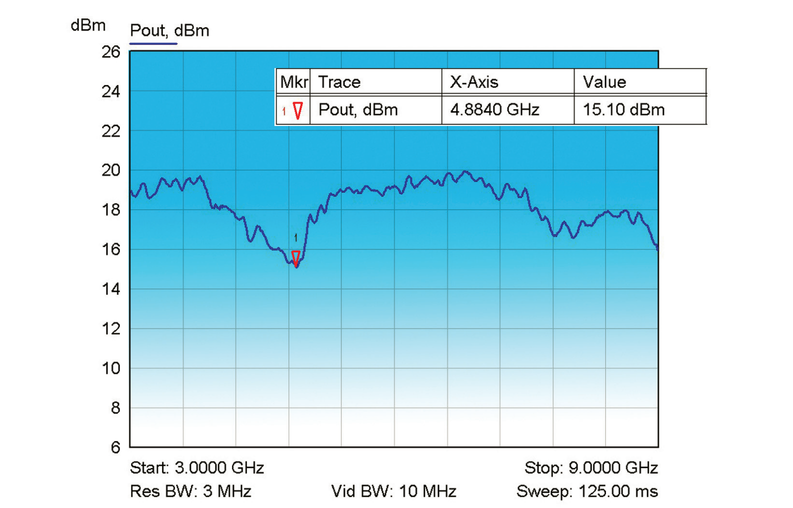

Figure 5: Output Power Variations

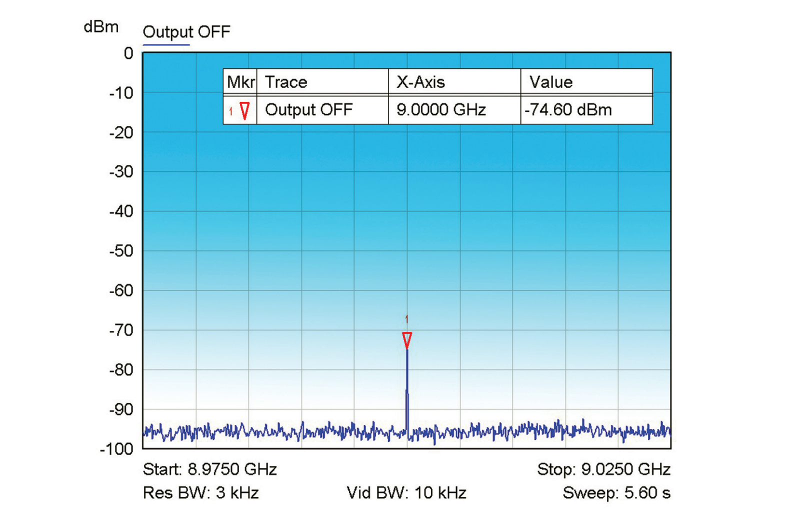

Figure 6: Output Power Mute

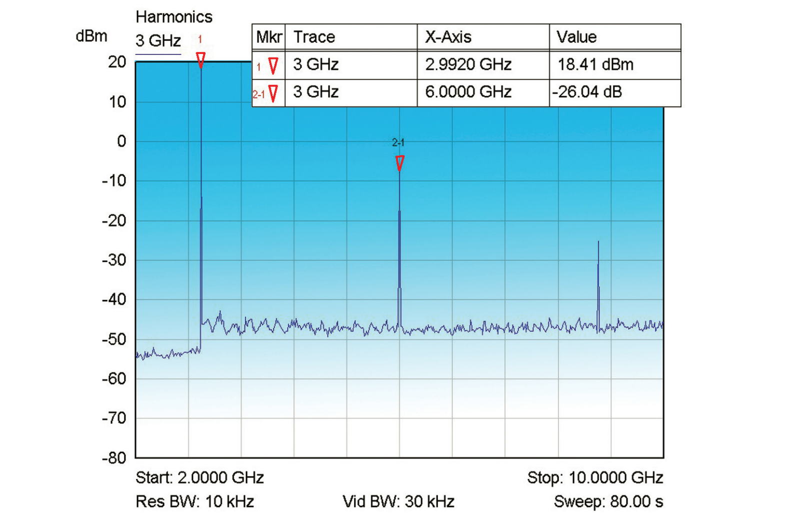

Figure 7: Synthesizer Harmonics

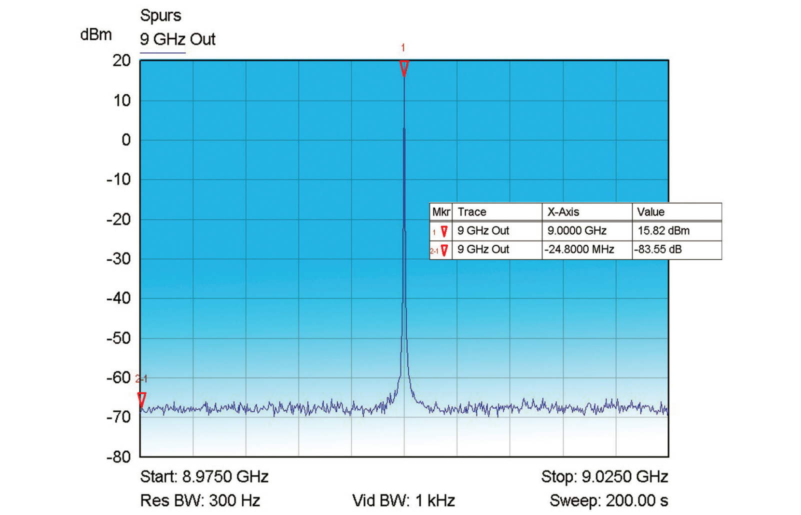

Figure 8: Spurious Performance

low-pass filter to suppress VCO harmonics from 10 GHz and above. The lower branch includes a divide-by-2 divider to bring the output frequency down to 3 GHz. Similarly, the lower branch utilizes a portion of the bandwidth (3-5 GHz) in order to achieve adequate harmonic suppression above 6 GHz. This approach provides 3 to 9 GHz overall frequency coverage with reduced harmonic content.

The VCO is locked to a built-in DDS device that provides sub-Hz frequency resolution without the common penalty of slower tuning and increased phase noise degradation. Since DDS-based designs are prone to increased spurious content, both hardware and software techniques are extensively utilized to suppress DDS spurs to negligible levels (in comparison with more copious PLL reference spurs), as discussed in more detail in [6]. Though PLL spurs dominate, they are easily managed by optimizing the loop filter. The VCO phase noise is effectively controlled by utilizing a relatively wide (a few hundred kHz) loop bandwidth as also suggested in [6]. Thus, the synthesizer phase noise within its PLL bandwidth mainly depends on the multiplied reference noise as well as residual noise characteristics of the locking mechanism. A high-frequency and fairly low-noise OCXO is utilized along with an advanced multi-loop architecture to achieve desirable phase noise performance.

The synthesizer reference and microwave circuits are put into a metal housing (shown in Figure 3) to prevent interference from the outside environment and possible signal contamination. A PXI interface board is placed on top of the housing to deliver all bias voltages and control signals from a PXI chassis.

Module Control

The module is controlled through a standard PXI bus with a LabView GUI, which is hosted on a separate computer. The GUI allows the user to set a desired output frequency, monitor frequency lock, and mute the synthesizer output, as shown in Figure 4. On the reference side, the user can independently mute 10 MHz and 100 MHz outputs, monitor the presence of external 10 MHz signal, and check the reference lock. The software also allows sweeping the synthesizer across the entire frequency range with programmable frequency step and dwell time.

Test Results

The developed hardware provides 3 to 9 GHz frequency coverage with 0.1 Hz step size and less than 300 µsec switching time. The maximum (unleveled) RF output power varies between +15 and +19 dBm, as shown in Figure 5. The output power variations are mainly due to the utilized low-pass filters; this issue will be addressed in the next design iteration. The signal output can be muted to about -75 dBm level (worst case) without disturbing the synthesizer VCO (Figure 6). Since the VCO remains locked, the muting is inherently fast and, therefore, can be potentially used for pulse modulation with a uSec pulse width and on/off ratio greater than 80 dB.

The synthesizer's output spectrum purity is depicted in the next few plots. The harmonics do not exceed the -25 dBc level across the entire band; the worst case at 3 GHz is shown in Figure 7. A typical spurious plot is presented in Figure 8; the spectrum looks clean and free of obvious perturbations down to the -80 dBc level. This demonstrates the effectiveness of the employed DDS spur suppression algorithm and careful loop filter design.

The synthesizer's phase noise plot taken at 3 GHz is presented in Figure 9. The noise at low frequency offsets depends on the multiplied reference noise (as well as residual noise of the measurement set-up, which brought its own contribution to the indicated plot). The noise between 10 and 100 kHz is mainly attributable to the PLL components; above 1 MHz, the VCO's free-running noise dominates. The module exhibits about -100 dBc/Hz phase noise at 10 and 100 kHz offsets at a 3 GHz output. Most noise performance at higher frequencies degrades slightly due to the employed frequency plan. The noise plot also reveals the loop bandwidth of a few hundred kHz that results in fast tuning speed, as mentioned above.

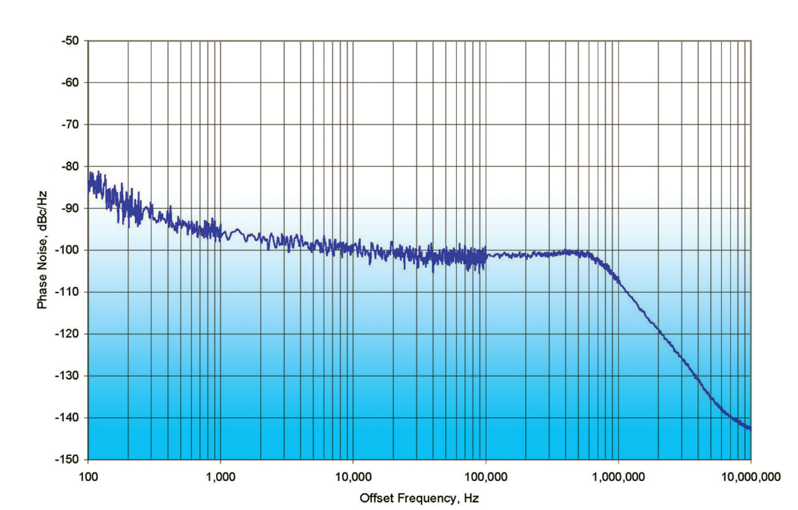

Figure 9: Phase Noise Performance

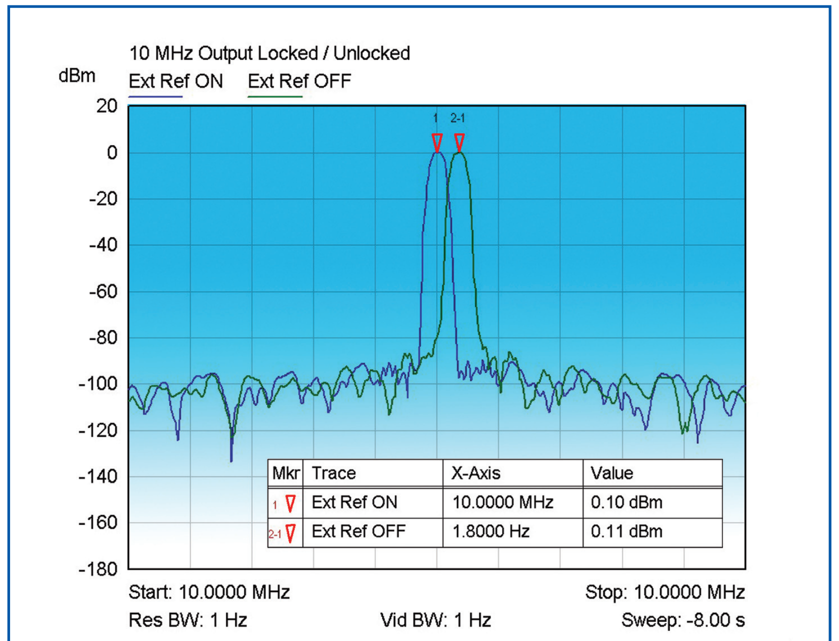

Figure 10: Reference Lock

The unit delivers 0 dBm reference signals at 10 and 100 MHz, which can be independently muted if required. It also accepts an external 10 MHz reference between -15 and +15 dBm to align the internal reference, as shown in Figure 10. The synthesizer module power consumption does not exceed 15 Watts.

Conclusions

A small form factor, highly integrated, fast switching speed frequency synthesizer module has been developed. The synthesizer employs a multi-loop VCO-based design that delivers +15 to +19 dBm power between 3 and 9 GHz. A built-in DDS, powered by a sophisticated spur suppression algorithm, provides fine frequency resolution of 0.1 Hz with excellent spurious and phase noise characteristics. The module also delivers highly stable 10 and 100 MHz reference signals, which can be automatically locked to an external 10 MHz reference if required. The module features low power consumption and can be used in a variety of synthetic instrumentation applications and platforms, including PXI, VXI, and LXI.

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