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Building a Microwave Frequency Synthesizer—Part 5: Advanced Techniques

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This series concludes with notes on advanced design options and features for greater functionality, with descriptions of their implementation in test and measurement products

This is the final article in a five-part series on microwave frequency synthesizers. It concludes with a review of advanced synthesizer solutions. Although synthesizers can be found in virtually any microwave system, test and measurement (T&M) is probably the most challenging application that calls for advanced synthesizer techniques. This final article addresses some specific T&M requirements and possible solutions.

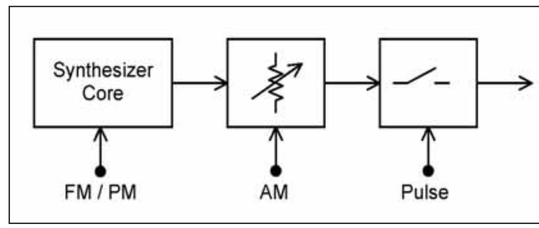

Figure 49 · Adding modulation capabilities.

T&M Synthesizer Considerations

Broadband operation, very fine frequency resolution, low spurious and low phase noise are the key specifications for T&M applications. More recently a lot of interest has been focused on fast frequency switching. This has been motivated by a need for increased data throughput of ATE systems, and the frequency agility demands of wide bandwidth receivers and transmitters [2, 3]. Besides the spectral purity and switching characteristics, the T&M applications require extended functionality that include output power leveling and control, frequency and power sweep, modulation, etc. These options can be realized by adding additional separate modules or can be incorporated into the synthesizer core module. For example, the amplitude and pulse modulators can be either external or internal to the synthesizer itself (Figure 49), while the phase and frequency modulation components are usually included into the synthesizer as a part of the PLL circuitry.

Test and measurement applications are usually associated with big bench-top instruments, which can be found in every engineering lab. Synthetic instrumentation is a cost-effective alternative for building complex test and measurement equipment [48-49]. It enables the emulation of various traditional bench-top instruments employed in automatic test systems using a reconfigurable combination of core hardware components (such as a signal generator shown in Figure 50).

Figure 50 · VXI signal generator covers 0.01 to 20 GHz.

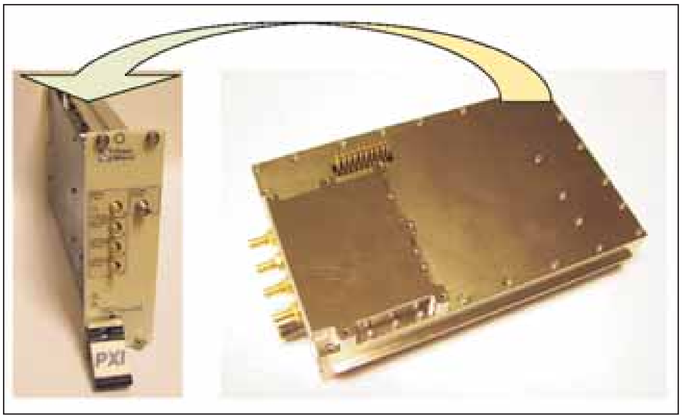

Figure 51 · Microwave synthesizer module for the PXI platform.

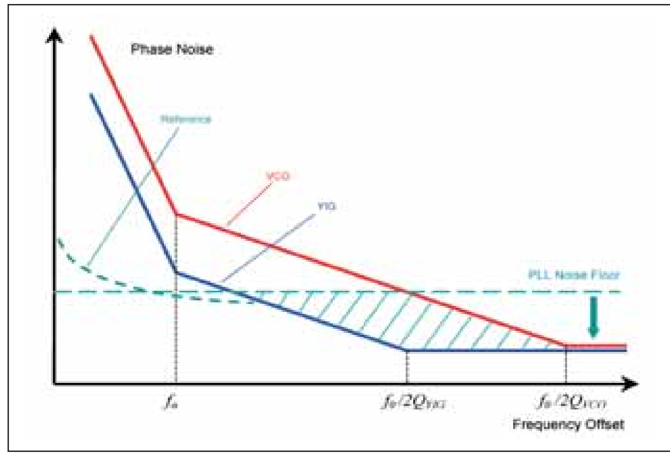

Figure 52 · VCO and YIG oscillator phase noise comparison.

Synthetic instrumentation utilizes various platforms (VXI, LXI); more recently a lot of effort has been put on PXI platform, which offers a lower size and cost benefits. A practical PXI microwave synthesizer example is shown in Figure 51. It is based on a small (4" × 6" × 1.5") module that covers 3 to 9 GHz frequency band with 0.1 Hz resolution and less than 500 µs tuning speed. The module construction and design details are presented in [50].

Thus, today's T&M market requirements demand that new synthesizers must be faster and smaller; simultaneously their other characteristics (e.g., resolution, phase noise, spurious) and functionality must be kept unaffected. Since the available space is continuously diminishing, it requires a certain engineering effort to compact all necessary hardware into available space.

Removing the YIG

One of the main contributors to the synthesizer speed and size parameters is the YIG oscillator, which has been widely used in T&M synthesizers due to its unique low-noise features. Today's market requirements (specifically, fast switching speed) encourage the use of VCO-based technologies, which, however, normally exhibit higher phase noise.

How can the VCO phase noise be controlled? First, let's compare phase noise behavior (Figure 52) of two hypothetical oscillators (YIG and VCO), which utilize identical active device arrangement. At very high frequency offsets both oscillators should demonstrate the same behavior (noise floor) defined by the ratio of the available RF power and active device thermal noise. The noise starts degrading at 20 dB/decade rate at lower frequency offsets set by the resonator Q. Clearly, the VCO demonstrates significantly higher phase noise in comparison with the YIG-oscillator due to the difference in their resonator Q-factors.

Let's build a synthesizer using these oscillators or, in other words, lock them to a low-noise reference source. What phase noise behavior is expected? A very typical YIG-based synthesizer phase noise profile is shown in Figure 53 (blue curve). The reference source noise normally dominates at very low frequency offsets (region 1), while a relatively flat noise plateau in the region 2 is mainly due to PLL components (e.g., phase detector, dividers, etc.) residual noise limitations. Outside the loop filter bandwidth the noise follows the YIG oscillator free-running curve (region 3). The loop filter bandwidth is

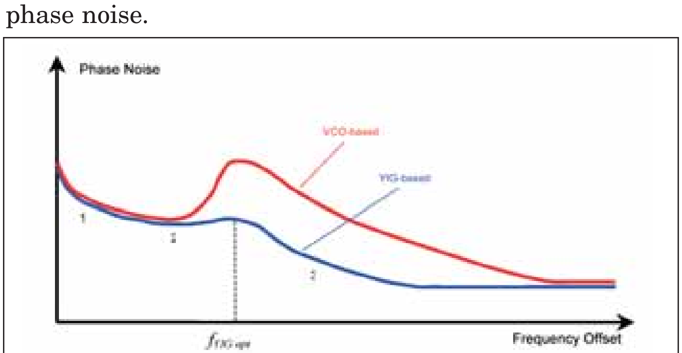

Figure 53 · Locking VCO and YIG oscillators within the same PLL bandwidth.

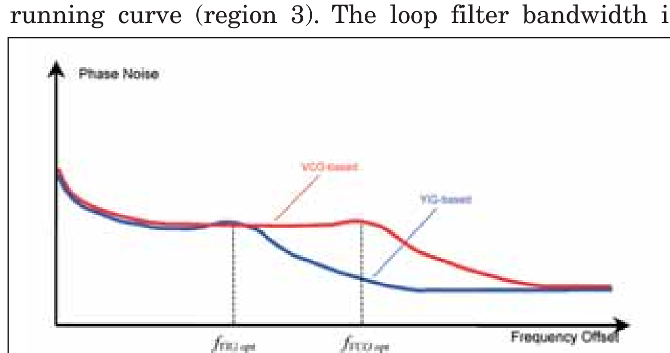

Figure 54 · Locking VCO and YIG oscillators within their optimal bandwidths.

Figure 55 · QuickSyn frequency synthesizer.

Figure 56 · QuickSyn phase noise at 2 GHz output.

preferably set at its optimal frequency (which is the cross point of the PLL multiplied noise and oscillator free-running noise curves) that provides the lowest overall phase noise response.

Trying to lock the VCO within the same loop bandwidth results in a very ugly noise profile due to excessive VCO noise at these offsets (Figure 53, red curve). A smoother phase noise profile can be obtained by locking the VCO within its own optimal bandwidth as shown in Figure 54. Nevertheless, it is still much higher in compassion with the YIG-based counterpart. The difference is indicated as a hatched area in Figure 52 and can be minimized as follows:

1. A very low-noise reference source has to be used.
2. The PLL residual noise floor has to be reduced.
3. The PLL loop bandwidth has to be extended.

Can a VCO-based design achieve YIG-comparable performance? We have already discussed that today's OCXOs provide better phase noise performance (recalculated to the same output frequency) at offset frequencies up to a few hundred kHz. A combined reference (OCXO + CRO or OCXO + DRO) will exceed the YIG-oscillator performance at any frequency offset. Therefore, the limitations are mainly set by a PLL residual noise or, in other words, by a particular synthesizer architecture.

Design Examples

A good example demonstrating the indicated above concept is QuickSyn synthesizer (Figure 55) manufactured by Phase Matrix, Inc. The core model covers 2 to 10 GHz frequency range with about 100 µs tuning speed using a broadband fundamental VCO. The VCO is locked to a built-in DDS that provides sub-Hz frequency resolution without the common penalty of slower tuning. Since DDS-based designs are normally 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). Though PLL spurs dominate, they are easily managed down to about –80 dBc level by optimizing the loop filter. The VCO phase noise is controlled by utilizing an ultra low-noise reference OCXO as well as very wide (a few MHz) loop bandwidth as suggested above. Thus, the synthesizer phase noise within its PLL filter bandwidth mainly depends on the multiplied reference noise as well as residual noise characteristics of the locking mechanism. A novel phase-refining technique (patent pending) is used to minimize the residual PLL noise floor [51]. The technique allows inverting the PLL division ratio (i.e., applying a multiplier within the PLL feedback path) that drastically improves both phase noise and spurious characteristics. The typical phase noise measured at the 10 GHz output and 10 kHz offset is –120 dBc/Hz. The phase noise at the 2 GHz output drops down to –131 dBc/Hz (Figure 56) that exceeds the performance of traditional YIG-based synthesizer designs at the same frequency settings. Phase hits (usually inherent to YIGs) are also reduced due to the use of a low-mass VCO and very wide loop filter bandwidth.

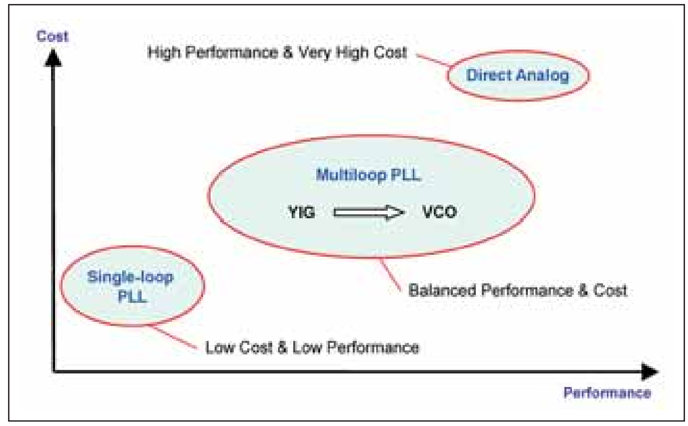

Figure 57 · Synthesizer technologies comparison.

QuickSyn also offers a great functionality including an output power calibration and control, various modulation options (AM, PM, FM, Pulse), external ALC input, independent power and frequency sweep, and list mode. A built-in power equalizer easily sets a flat or virtually any desirable output power-to-frequency profile. It is worth mentioning that these noteworthy characteristics are compacted into a relatively small package (5" × 7" × 1") ideal for a variety of stand alone and embedded OEM applications.

Future Developments

Microwave synthesizers have been continuously evolving and will continue to do so with time. The advancements will be made through architecture optimization, as well as the introduction and improvement of individual components such as VCOs, phase detectors, DDS, fractional-*N* dividers, etc. What architecture will gain in popularity? A quick comparison between the most popular architectures is shown in Figure 57. The direct analog synthesizer is obviously the most advanced solution providing unsurpassed tuning speed and phase noise characteristics. Unfortunately, today's direct analog designs are hardware intensive and, therefore, are limited to the applications where fairly high cost can be tolerated.

Although, some cost reduction is expected with the introduction of new devices (such as a wideband DDS), the most practical near-term developments are likely to be associated with multiloop VCO-based designs. Much of the progress here will be brought by reduction of the PLL residual noise characteristics and simultaneous extension of the PLL bandwidth (targeting the VCO noise floor region). Equipping the synthesizer with a low-noise reference will provide very fast microseconds tuning speed with a "YIG-grade" noise performance at much lower cost in comparison with traditional direct analog and YIG-based techniques. The continuous performance improvement, functionality extension, reduction in cost and size are targets for the new synthesizer designs.

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Editor's Note

The first four parts of this series on synthesizer design are now available online in the Archives section of www.highfrequencyelectronics.com. This final part will be placed in the archives in mid-October.