

An Overview of Today's Microwave Signal Generators Market and Technologies

Alexander Chenakin, Suresh Ojha, Nikolay Shtin

[Summary]

Microwave signal generators are key instruments and are among the most challenging of high-frequency designs. This article presents a brief overview of today's microwave frequency synthesizer technologies for test-and-measurement applications. It begins with general market trends followed by a survey of various synthesizer techniques, which are compared in terms of performance, circuit complexity, and cost impact. Included are direct analog, direct digital and indirect synthesizer architectures along with their main characteristics and performance trade-offs. The latest technology trends, design challenges, and various solutions are discussed.

1 Market Trends

The signal generator (aka frequency synthesizer) is a key instrument of virtually any RF/microwave test-and-measurement system¹⁾. It generates a stimulus signal or is used as a local oscillator on the receiver side. The signal generator is widely used to test, repair, and troubleshoot a variety of electronic devices and systems. According to Frost & Sullivan²⁾ signal generators will be one of the fastest growing segments in the global test-and-measurement market over the next few years as shown in Figure 1. Demand will be driven by the wireless communications, aerospace and defense, automotive industries as well as new technologies such as 5G. The total market for test-and-measurement microwave signal generators is estimated at \$300M with an annual growth rate about 7%³⁾. The growth will be highest in the high frequency segment of the signal generators market (greater than 26.5 GHz). This represents a significant change in the signal generators market, as most revenue is currently generated by the lower than 6 GHz frequencies segments.

Overall, the industry feels persistent pressure to deliver higher-performance synthesizer designs. The ideal synthesizer should be broadband with a fine frequency resolution that allows addressing a wider range of potential applications. Aside from frequency coverage and resolution, phase noise and spurious performance are critical parameters that impose the ultimate limit in the system's ability to resolve signals of small amplitude. Another key parameter of the synthesizer that impacts overall system performance is the frequency switching speed. The time spent by the synthesizer transitioning between frequencies becomes increasingly valuable since it cannot be used for data processing. For example, a synthesizer that switches frequencies in 100 μ s gives a higher measurement capacity than of a synthesizer that switches frequencies in 1 ms. The faster switching synthesizer gives ten times higher throughput and increased product yield in the same time as a single measurement using the slower synthesizer. However, today's systems demand both fast switching speed and the low phase noise performance historically associated with slower frequency switching synthesizers.

Furthermore, today the industry demands more complex waveforms ranging from traditional analog modulation to complex vector formats such as IQ modulation. A shift in market requirements toward higher operating frequencies and wider modulation bandwidths is expected due to the advent of new technologies such as 5G, the next generation of wireless cellular technology, and others.

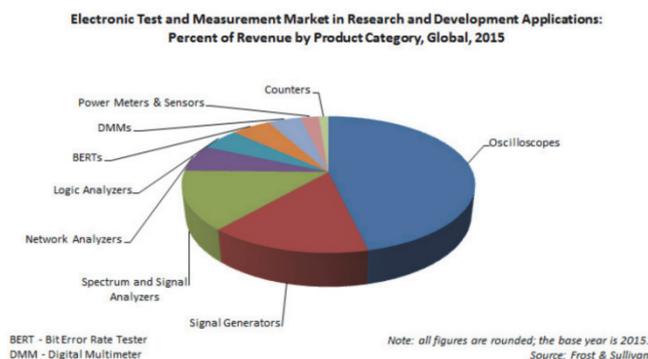


Figure 1 Test-and-measurement instruments

2 Architectures

Microwave signal generators are among the most challenging of high-frequency designs^{4) to 7)}. Synthesizer characteristics depend heavily on a particular architecture that can be classified into a few main groups as indicated in Figure 2. The direct architectures are intended to create output signals directly from the available base frequencies either by manipulating and combining them in the frequency domain (direct analog synthesis) or by constructing the output waveform in the time domain (direct digital synthesis). The indirect methods assume that the output signal is regenerated inside the synthesizer in such a manner that the output frequency relates (e.g., is phase-locked) to the input reference signal. Similarly, indirect synthesis can be accomplished with analog and digital techniques. A practical synthesizer, however, is usually a hybrid design that combines various techniques to take advantage of the best aspects of each.

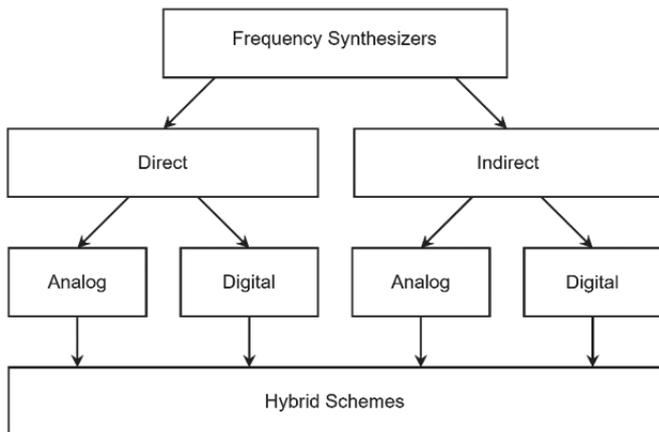


Figure 2 Frequency synthesizer classes

Direct analog synthesizers are realized by mixing base signals at some fixed frequencies followed by switched filters as shown in Figure 3. The main advantage of the direct analog synthesizers is extremely fast switching speed, ranging from micro- to nanoseconds. Another distinct advantage is the ability to generate low phase noise due to usage of components with negligibly low residual noise compared to the base frequency sources. Hence, the direct analog synthesizer phase noise mainly depends on the noise of the available fixed-frequency sources and can potentially be very low. The main disadvantages of the indicated topology are limited frequency coverage and step size as well as high cost. The number of output frequencies can be in-

creased by using a larger number of base frequencies and/or mixer stages. However, this rapidly increases the design complexity and overall component count. Another serious problem is a large number of undesired spurious products generated by mixer stages. These spurs have to be filtered thoroughly that is a serious challenge for the development of a particular synthesizer frequency plan.

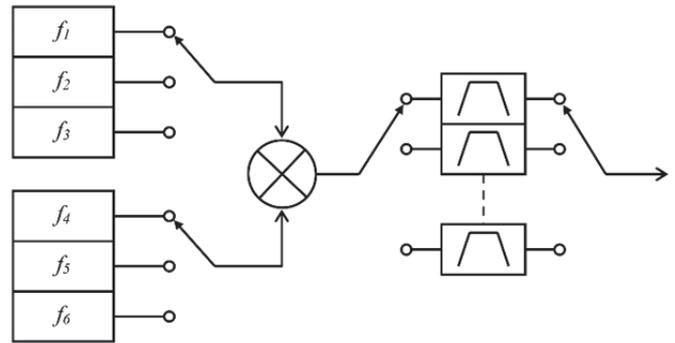


Figure 3 Direct analog synthesizer concept

Another promising approach is based on the concept of consecutive spreading of the synthesizer operating frequency bandwidth. Such a synthesizer structure consists of several cascades that include a programmable frequency divider, mixer and bandpass filter (or switched filter bank) as shown in Figure 4. Several LO frequencies generated by the programmable divider are utilized. The input frequency bandwidth and division coefficients are selected in such a manner that $\Delta f_{i+1} > \Delta f_i$ at continuous coverage. Therefore, every mixer stage increases operating bandwidth until it reaches a desired value.

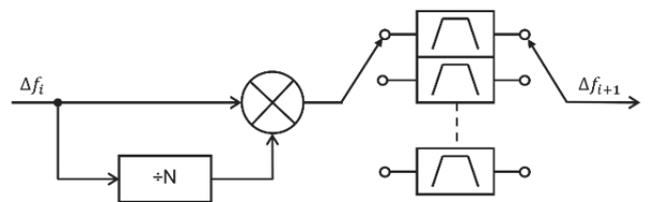


Figure 4 Frequency bandwidth spreading

In general, a large variety of mixing and filtering organization schemes are possible. However, they tend to be hardware intensive if a small frequency step size and wide coverage are simultaneously required. Therefore, while direct analog synthesizers offer extremely fast switching speed and low phase noise, its usage is limited because of high cost characteristics.

In contrast to traditional analog solutions, direct digital synthesizers (DDS) utilize digital signal processing to con-

struct an output signal waveform from an input clock signal. DDS switching speed is mainly limited by its control interface and can be extremely fast - comparable with direct analog schemes. DDS also provides reasonably low phase noise. However, the most valuable DDS feature is its exceptionally fine frequency resolution; sub-Hz levels are easily achieved. The main disadvantages are limited usable bandwidth and high spurs mainly due to quantization and digital-to-analog conversion errors.

DDS are currently available as special integrated circuits or can be built using field-programmable logic arrays (FPGA) and external DAC. Parallel (multichannel) digital structures coupled with high-frequency DACs allow generating output signals directly at microwave frequencies. Further improvements (wider frequency coverage, lower spurs) are possible using two or more DACs in an interleaved data mode as conceptually shown in Figure 5.

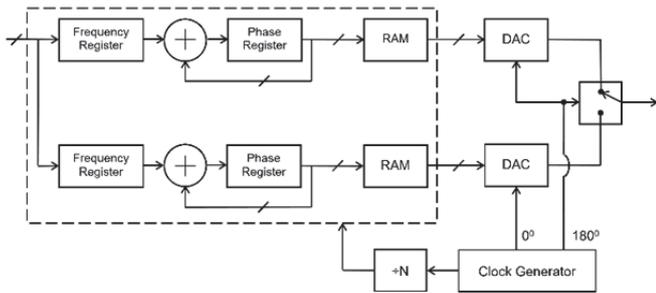


Figure 5 Multichannel DDS with interleaved DACs

Overall, DDS have a tremendous potential for future growth. The extension of DDS usable bandwidth together with its spurious content reduction is the key improvement required by industry. DDS is also widely used in direct analog and indirect synthesizers to provide a desired frequency resolution.

Indirect PLL synthesizers use an additional high-frequency oscillator to generate an output signal at microwave frequencies that is in a certain relationship with the reference signal. The major advantages of PLL synthesizers are reduced levels of spurious signals owing to the low-pass filter action of the loop, and much lower level of complexity compared with the direct analog synthesizers. The main disadvantages are longer frequency switching time (due to a natural delay involved in the phase-lock-loop approach) as well as considerably higher phase noise in comparison with direct analog schemes. Phase noise heavily

depends on the overall division coefficient within phase-lock loop that can be relatively large in order to provide a high-frequency output with a fine resolution.

There is a number of solutions to decrease the loop division coefficient, for example, using fractional division ratios. On the other hand, there are solutions that allow eliminating a frequency divider from the PLL and, therefore, drastically decreasing phase noise. These solutions include various offset schemes as well as multiloop architectures. It is also possible to use some direct analog synthesis methods, for example, using a chain of mixers within phase-lock loop as depicted in Figure 6. All mixer LO signals can be extracted from a common reference source. In this case, all harmonic and intermodulation products generated by the mixer chain are multiples of the phase detector comparison frequency and can be easily filtered out. Further improvements are possible by inserting a frequency multiplier into the PLL feedback path as conceptually shown in Figure 7.

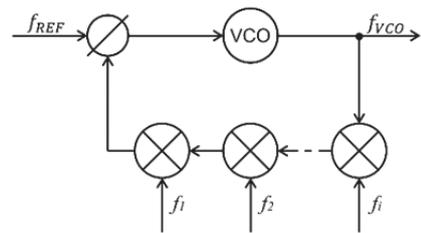


Figure 6 Consecutive frequency conversion within phase-lock loop

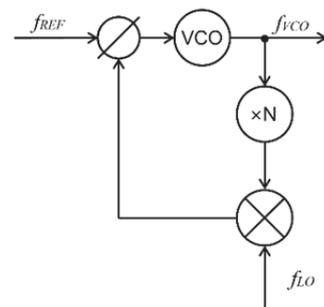


Figure 7 Frequency multiplication within phase-lock loop

Overall, the indirect synthesizer remains the most popular approach at the moment. Further improvements are expected by reduction of PLL residual noise floor in order to support megahertz-range loop bandwidths. Fast switching speed (to several microseconds) and low phase noise (from -130 to -140 dBc/Hz at 10 kHz offset, 10 GHz output) are targets for today's and near future designs.

3 Reference Source

Phase noise of modern microwave synthesizers mainly depends on utilized references such as 100-MHz oven-control crystal oscillators (OCXO). The 100-MHz OCXO can be locked to a 10-MHz OCXO to reduce phase noise at low frequency offsets. Similarly, a higher-frequency oscillator (such as SAW or DRO) can be added to improve phase noise at high frequency offsets. A combined reference source (that contains several oscillators locked to each other) can be used to achieve the lowest phase noise profile at any frequency offset as shown in Figure 8. Further improvements are possible using higher-Q resonators such as a sapphire-loaded cavity oscillator with combined frequency stabilization or optoelectronic methods. It has been reported that sapphire resonator based oscillators have achieved phase noise measurements of -170 dBc/Hz at an output of 10 GHz and 10 kHz offset⁸⁾.

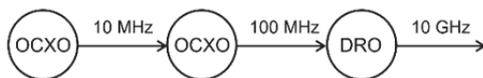


Figure 8 Combined reference source

4 Conclusions

The test-and-measurement synthesizer market is currently estimated at \$300M with an annual growth rate about 7%. As of today, traditional indirect PLL architectures still dominate. On the other hand, direct analog synthesis is the most advanced approach that demonstrates extremely fast switching speed and low phase noise. Although direct analog synthesizers are usually quite expensive, they can be successfully used at some applications where fairly high cost can be tolerated. Future developments are associated with direct digital synthesis due to the rapid progress in solid-state technologies. The extension of DDS usable bandwidth to several tens of gigahertz with its spurious content reduction is expected. Modern synthesizers are also expected to generate complex waveforms using vector IQ-modulation. Further major breakthroughs are possible operating the reference with other physical principles or materials such as DRO or sapphire-loaded cavity oscillators with combined frequency stabilization.

References

- 1) A. Chenakin, "Frequency Synthesis: Current Status and Future Projections," *Microwave Journal*, April 2017, pp. 22-36.
- 2) "Signal Generators Market: Key Specifications Change with 5G," Frost & Sullivan, www.frost.com, April 2016.
- 3) "Analysis of Opportunities for Signal Generators Market," Frost & Sullivan, www.frost.com, September 2015.
- 4) A. Chenakin, *Frequency Synthesizers: Concept to Product*, MA: Artech House, 2010.
- 5) V. Manassewitsch, *Frequency Synthesizers: Theory and Design*, 3rd ed., NJ: Wiley, 2005.
- 6) V. Kroupa, *Frequency Synthesis: Theory, Design and Applications*, New York: Wiley, 1973.
- 7) J. Crawford, *Advanced Phase-Lock Techniques*, MA: Artech House, 2008.
- 8) C. McNeilage, et al., "A Review of Sapphire Whispering Gallery-Mode Oscillators Including Technical Progress and Future Potential of the Technology," *IEEE Int. Frequency Control Symposium Proc.*, August 2004, pp. 210-218.

Authors



Alexander Chenakin
Service Infrastructure Solutions
US Division
Measurement Business Division



Suresh Ojha
Service Infrastructure Solutions
US Division
Measurement Business Division



Nikolay Shtin
Service Infrastructure Solutions
US Division
Measurement Business Division

Publicly available