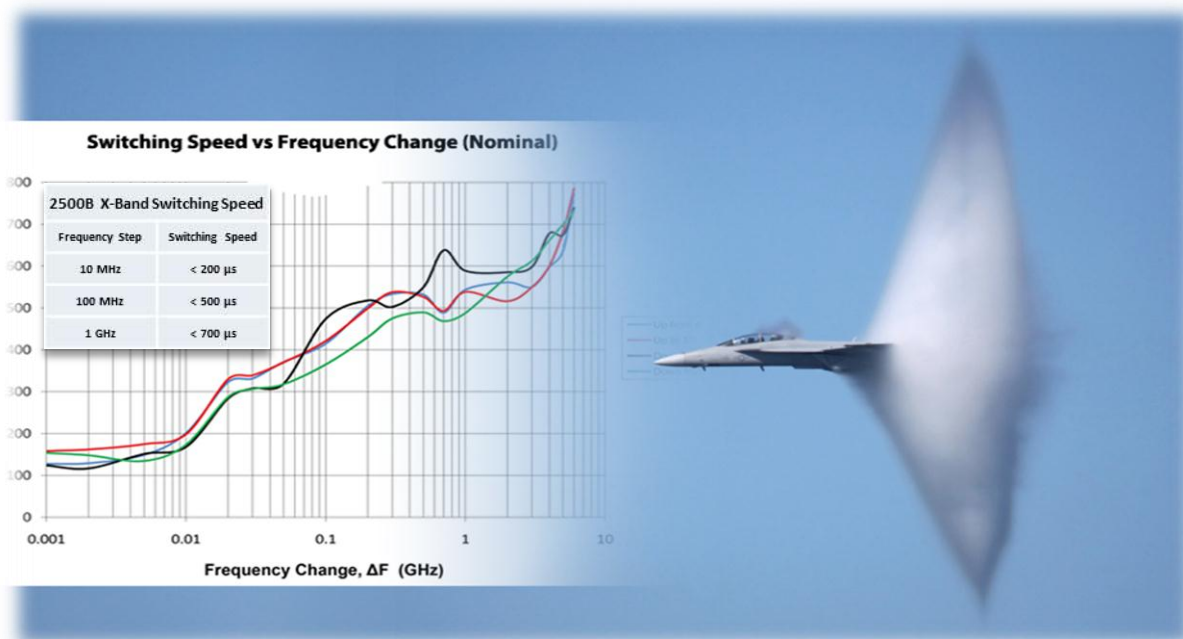


Frequency Switching Speed in Microwave Signal Generators

Application Note



Agile Frequency Generation – how fast can I tune?

From calibrating Cellular receivers to agile Electronic Warfare transmitters, the ability to change from one frequency to another and settle within a specified amplitude and frequency is a key requirement for microwave signal generators. But what actually defines the frequency switching speed? What components in the block diagram contribute? What is the specification trade-off with respect to architecture and technology choices? To help answer all these questions, and hopefully generate a few more, let's take our signal generator apart and see what contributes, and why.

First we should define what we mean by "frequency switching speed." For the purposes of this article we will define it as the time it takes to move the output frequency of a synthesizer from frequency A to frequency B. By the end of that time we will specify how close we are in Hz to the desired frequency and to within how many dB's of amplitude the output of the source is to the desired absolute amplitude.

Question: Why can't it be the frequency and amplitude desired, why do we have to specify these "settling" parameters? We'll learn the answers in detail as we go through this paper, but for now the short answer is that the frequency and amplitude accuracy circuits all employ some type of filtering or feedback mechanism. These mechanisms include the associated time constants caused by filter group delay, components charging/discharging, hysteresis functions, temperature variance and electronic switch speeds. Of course the less analog circuitry there is the faster the instrument will be; there is an all di

gital method and we can show why and where Direct Digital Synthesis works (DDS), and how it compares to VCO (Voltage Controlled Oscillators) and YTO (YIG Tuned Oscillators)-based analog generators.

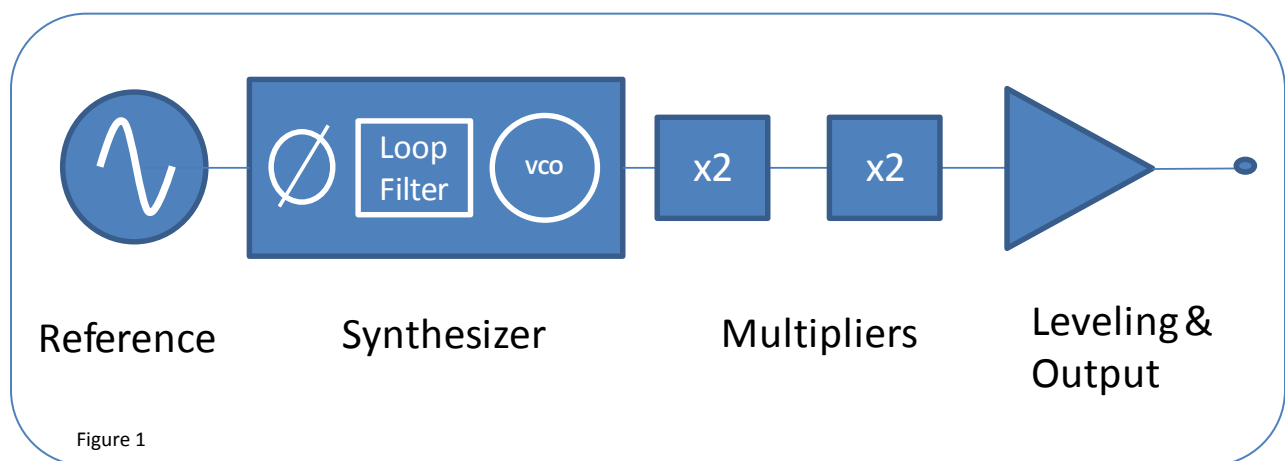


Figure 1 shows the block diagram of a conceptual signal generator. The principle of operation is straightforward: starting with the reference - this does what it says, and generates a reference

frequency for the synthesizer to compare against or multiply (depending on the type of synthesizer architecture employed). The synthesizer component of the block diagram generates a range of frequencies. For example the Giga-tronics 2500B Microwave Signal Generators, which is called an indirect synthesizer (more on that later), uses what we call a wide-range 4 to 10 GHz YIG-tuned oscillator. Then banks of switched banded multipliers provide the higher frequencies, for example 10 to 20 GHz is provided by x2 multiplication, 20 to 40 GHz by x4 and 40 to 50 GHz by x6. Finally to ensure the amplitude is set correctly there is usually an Output and Leveling stage, which often utilizing a circuit that fine tunes the amplitude level automatically – referred to as the ALC, or Automatic Level Control.

Let's now dissect this block diagram and see how each of the components contributes to the frequency switching speed.

The Reference

No matter the type of architecture employed all signal generators use a frequency reference. This is a fixed frequency device and provides a very stable "reference" signal that is used to derive the microwave signals we wish to generate. It's a crucial element in the block diagram and a major contributor to close in phase noise – but for the purposes of this paper, it has no impact on the frequency switching speed.

The Synthesizer

This is the heart of the instrument; here we generate what we will call the fundamental microwave frequencies. There are essentially two methods architectures that can be employed these are often referred to as Direct and Indirect Synthesis methods.

1. Direct Synthesis

There are a number of analog direct synthesis generators in the market today. They do exactly as advertised and perform a series of arithmetic operations on the signal from the frequency reference to achieve the desired output frequency. The direct synthesis approach has the advantages of permitting fine resolution and fast switching as well as a spectrally clean output signal. As these types of generators usually use a lot of components, they tend to be expensive and also have lower mean time between failures than an indirect synthesis approach.

Recently we've begun to see the emergence of Direct Digital Synthesis technology (DDS). In terms of speed, DDS is by far the fastest way to generate frequency A, then frequency B. In the microwave source world this is an up and coming technology, which offers excellent tuning speed (sub microseconds) combined with great phase noise. In terms of what signals can be generated to what level of spectral purity, DDS technology is limited today to a frequency range of a few GHz with a



high spurious content. So whatever speed advantages are gained in the synthesizer, elements such as banks of switched banded multipliers to get to higher frequencies, (more details on these later), and filters to help attenuate its spurious signals contribute to a degradation in overall switching speed of the instrument.

2. Indirect Synthesis

Most commercially available high frequency signal generators today use either a Voltage Controlled Oscillator (VCO) or a YIG Tuned Oscillator (YTO) approach or even a combination of both. (Some may even include a DDS.) YTO and VCO technologies have excellent high frequency generation capability combined with excellent spectral performance. In terms of speed this type of approach can provide very clean signals with frequency switching speeds in orders of sub milliseconds. Both technologies are key elements and variants in the phase locked loop (PLL) architecture used in many frequency synthesis circuits. The operation of a PLL is fundamentally simple - the oscillator - VCO or YTO's frequency accuracy is a function of the difference between the generated signal and the reference signal. If the reference signal is 100MHz and the desired output signal is 100MHz then the error is zero, which means zero Hz error and zero phase error. If the desired frequency is 100MHz and the oscillator output is 100.1MHz, then we have a 0.1MHz error, which will translate into a phase comparison error; ultimately after filtering this translates to a correction voltage. Of course the desired signal is rarely the reference signal, so a frequency division circuit is used to reduce the generated signal frequency to that of the reference frequency, plus of course the frequency error. As you can see, the feedback mechanism employed has a time associated with the how quickly the desired frequency can be obtained. The Giga-tronics 2500B series of signal generators use a patented Accumulator High Frequency Feedback (AHFF™) technology delivers to ensure feedback times are kept minimal.

VCO's in this type of circuit have the reputation of being second in the speed race after DDS. However the noise performance can be a limiting factor especially in terms of phase noise, around 1kHz to 1MHz. There are techniques that can reduce this and synthesizers exist in the market with comparable low phase noise.

The YIG tuned oscillator approach yields the highest spectral purity but does have a reputation of being slower than the VCO approach. However instruments such as the Giga-tronics 2500B have a unique design with respect to the YTO employed in the synthesizer. By reducing the number of turns on the YIG main coil and using a high voltage to induce a high EMF, the tuning speed of the system can also be dramatically improved.

So far, we've learned that if we can generate a frequency in the low GHz range utilizing a DDS with sub microsecond speed, but with a high spurious content, then higher and more spectrally pure frequencies can be generated using a PLL utilizing either a VCO or a YTO with sub millisecond speed.



VCO's have the reputation of being faster and but less spectrally pure, while YTO's have the reputation of being slower but with excellent spectral purity. By searching through various patents you'll find techniques for fast YTO circuits (an example being the Giga-tronics 2500B) and excellent phase noise VCO circuits.

Frequency Multipliers, Filters and above all Switches

Say we want to multiply our 1 GHz DDS, or 10 GHz YTO signal? To do this we need to employ a frequency doubling circuit. In the analog realm, frequency multiplication is usually done by creating a harmonics by rectifying, or in some cases distorting the signal; both methods require a bandpass filter (or a bank of filters) to attenuate everything but the desired harmonic. The largest timing elements that come into play here is that the multipliers and filters are usually multiplexed using switches. Each switch has a time associated with both the driver circuit employed and the bias circuit. If the switch is electronic then the timing could be negligible (say 10's of nano seconds); however this switch time needs to managed, i.e. set within the tuning and setting of the PLL, or the translation time from the setting of the frequency word to the actual generation of the signal in a DDS.

The Output Stage

Absolute amplitude accuracy can be crucial, especially if you are using the Signal Generator to calibrate the flatness of a receiver. However, maintaining absolute amplitude accuracy over a range of varying operating conditions over time requires a feedback loop to measure the actual amplitude and correct for the desired amplitude. As with the PLL, this is another operation within the instrument that can add further timing delays. Many instruments offer an option to not use the ALC, which may be possible if the generator is not being used to calibrate a receiver or the temperature can be controlled.

Control Considerations

We can split this into two types of speed - Deterministic speed, i.e. we know the absolute speed of the transaction and Non-Deterministic speed, i.e. the speed will vary based on other factors such as how many instruments sharing the control interface. LAN and PCI (used in PXI instrumentation), are example of the latter as they primarily rely on a serial interface. To overcome interface speed deficiencies, many instruments have a facility to program a set of instructions within the instrument; these are sometime referred to as lists. The list stored within the instrument would contain a list of frequencies and amplitudes for example; each list element may be incremented by either a defining a dwell time for a single list element, or have the list increment by using an external trigger. The 2500B series of instruments comes with an easy-to-use piece of software called Automation Express to ease the creation of lists. Some high speed direct frequency



synthesizers employ highly deterministic interfaces, as sometimes the next frequency the instrument has to tune to may not be known.

Conclusion: The moving bottleneck

In conventional high performance instruments, the speed bottleneck today is the synthesizer. As DDS technology matures we may see the bottlenecks move from the synthesizer itself to the switches that select the multipliers and even, in some extreme cases, to the group delay of the filters. As with every engineering problem, we are presented with a number ways of solving this problem, each having a specific set of trade-offs. DDS technology, while being extremely fast, requires filtering and a many stages of multiplication, not only introducing more switching time losses across bands, but also a degradation in phase noise for every multiplication. The work horses of the industry today are YTO based or YIG based synthesizers, offering sub millisecond switching times with excellent spectral purity. Finally, regardless of the synthesizer approach an instrument uses, don't forget to take into account the final two bottlenecks: (1) The output circuitry required for accurate absolute amplitude accuracy, and (2) Determining the best choice of how the instrument is controlled: either by using direct control across LAN or PCIe, or by utilizing an internal list.



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