A new breed of VXIbus microwave signal generator architecture

By Michael N. Granieri, PhD

The need for flexible Microwave (MW) signal sources is fundamental to the testing process. With the recent boom in microwave and digital communications, an increased need for MW signal sources has emerged in both manufacturing and depot/maintenance testing environments. The small form factor and modularity afforded MW sources implemented in the VXIbus standard ensure that the needs of these diverse environments can be accommodated in support of rack-based systems as well as portable/transportable test system applications.

Microwave signal generators perform their frequency generation function by employing any number of direct and/or indirect *frequency synthesis* technologies. *Frequency synthesis* may be defined as a process by which a set of frequencies with predefined upper and lower bounds may be generated from a single time base (frequency reference) in such a way that the ratio of the output to the reference frequency is a rational fraction. Frequency synthesizers are essential to Test and Measurement (T&M) applications where flexible stimulus sources are required to produce variable or programmed frequency signals in support of both CW and signal modulation applications. Frequency synthesis technologies often employed in a T&M context include: Phase-Locked Loop (PLL) frequency synthesizers, Direct Analog (DA) frequency synthesizers, and Direct Digital Synthesis (DDS)[1].

Frequency synthesizers employing PLL technology, an indirect frequency synthesis technique, are commonly used throughout the electronics industry. The PLL employs a feedback mechanism, locking its programmed or selected output frequency to a highly stable reference frequency. PLL synthesizers are extremely popular due to their simplicity, availability in a variety of integrated circuit formats, and relatively low cost.

Direct Analog frequency synthesizers, a direct frequency synthesis technique, typically employ a number of crystal oscillators, frequency multipliers/mixers, filters, and switches to affect the frequency synthesis function. Using this technique, it is possible to generate a vast array of frequencies with the same time base accuracy that the fundamental crystal oscillator employed. This frequency synthesis technique often offers excellent spectral purity and switching speed – frequency hopping from frequency to frequency – but is often more complex, more costly, takes up more volume, and consumes more power than indirect synthesis techniques.

Lastly, Direct Digital Synthesis is a DSP discipline that employs direct digital synthesis techniques to create, manipulate, and modulate a signal digitally and subsequently convert the digital signal to its analog form by employing a Digital to Analog Converter (DAC). DDS is an extremely powerful technique; in T&M applications, signal generators employing such techniques are often referred to as *Arbitrary Waveform Generators* (AWG). As the name implies, the output is completely arbitrary and only limited by the user's imagination. However, DDS technology is not without its limitations; current, state-of-the-art DDS technology may be limited in terms of stimulus bandwidth to 1 GHz. Often, signal generator and Local Oscillator (LO) manufacturers utilize a *hybrid* approach employing a combination of these technologies to optimize price, speed, spectral performance, power consumption, and/or volume and weight in order to satisfy end-user test requirements.

A flexible architecture

A traditional *legacy* instrument architecture (circa 1980s timeframe) employed by prior generations of RF/MW stimulus generators is depicted in Figure 1[2]. This class of instrument architecture has served the T&M industry and its customer base well in the past few decades. The instrument's functional capability consisted of RF/MW CW signal generation and classical analog amplitude, frequency, and pulse modulation capabilities. This functional capability was adequate to support the test and measurement needs of both legacy commercial and aerospace/defense communication systems. During the past decade, a new breed of communication system has evolved, employing extensive use of DSP and Digital Modulation (DM) concepts. This new class/type of Unit Under Test (UUT) cannot be adequately tested by legacy RF stimulus generators due to their limited/fixed signal modulation capabilities.

Because of this *digital revolution* in both the commercial and aerospace/defense sectors, a need has emerged for a new class/type of RF stimulus generation architecture and capability in Automatic Test Systems (ATS) that can accommodate both legacy and new/emerging DM formats.

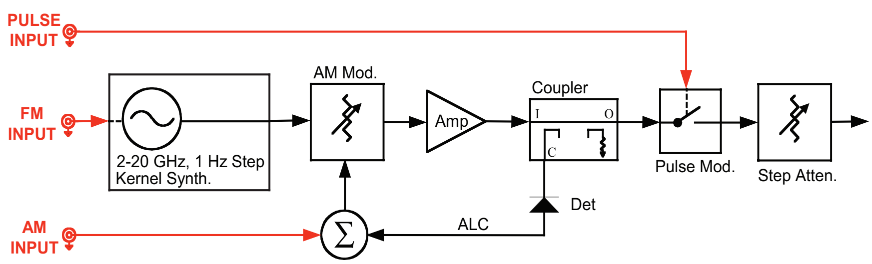

Figure 1

> "… the modern day VXI-based microwave signal generator must encompass the dual functionality of a generic frequency synthesizer and upconverter integrated with the signal modulation attributes of both traditional analog and emerging digital modulation technology …"

Figure 2 depicts an example of a state-of-the-art microwave synthesizer/upconverter architectural design employing a flexible mix of primary functional modules such as: frequency synthesizer, mixer, Yttrium Iron Garnet (YIG) band pass filter, RF amplifier, modulation circuitry, programmable output step attenuator, and a versatile IF function module[3]. These functional modules provide critical VXI user capabilities such as CW frequency synthesis, analog and digital modulation, emulation of complex *threat* scenarios, and intermediate frequency upconversion. Due to space limitations in small portable/transportable test systems, the modern-day VXI-based microwave signal generator must encompass the dual functionality of a generic frequency synthesizer and upconverter integrated with the signal modulation attributes of both traditional analog and emerging digital modulation technology. This dual synthesized upconverter functionality is needed to address user needs in terms of both a broad and flexible CW and modulation capability when employed within a Synthetic Instrument (SI) context in modern-day test systems. The flexible synthesized upconverter architecture depicted in Figure 2 can be tailored/adapted in a modular fashion to address the unique needs of each major use case and application. A brief description of this flexible upconverter architecture is provided in the ensuing paragraphs.

Synthesized upconverter explained

In the CW operation mode, the architecture employs a hybrid mixture of frequency synthesis techniques described previously to generate stable, spectrally pure RF/MW CW signals in the range of 2 to 20 GHz, with a 1 Hz resolution. The output signal of the mixing process is filtered by a tunable YIG filter with a minimum 50 MHz bandwidth and amplified.

To illustrate, suppose a 10 GHz signal is desired from the upconverter/synthesizer. In order to generate this signal, the kernel synthesizer internally sets its fine and coarse loops to generate a 9.0 GHz signal from the *kernel* synthesizer's output to the *L* input of the mixer. This signal is then mixed with an internal 1,000 MHz signal from the IF driver functional block to produce the 10 GHz output. The YIG filter is programmed to 10 GHz to eliminate superfluous mixer products and ensure that a spectrally pure 10 GHz signal is subsequently transmitted to the upconverter's signal output port. This signal generation/architectural technique is employed to keep the *mixer in play* in support of both classical CW synthesis and modulation applications and to eliminate RF/Microwave mode switching and its associated signal degradation effects.

With the architecture depicted in Figure 2, it is a simple process to translate or up/down convert an IF signal to any microwave output frequency in the frequency range of 2 to 20 GHz. Besides providing a fixed 1,000 MHz internal signal, the IF function module has the flexibility to also pass through a complex external IF signal encompassing a multitude of discrete frequency components in the 300 to 1,000 MHz (UHF band) range from a front panel IF input; this complex IF signal can be emulated via an arbitrary function generator. This attribute enables a complex IF signal – for example, sophisticated signal jamming scenarios – to be incorporated within the band pass limit of the YIG filter into the upconverted output signal at the target microwave carrier frequency. If desired, the microwave carrier frequency of the complex IF signal can be changed to any value between 2 and 20 GHz via setting/programming the kernel synthesizer to the new desired value. The architecture allows the Automatic Leveling Control (ALC) loop to control the output level of the upconverted signal or, if the level of the IF input is to be maintained, the leveling loop can be turned off.

Besides having the facility to perform complex IF signal generation/emulation, the synthesized upconverter architecture depicted in Figure 2 can perform classical AM, FM, and pulse modulation as well as DM.

A digital modulation capability provides more information capacity, higher data security, compatibility with data services, and better quality of service than traditional or legacy communication systems.

Digital modulation mathematics

DM is affected via employing an I&Q modulation capability whereby a binary digital stream (00,01,10,11) can be represented by a unique RF composite signal, or signals, in the I/Q domain that is characterized by the magnitude and phase of both its in-phase and quadrature components (or I&Q)[4]. I&Q modulation is a method for combining two channels of information at the signal transmission end of a communication system in order that they can be separated at the receiving end. Let's look at the concept of I&Q in a little more detail from a mathematical perspective.

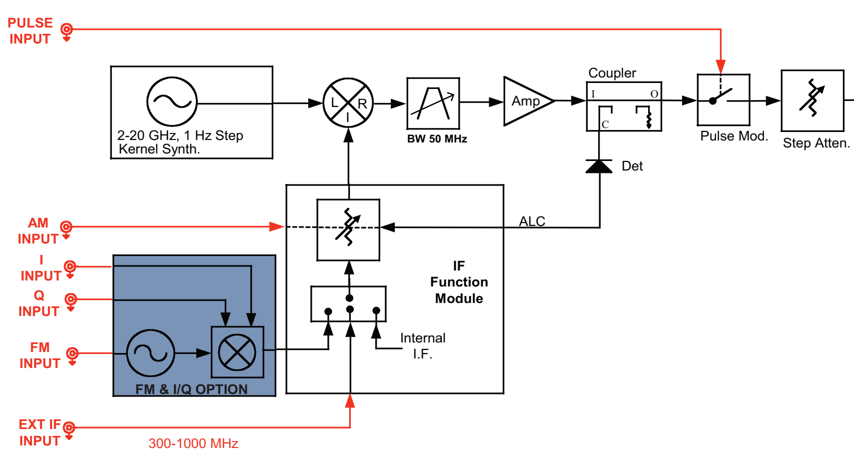

Figure 2

Mathematically, any RF/MW signal can be expressed as the sum of an in-phase and quadrature component as follows:

(1) $S(t) = A(t) \bullet \cos(\omega t + \phi(t))$

Substituting the trigonometric identity:

(2) $\cos(\omega t + \phi(t)) = \cos(\omega t)\cos(\phi(t)) - \sin(\omega t)\sin(\phi(t))$

Expanding the equation results in the following expression:

(3) $S(t) = A(t) \bullet [\cos(\omega t)\cos(\phi(t)) - \sin(\omega t)\sin(\phi(t)]$

Collecting terms we have:

(4) $S(t) = [A(t) \bullet \cos(\phi(t))] \bullet \cos(\omega t) - [A(t) \bullet \sin(\phi(t)] \bullet \sin(\omega t)$

Where the in-phase component of the composite signal is referred to as the *I* component:

(5) $I(t) = A(t) \bullet \cos(\phi(t))$

Conversely, the quadrature component of the composite signal is referred to as the *Q* component:

(6) $Q(t) = A(t) \bullet \sin(\phi(t))$

Substituting equations **(5)** and **(6)** into equation **(4)** results in the final form below:

(7) $S(t) = I(t) \bullet \cos(\omega t) - Q(t) \bullet \sin(\omega t)$

Thus, at any point in time, any RF/MW signal can be represented by a unique vector:

(8) $S(t) = A(t) \bullet e^{j\phi(t)} \bullet e^{j\omega t}$; with a magnitude $|A|$ and phase angle ϕ rotating at an angular carrier frequency of ωt.

It should be noted that the baseband I (t) & Q (t) terms define a modulation signal M (t), which can be expressed as a complex quantity as follows:

(9) $M(t) = \mathbf{I}(t) + \mathbf{J}\ \mathbf{Q}\ (\mathbf{t})$; or in vector notation $M(t) = A(t) \bullet e^{j\phi t}$

Thus from a digital communications perspective, it is possible to generate and detect N unique vectors that are representative of a composite signal that maps to a specific signal constellation of magnitude and phase. For example, *Quadrature Phase Shift Keying* (QPSK) is a modulation methodology that can map a two-bit binary bit stream [00, 01, 10, 11] to a unique signal constellation or vector space [S11, S12, S13, S14] where each vector has a unique magnitude and phase signature. Equation (9) is the basis for the design and development of vector signal generators that develop a succession of I&Q data pairs. The resultant signal corresponding to each pair of values can be represented as a vector of the absolute value of length A (such as $|A|$) rotated by an angle ϕ.

That is, an I&Q-capable stimulus generator provides the capability to transform bits-to-microwave signals and provide a virtually unlimited signal modulation capability – Binary Frequency Shift Keying (BFSK), QPSK, and Quadrature Amplitude Modulation (QAM) – within the bit error constraints of a target application.

Hardware

DM involves the control of the phase of a signal through a device referred to as an *I&Q modulator*. Figure 3a below depicts a high-level physical model of an I/Q modulator based on equation (7) above where a carrier wave S(t) with an applied phase shift ϕ is represented mathematically (see Figure 3b) as the sum of two components, a Cosine wave and a Sine wave.

I(t) represents a binary bit stream in time that controls the real, or in-phase, *I* component of the modulated carrier signal, and conversely, Q(t) controls the imaginary, or quadrature-phase, *Q* component of the signal. As shown in Figure 3a, the two carrier waves of the same frequency, a Cosine and Sine, are combined to form the composite output signal. For DSP purposes, the two components are normally represented as a complex number I+jQ; the term *complex digital modulation* is often attached to this vector signal generation technique.

It is essential that modern-day VXI synthesizers/upconverters incorporate modulation capabilities that can accommodate not only user legacy analog modulation needs but also have the flexibility of accommodating both current and future DM formats as well. Incorporating an I&Q modulation capability into an MW signal generator's baseline architecture achieves this objective.

Microwave signal generators increasingly critical

In the context of supporting modern day, communication intensive systems in a VXI portable/transportable automatic test system environment, the microwave signal generator is increasingly becoming a critical ATS component and should provide, in addition to its fundamental frequency synthesis functional capability, the dual functionality of a RF/microwave upconverter and a flexible modulator employing both classical analog and digital modulation capabilities. The synthesized upconverter architecture described demonstrates the utility/usefulness of employing these attributes and has the architectural flexibility of being employed in both commercial and DoD SI-based systems with broad-based and evolving test requirements and long service lives. Ω

References

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[3] http://www.phasematrix.com, Synthetic Instruments.

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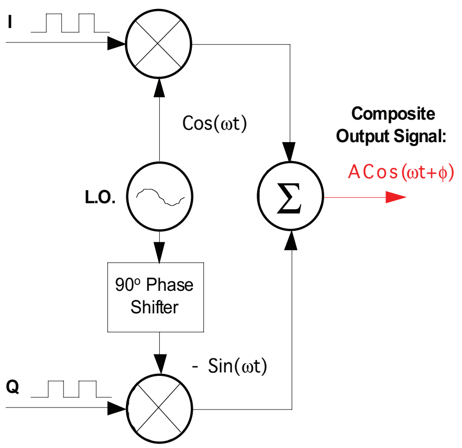

Figure 3a

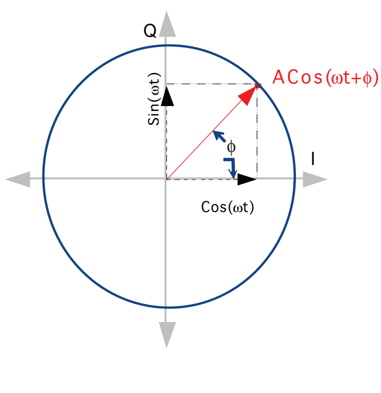

Figure 3b