PHASE COHERENT MULTI-CHANNEL RF SYNTHESIS

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INTRODUCTION

Multi-channel synthesis applications require specific performance parameters that are often overlooked with the design of single channel synthesizer systems. Performance specifications for multi-channel synthesis applications typically require channel to channel, short and long term phase coherence that is not possible with phase-locking an N-number of single channel synthesizers together. This configuration only creates a long term phase-lock 'average' between the outputs. Each individual synthesizer also contributes to the short term stability of this system, which is problematic with traditional phase locked synthesizers.

Holzworth Instrumentation has taken a new design approach to the multi-channel synthesis system. The unique architecture of Holzworth's single channel series of synthesizers actually provides optimal performance in a multi-channel synthesis environment due to the elimination of the PLL. These non-PLL synthesizers provide superior channel to channel short and long term phase stability and phase coherency. The compact size, relative low cost and high performance of a single channel has enabled Holzworth to provide four and eight channel synthesizer modules with independently tunable channels that consume only 1U of space in a 19 inch rack.

SINGLE CHANNEL SYNTHESIS

There are two main methods of reference based frequency synthesis: phase locking and frequency multiplication (including translation). Phase locking a free running high frequency oscillator (VCO) to a lower frequency reference is by far the most common method and has several advantages which include: compact size, low cost and relative ease of implementation. However, there are several disadvantages to be noted: additional phase noise within the feedback loop, potential phase hits from the free running VCO, slow frequency tuning and phase drift. In contrast, frequency multiplication based synthesis has superior phase stability, faster frequency switching speeds and phase continuous frequency changes.

Holzworth synthesizers utilize proprietary frequency multiplication and translation techniques that eliminate the need for any free running oscillators and feedback loops. The synthesized output is exactly phase coherent with each reference clock cycle of either the internal 100MHz OCXO (Oven Controlled Crystal Oscillator) or an external reference. One of the primary advantages is residual phase noise performance (additive noise) that is among the lowest in the industry.

TRADITIONAL PLL BASICS

The phase-locked loop (PLL) has been widely used in traditional tunable RF synthesis design to maintain a "fixed" phase relationship between a generated (output) frequency and that of a reference signal. The phase relationship of a voltage controlled oscillator (VCO) is compared to that of a reference and the error difference between these signals is output to an integrating filter and back to the VCO. This is a very effective method for achieving long term stability, but short term phase stability can suffer. When a phase (frequency) variation within the VCO occurs, an error must first be generated in the phase detector before a correction can be sent back to the VCO. The average phase relationship over time remains stable, but is subject to deviations until the correction occurs. Free-running VCOs are susceptible to phase hits (temporary jumps in phase or frequency). These phase hits can be caused by nearby oscillating modes in the VCO, EMI, vibration and/or power supply variations. The PLL does correct for these hits, but will take time to accomplish the task. Figure 1 contains an example of how a phase hit can shift the overall phase of a signal prior to PLL correction.

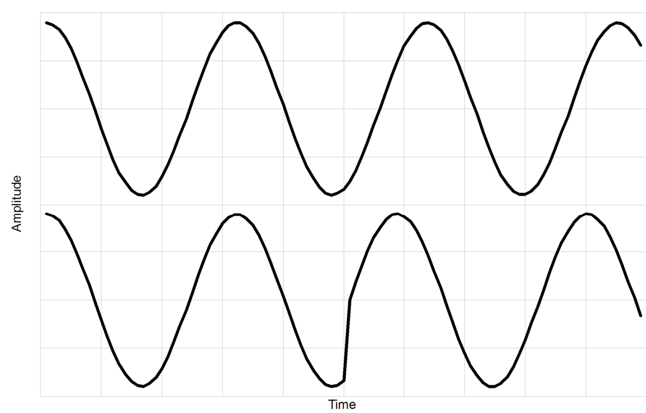

Figure 1: Phase Shift resulting from a 'Phase Hit'

The PLL also affects factors such as tuning speed and settling time. When a new frequency is selected it takes a finite amount of time to tune close to the new frequency and then a relatively greater amount of time to settle to the more precise value. This can be compared to an L-C or R-C filter response. When applying a step response, these basic circuits will settle to near the final value very fast, but then takes an order of magnitude greater time to settle to a very exact value. Even fast tuning PLLs will take 10us-100us to settle to a precise value. Phase errors are introduced during this settling time.

MULTIPLIED SYNTHESIS BASICS

The most obvious difference in a frequency multiplication based synthesizer is the absence of a frequency or phase feedback loop. The output is a near-exact multiplication of the input reference in terms of phase and frequency. Gone are the majority of issues regarding switching speed and settling time as well as errors in the phase relationship between the output and reference signal beyond thermal drift of components (i.e. RF amplifiers). The higher frequencies are related in time to the zero crossings of the reference. Figure 2 shows the time domain representation of a 2X (doubled) frequency multiplication.

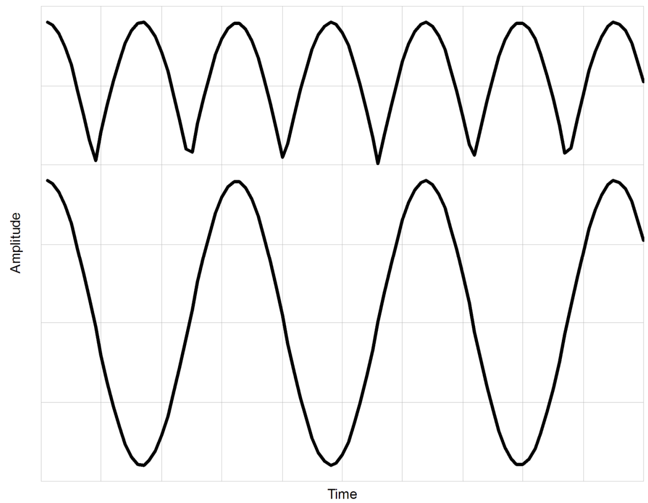

Figure 2: Example of Frequency Doubling

The phase noise performance of frequency multiplication architectures is typically better in the 1kHz to 100kHz offset region because there is no PLL feedback circuit noise to cause degradations. Below 100Hz offset, the phase noise in both PLL and non-PLL architectures is dominated by the phase noise of the reference. Far from the carrier phase noise (>1MHz) is typically better in PLL-based synthesizers because the free running VCO also serves as a cleanup loop.

Finally, frequency multiplication architectures are known to exhibit undesired sub-harmonic spurs. Holzworth has developed a proprietary filtering architecture that removes spurious signals to below -70dBc, while maintaining extremely fast switching speeds and monotonic phase coherence between frequencies.

When properly architected, the primary advantages of the multiplied synthesis architecture include:

- Improved settling time
- Improved switching speed
- Short and long term phase stability
- Phase continuous frequency switching
- Improved close to the carrier (<1MHz) phase noise
- Significantly reduced chance of phase hits
- Thermal continuity between channels reduce drift

MULTI-CHANNEL SYNTHESIS

Holzworth Instrumentation has invested years of development to refine proprietary architectures which allow for optimized synthesis performance from frequency multiplication and translation, while completely eliminating the VCO and the PLL.

This unique architecture allows for independent control of each channel within a multi-channel module. Beyond the standard performance demonstrated in Holzworth's single channel synthesizers, cycle to cycle coherency, independent phase offset capability and the lowest possible channel to channel phase drift are key advantages to the Holzworth proprietary architecture. The phase drift between channels will typically deviate no more than 1 degree over a 12 hour period. Figure 3 contains 1 hour phase drift data measurement between two channels at 3GHz under standard laboratory operating conditions.

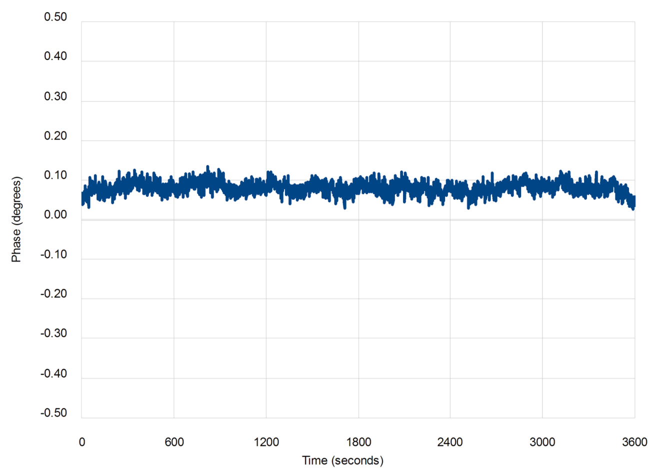

Figure 3: 3GHz 2-Channel Phase Drift at 3GHz

To better demonstrate the advantages of leveraging the frequency multiplication architecture in multi-channel synthesis, some specific applications examples are outlined below.

1. Ramp (Chirp) Generation with Integrated Down-Conversion

Multi-channel synthesis may have additional 'desired' expectations besides phase noise and phase stability. Phase-continuous frequency switching is a parameter that can leveraged for ramp generation. Given any two channel output signals with one set at a fixed frequency (for later down-conversion), the second channel is used to develop a ramp (or chirp) relative to the first frequency. The changing difference in frequency and phase between the two channels remains both coherent and continuous. The lack of short term phase deviation, as in a PLL environment, enables an extremely high resolution of returned Doppler shifted frequencies. Figure 4 demonstrates phase continuous frequency switching graphically.

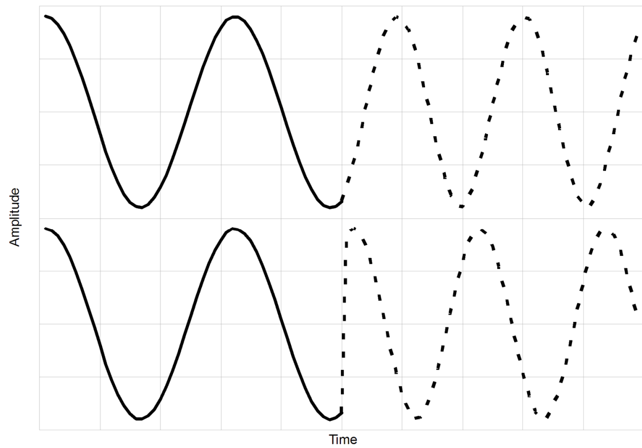

Figure 4: Phase Continuous vs. Discontinuous Switching

2. Laboratory Grade Arbitrary Frequency Distribution

In a high accuracy timing environment, as with a standards laboratory, there are advantages to route multiple high coherent reference signals around a laboratory at arbitrary frequencies and phase, but all signals must remain coherent to a stable reference. Holzworth multi-channel synthesizes can be manufactured with a 10MHz reference input option. This allows for channel to channel coherence with each cycle of a precision 10MHz reference without the need for phase locking.

3. Array Type Applications

A multi-channel synthesizer may be used to drive a fast tuning phased array directly. Using the programmable USB update rate of 1ms, the internal lookup table with rates of <20µs, or the optional SPI interface; Holzworth multi-channel synthesizers can be used to beam steer an array directly. Simultaneous pulse modulation or frequency modulation may also be used to create enhanced pulse or chirp features.

CONCLUSION

Holzworth Instrumentation has developed specific proprietary architectures that initially targeted ultra low phase noise performance. As customer requirements became more and more specific, the engineering team refined these architectures to meet the demands of multi-channel applications. The current product line is the result of an evolutionary design process which has yielded one of the best all-around performance synthesis platforms available.

HS3008: Eight Channel RF Synthesizer

Holzworth synthesizers are recognized for having industry leading phase noise performance and spectral purity. With the introduction of the multi-channel synthesizer product line, Holzworth is now becoming known for exceptional phase coherency and phase stability. These multi-channel synthesizer modules can be reference locked between multiple modules to create an arbitrarily high number of absolute phase coherent channels in a relatively compact space. For example, 64 phase coherent channels can be integrated into a single 19" rack that is less than 0.5 meters tall. With additional focus on low power consumption, a fanless design results in improved microphonics over traditional instruments.

Multi-Channel Highlights

- Highest channel density: 64 channels: 0.125m^3
- Ultra Low Phase Noise: -131dBc/Hz at 1GHz, 10kHz Offset
- Fine Tuning Resolution: 0.001Hz, 0.1degree, 0.1dBm
- Thermal Phase Drift: < 1.0 degree over 12hours
- Output Power Range: -110dBm to +13dBm (0.1dB steps)
- Fully Independent, stand alone channel control
- Phase continuous frequency switching
- Absolute Phase Coherency

With the existing technologies and intellectual property, Holzworth is able to push the design beyond current expectations. Improved phase noise performance and extended frequencies are available in both single and multi-channel platforms.

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