Orthogonal Perturbation To Tangent In LTV Oscillator Theory

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[Back to Contents](#)

[Back to Phase Noise](#)

Overview

It is shown here that the "orthogonal perturbation to the tangent of the limit cycle", as required in the Hajimiri-Lee LTV phase noise model for oscillators is invalid. Furthermore, it is invalid for the most basic topology of any real physical design.

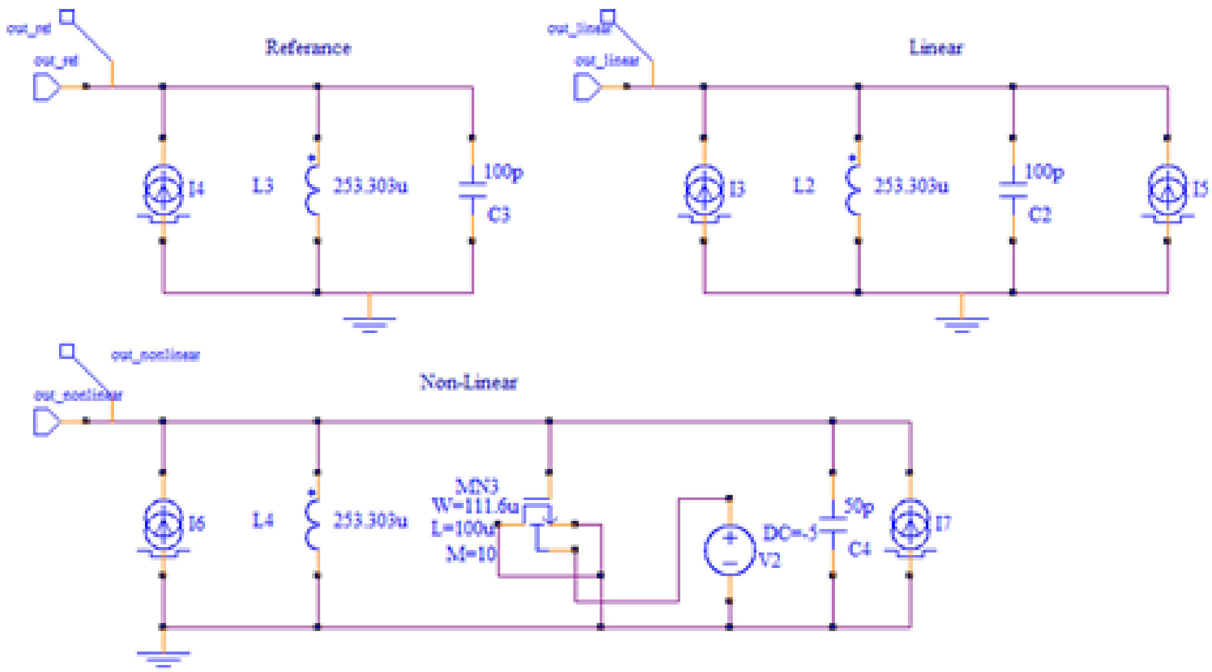
Introduction

Well, what does that mean in simple terms to Analog Designers? It means that injecting an impulse at the maximum or peak of an oscillator waveform can indeed cause a persistent phase error.

It is a basic principle of The HL phase noise theory that injecting such a pulse at the peak of the waveform results in minimal to zero steady state phase disturbance. For the HL phase noise theory it is a serious flaw that this assumption is proven false. At its core, the HL theory attempts to dispense with non-linearity and asserts that that a Linear Time Variant model is the crux to, for example, up-converted 1/f noise. To the contrary, such effects are physically due to non-linear components and transfer functions of oscillators, and as such, these effects can not be explained by remodelling the system as an LTV system.

Orthogonal Perturbation Simulation

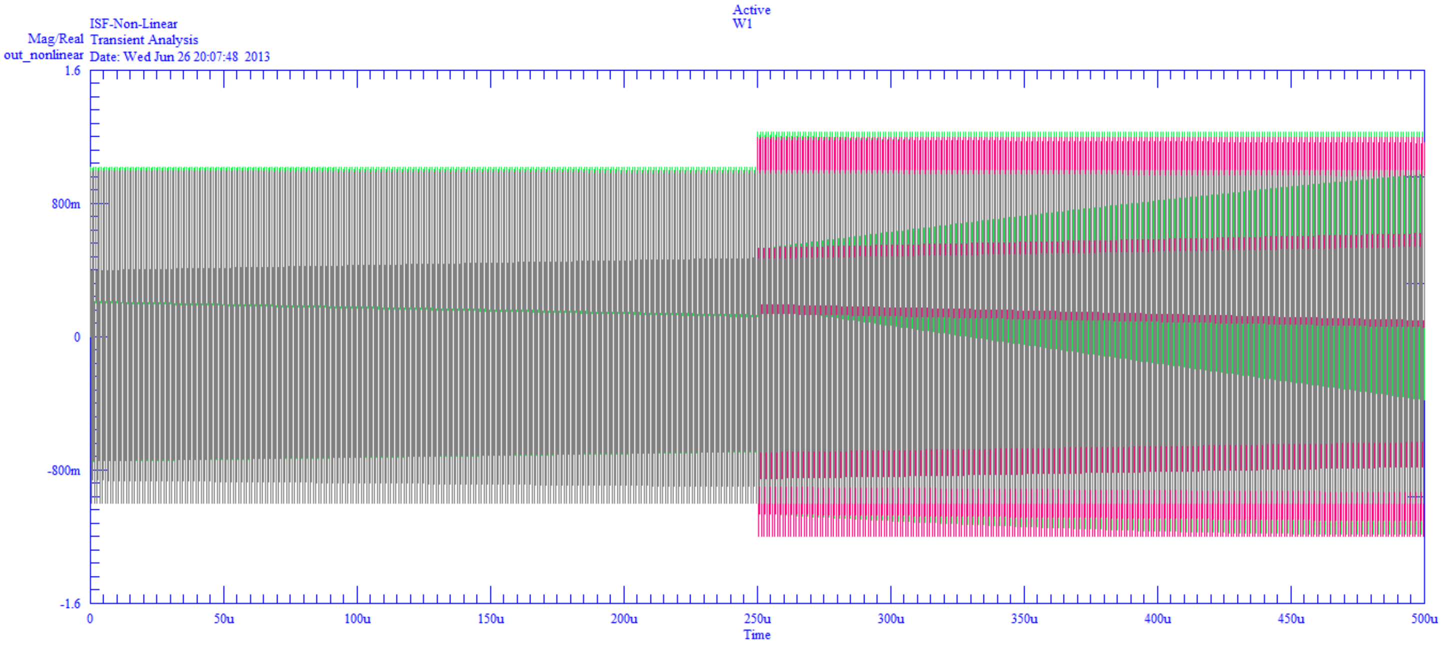
The following schematic ([isf_nonlinear.sss](#)) was simulated in [SuperSpice](#)



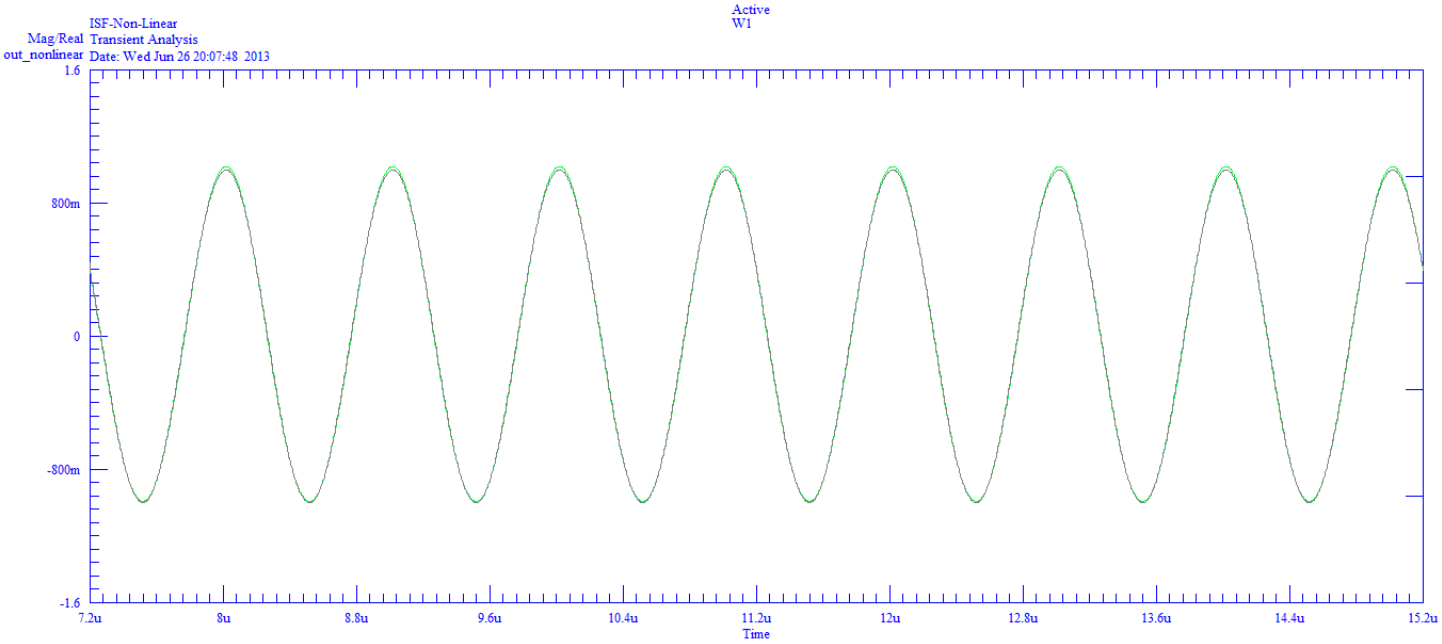
The schematic shows 3 LC tank circuits. One tank forms a reference to which the phase of the other tanks can be referred to. One tank is a simple linear LC, the other is formed by the gate capacitance of a mosfet. Such a capacitance is highly non-linear, and forms a very typical and realistic model of any real CMOS oscillator.

Care was taken in adjusting the size of the mosfet so that all tanks ran at the same frequency to the accuracy of the simulation. The TRAN simulation was ran for sufficient number of cycles to verify that observed phase shifts were not the result of frequency slippage. The fundamental frequency was set to 1MHz, with the run time set for 500us, with pulses for each perturbed tank instigated at 250us.

Full Waveforms

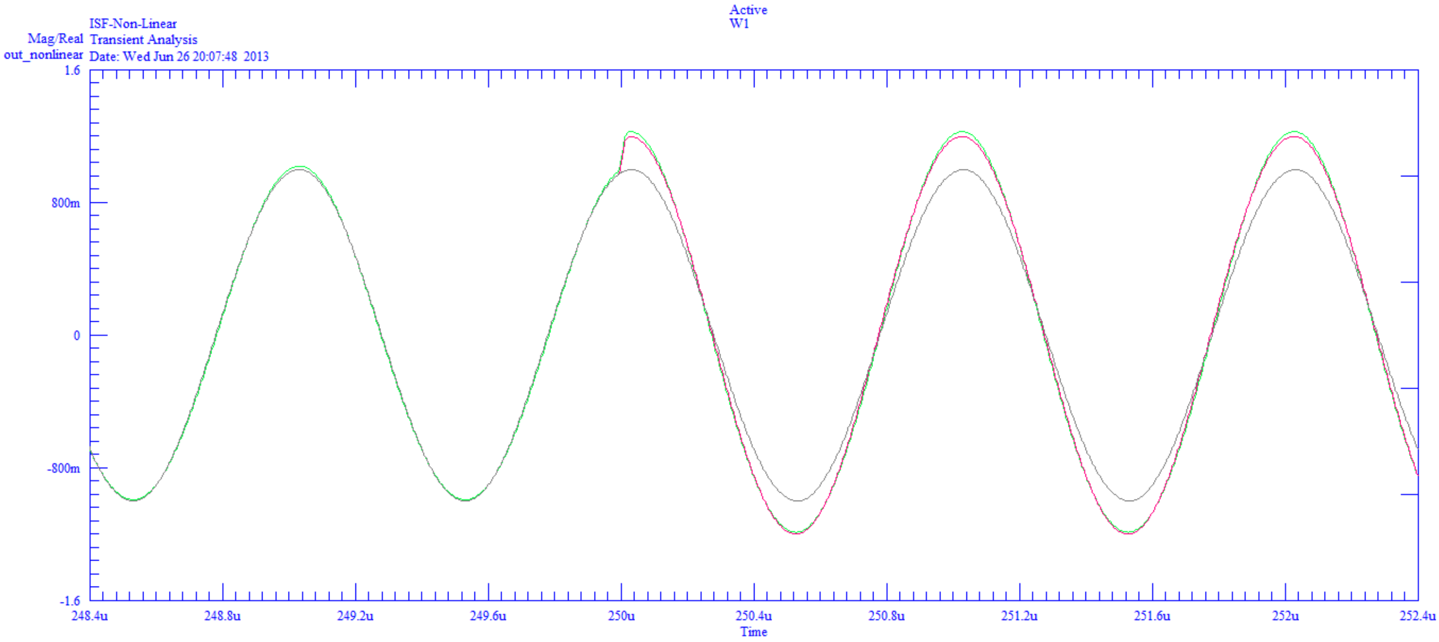


Start Waveforms



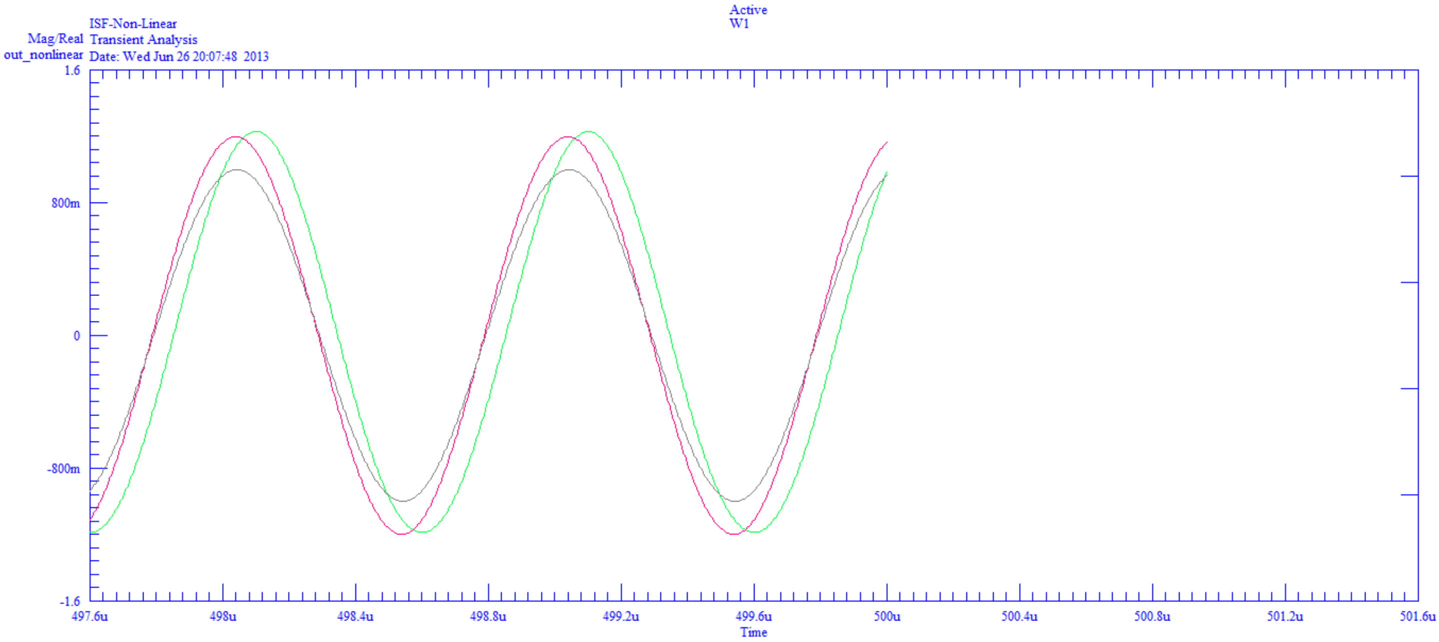
The start waveforms show all tanks are aligned to each other after the initial start impulse.

Middle Waveforms



The middle waveforms show that all tanks are still aligned to each other just prior to the second impulse.

End Waveforms



The end waveform clearly shows that, although the linear tank remains in phase, the non-linear mosfet tank shows, what is apparently a persistent steady state phase shift. In fact, what has actually happened is that the tank frequency has shifted, and this has been confirmed by running for many more cycles.

When the tank voltage was raised due to the impulse, the capacitance changed. This resulted in the instantaneous frequency of the tank being different from its initial value due to its new LC time constant. The new tank voltage trajectory then targets a different zero crossing point consistent with its new frequency.

In the case the case of an oscillator, the non-linearity that keeps the oscillator at constant amplitude would, over time, bring the amplitude and frequency back to its steady limit cycle state. However, the effect of the initial change in trajectory will still result in a steady state constant phase error.

Thus it can be concluded that non-persistent phase errors for peak level impulses, are only true in linear systems.

In principal, depending on the actual voltage-capacitance transfer function it would be possible to construct a topology where the maximum phase change occurred at the waveform peaks, and minimum at its zero crossings. For example, where the capacitance rate of change with voltage was smallest at its zeros and greatest at its peak. In this way, it can be concluded that the HL- theory with regard to the ISF function being shaped similar to the derivative of the waveform, in general, is false.

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