ECEN 5224: Week 3 Lab Report

Part 1: Spectrum Analysis of Signals using Keysight ADS

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Objective of Lab: Explore the concept of Bandwidth of signals, and identify the impacts of rise-time and its effect on the signal bandwidth.

Summary of Experiment: In this lab, we use the fs() function in Keysight ADS to simulate output of a signal from a real-life instrument such as a Vector Network Analyzer (VNA). We compare the results of Discrete Fourier Transform of Square Waves with varying rise time (none, 7%, 20%) and Pseudorandom Binary Sequence (PRBS) signal.

As rise time increases (in proportion) compared to its period, the signal looks closer to a sine wave at its fundamental frequency. 7% period 10-90 rise time are good estimates of a real-life square wave signal with degradation.

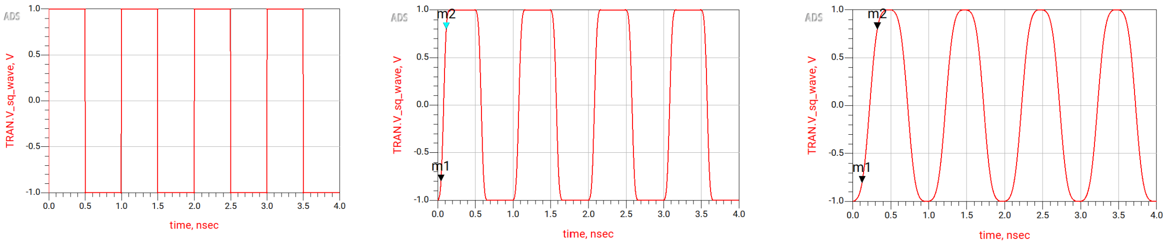

Figure 1: Square Waves with different rise times with period of 1ns (Left: 0%/ideal, Middle: 7% period, Right: 20% period)

Fourier Representation of an Ideal Square Wave: An ideal square wave has an amplitude component with odd harmonics (k=1,3,5..) that decays with the factor of k, where k=1 is the fundamental.

$$f(t) = \frac{4A}{\pi} \sum_{k=1,3,5\ldots}^{\infty} \frac{1}{k} \sin\left(\frac{2\pi k t}{T}\right), \quad \frac{4A}{k\pi}$$

Figure 2: Expected coefficients of an ideal square wave

In Figure 3 below, the blue line represents the amplitude of the square wave of odd-numbered harmonics using the formula from Figure 2. All 3 square waves with varying rise-times have their first intersection with the blue line (expected amplitude) on its fundamental frequency (1GHz). There is a peak in odd-numbered harmonics (1GHz, 3GHz, 5GHz…) as expected. There are also spectral leakage in nearby frequencies due to limitations of Discrete Fourier Transform.

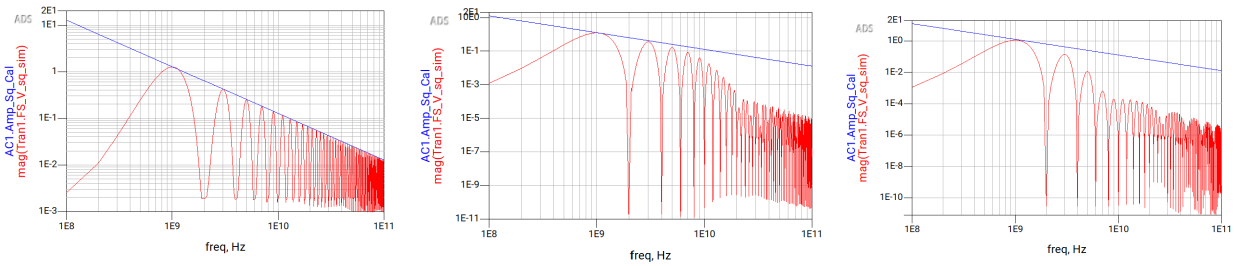

Figure 3: Spectral Analysis of Square Waves, Frequency=1GHz (Left: 0%/Ideal, Middle: 7% Rise-Time, Right: 20% Rise-Time

As rise times increase, the loss in amplitude in higher frequency components (7Ghz, 9Ghz… etc) compared to the ideal square wave becomes more significant. There are bigger losses for the 20% rise-time than the 7% rise time. Loss of the signal becomes significant after the 5th harmonic (5GHz), as noted by the sharp difference between the blue line and the red peak, and **bandwidth of non-ideal waves can be estimated to the 5th harmonic.**

Pseudorandom Binary Sequence (PRBS) signal, a randomly generated digital signal, contains lower frequency components ranging from DC (all 0s or 1s) to impulse signal (one 1 followed by 0s) to ideal square wave (alternating 0s and 1s). Using a PRBS signal of 2GBPs gives us a 1GHz square wave for alternating signals.

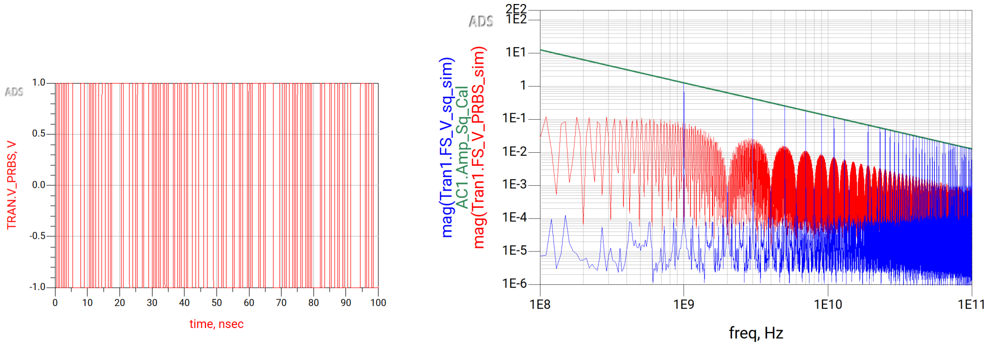

Figure 3: 2GBps PRBS Signal (Left), Spectral Analysis (Red: PRBS signal at 2GBps, Blue:1GHz Square Wave with 7% Rise-Time, Green: Amplitude of Odd Harmonics of Ideal Square Wave)

Because PRBS signals contain frequency elements all the way down to DC (0Hz), the amplitude of frequencies from DC to fundamental frequency (1GHz) is flat. Like square waves, there are peaks in the odd harmonics (3Ghz, 5Ghz…) similar to square waves, but the spectral leakage is much wider and severe, Amplitude of the odd-numbered harmonics are significantly lower (by factor of ~100) as well. Decay of higher harmonics is similar to the ideal square wave in log-scale. The same rule-of-thumb of **5 times fundamental square-wave frequency (half bit-rate)** is a good approximation for bandwidth.

Conclusion for Lab: Bandwidth of signals are correlated to the rise time of the signal. Quicker the rise time, wider the bandwidth. For non-ideal square waves, a rule-of-thumb of 5th harmonic is a good estimate of the bandwidth. Higher harmonics decay much faster than lower harmonics with increase in rise time in square waves. PRBS signals have frequency components lower than its square-wave equivalent fundamental, which leads to more spectral leakage, and flat amplitude below “fundamental”. However, its bandwidth can also be approximated to the “5th harmonic” of half-bitrate.

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Part 2: IBIS model vs. Thevenin/Capacitor model Simulation with ADS

Hyounjun Chang

Objective of Lab: Explore IBIS model simulations in Keysight ADS, and create simpler models (Thevenin, Capacitance) which can imitate the IBIS models within specifications

Summary of Experiment: Simulation IBIS model of a Hex Inverter (74HC14) was compared to its equivalent Thevenin Model (output) and Capacitance model (input) in Keysight ADS. Accuracy of the simpler models (Thevenin/Capacitance) was put under test with varying impedance. Effects of packaging of the Hex Inverter was considered as well.

An IBIS model for 74HC14 Hex Inverter was provided by Prof. Bogatin in "hc14.ibs" file. Schematic of thevenin equivalent model was created, with the same load Impedance (Resistor) placed. A quick fall-time signal was used, since the 74HC14 Hex Inverter has limited bandwidth, which would "slow" fast signals.

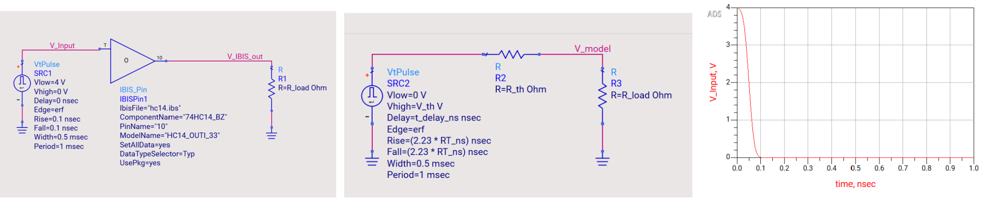

Figure 1: Schematic for IBIS (Left) and Thevenin Model (Middle) for Inverter Output, Input signal of Hex Inverter(Right)

Response of 74HC14 hex inverter varies significantly based on load:. For high load-resistance (10k ohm), the output voltage is expected near 3.3V (as specified by the inverter). However, for low load-resistances, rise time of signal increases, and output voltage drops noticeably, suggesting the thevenin voltage is high for the inverter.

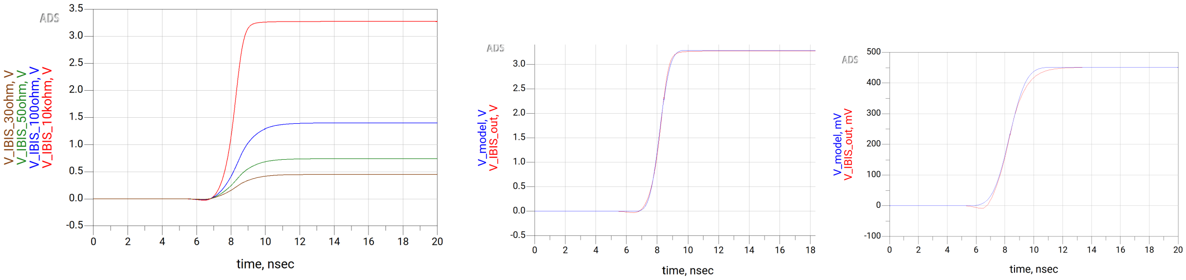

Figure 2: Simulation of IBIS model for various loads (Left), matching Thevenin models with various parameters (Middle: 10k ohm load, Right: 30 ohm load)

Thevenin model can output responses similar to an IBIS model by modifying various parameters (rise-time, delay, R_th), but the equivalent Thevenin resistance (R_th) changes depending on load-impedance, as suggested by Figure 3. **Thevenin resistance model is unreliable across a wide-range**, so should only be used when the precise impedance of load is known. **As load impedance decreases, Thevenin resistance increases for the inverter.**

R_load (Ohms)	t_delay (ns)	10-90 Rise Time (ns)	R_th (ohms)	V_th (V)
10k	6.7	1.32	50	3.35
100	5.91	2.32	140	3.35
50	5.81	2.31	175	3.35
30	5.76	2.28	193	3.35

Figure 3: Table of Parameters adjusted to match IBIS model for Thevenin model

Input of the inverter can be modeled using a capacitor. A sine-wave voltage source with 0.1V amplitude was used on both IBIS model and capacitor model, and a current-probe was used to compare the differences. **A 3pF capacitor was used to model the IBIS model without package leads. This is very close to the C_comp provided by the IBIS model, which is 2.99pF.**

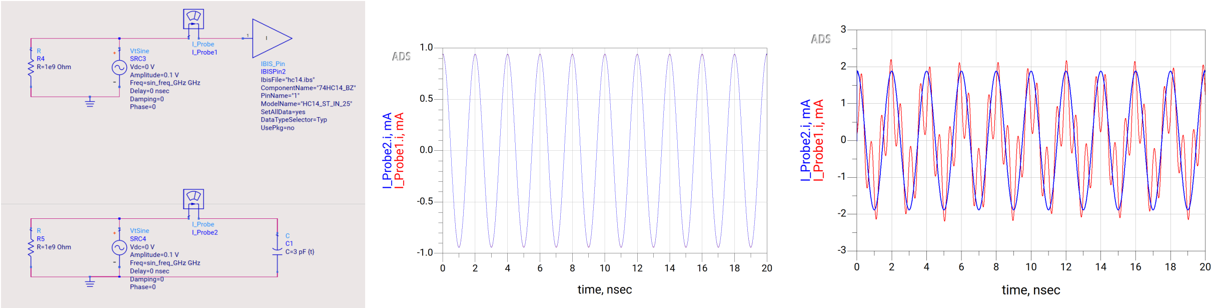

Figure 4: Schematic for IBIS/Capacitor model (left), Simulation of IBIS/Capacitor(3pF) model w/o package leads (Middle), Simulation of IBIS/Capacitor(6pF) model w Package Leads(Right)

Adding the package model adds more real-life components to the circuitry. Package leads have RLC components, which make their behavior harder to model, as seen in the graph in Figure 4. Input capacitance was **increased to 6pF** to match the magnitude of current.

Conclusion for Lab: Thevenin Resistance model and Capacitance model are simple models which can simplify complex behavior of IBIS models. Even though output response of 74HC14 Hex Inverter can be matched in the Thevenin model, the Thevenin model is not consistent across a wide range of output loads. Real-life components have varying Thevenin resistances, and should be considered when designing circuits. The capacitance model of the inverter can accurately model the IBIS model without the package. The package leads contain RLC components (real-life) which can't be modeled by a simple capacitor-model. However, increasing the capacitor size can act as a simple substitute to match the current amplitude.