Application Report

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Single-Ended Clock Signals

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Clock Distribution Products

ABSTRACT

When designing a single-ended clock tree, a system designer can choose between two commonly-used waveform types: rectangular or sinusoidal. This application note gives a short overview of both signal types and shows the advantages and disadvantages of each using the CDC3S04 quad sine-wave clock buffer with an integrated low-dropout regulator (LDO). Additionally, the clipped sinusoidal waveform is addressed to demonstrate a possible alternative to the widely-known two opposing waveforms.

This document is not intended to offer a complete mathematical explanation of the described effects, but rather to provide a quick, easy, and understandable introduction to the problem of clock signal type selection in terms of how it affects overall system performance.

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1 Waveforms and Spectrums

This application note discusses the major differences between sinusoidal and rectangular-shaped waveforms. It also reviews the advantages and disadvantages of the respective waveforms in terms of board design. For this purpose, it is important to clearly understand the characteristics of each waveform. Figure 1 compares the two types.

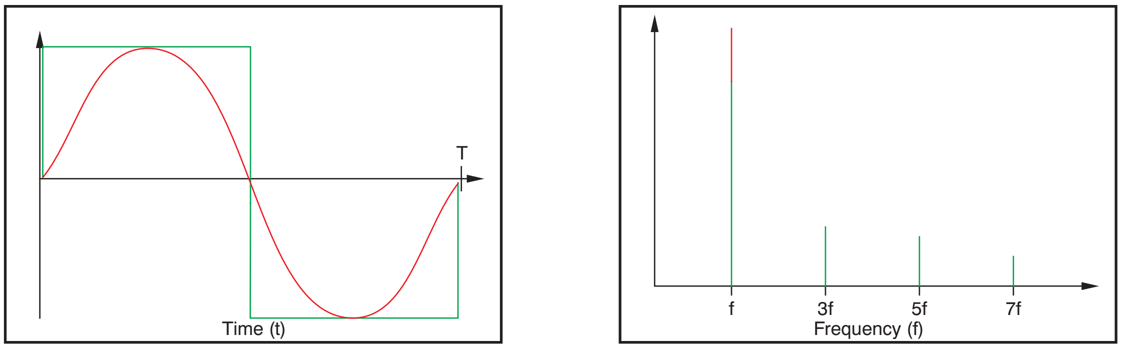

Figure 1. Waveform (Left) and Spectrum (Right) of a Sine Wave and a Rectangular Signal

In addition to the clear difference in the shape of the waveform, the sinusoidal waveform has a much different spectrum than the rectangular waveform.

While the sine wave displays only the fundamental component at 1/T, the rectangular waveform has higher-order harmonics at 3/T, 5/T, 7/T, and so on. In an ideal situation, this series expansion continues indefinitely. However, in the real world, the harmonics become so small that they deteriorate into the noise. For most practical applications, then, the seventh harmonic or the ninth harmonic is enough to consider.

2 Looking at the Signals from a Radiated EMI Perspective

The spectral components of any signal are very important for the electromagnetic interference (EMI) performance of the system. EMI performance is typically measured through the electromagnetic radiation (EMR) of the system. Therefore, this type of EMI is often called ***radiated EMI***.

To understand the impact of a signal type on radiated EMI, one must understand how a signal radiates from a line.

Looking into the radiation characteristic over frequency of a simple transmission line, it becomes clear that at some frequencies, the line acts as an antenna. The radiation occurs at frequencies where the wavelength of the signal is equal to the line length (or an even divider of the line length). Thus, the points of maximum EMI emission are seen at frequencies that are at λ, $\lambda/2$, $\lambda/4$, $\lambda/8$, and so on [with $\lambda = c/f$; c = 299792458 m/s (speed of light)]. It is important to note here that the emitted energy will be lower at higher dividers.

From this characteristic, it can be easily seen that even with relatively short line length and low signal frequency, there is a possible EMI issue because the transmission line can easily reach as long as λ/n-th power of the higher-order harmonics.

Because in most cases the line length is somehow generated by other circumstances, this factor is usually not a variable to the board designer. One valid way to reduce the risk of EMI radiation from a line would be to use a signal with a lesser amount of harmonics. Consequently, we see that using a sine wave signal reduces the risk of EMI that comes from the transmission lines for the clocks signals.

3 Single-Ended Clock Signal Types and Noise

As a result of the complex nature of modern-day systems, a large number of external factors can impact the signal integrity. This likelihood also is true for the lines that the clock signals must travel across. As long as no differential signal is used, the noise injected into a transmission line has a direct impact on the signal performance. To understand what this effect means for a clock tree design, one must first understand that most device inputs use inverter-type input structures for the clock inputs. In such a case, the input switches only if the input voltage reaches the threshold voltage. If noise couples onto the line, the input stage may react earlier or later than it would in a noise-free environment. This type of reaction is effectively seen as ***jitter*** within the system. Figure 2 illustrates the different impact that noise has on both a sine wave and a rectangular waveform. (Both signals have added noise of the same amplitude.)

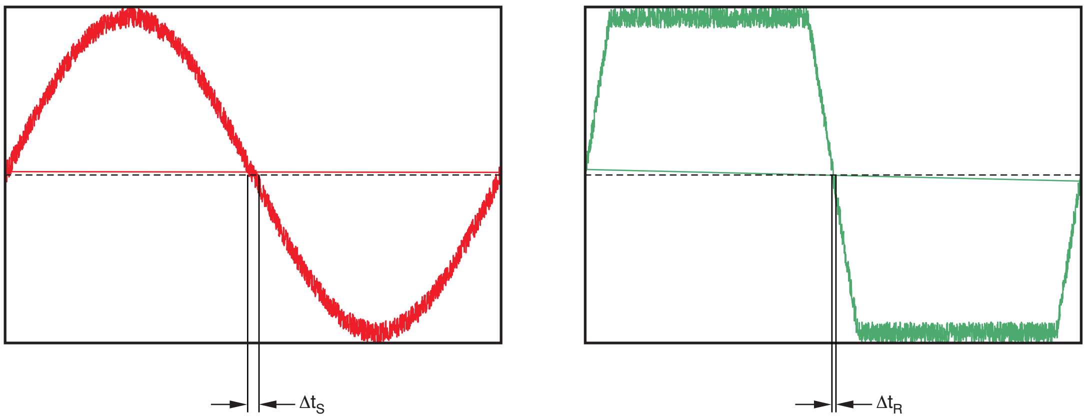

Figure 2. Impact of Noise on the Jitter on a Sine Wave (Left) and a Rectangular Signal (Right)

It can be clearly seen from Figure 2 that noise in a sine wave signal can have a greater impact on the correct timing (as a result of the slow rising and falling edges of this signal type) than a signal using a rectangular waveform if an inverter-type input is used. From a systemic point of view, this distortion in time is observed as jitter.

Linear input stages such as those used on the CDC3S04 do not translate the noise into jitter, but rather attenuate the effects because of the band-pass behavior of the device.

It also is important to note here that the source for the unwanted signal distortion does not necessarily have to be noise; it can also be caused by interference from within or without the same system. These sources of interferences do not have to be constant (as the noise discussed earlier) but can be of a more sporadic nature and occur only temporarily during a period of the signal and repeated after every nth period. These interferences have a much greater impact on system jitter than in systems that use waveforms with slower rising and falling edges.

4 Clock Signal Type and Its Impact on Power-Supply and Ground Noise

Although the precise impact on power-supply and ground noise depends greatly on the implementation of the drivers in a given device, there are several general points to be noted here.

For a clock driver device, the current consumed at a certain point in time is significantly dependent on the capacitive load seen by the driver. To reach a different voltage level, this capacitance must be charged or discharged. As generally known, the current required for this charging (or discharging) can be calculated with the formula shown in Equation 1.

$$I(t) = C\frac{dU}{dt} \tag{1}$$

From this equation, it is easily seen that given the same capacitive load, a signal with a faster rise and fall time draws much more current than a signal with a slower rise and fall time. Applying this conclusion to the signals we are discussing here, it can be easily seen that a sine wave signal consumes less current than a rectangular-shaped signal.

This principle has a direct impact on board design, because it means that the sine wave device does not require as much energy for switching (as a result of its slower rise and fall time). Additionally, because the sine wave curve is much softer than that produced by a rectangular device, it also generates fewer distortion effects on the power and ground levels; see Figure 3 and Figure 4.

Thus, for a system that uses sine wave signaling, the amount of external components used for power decoupling and noise reduction on both ground and power supply can be reduced. This consequence can be an advantage in applications that require optimal board space management such as smartphones.

5 Power-Supply and Ground Noise vs EMI

From Figure 3 and Figure 4, it can be seen that the power noise coming from the switching of the outputs of a device has a much higher frequency than the switching signal itself. This effect allows an EMI emission to pass through the power and ground planes that are usually constructed as large as possible, and consequently offer a greater chance to radiate high-frequency signals. A device with softer switching outputs generates much less distortion on the power and ground planes, and therefore has much less possibility to radiate this type of noise.

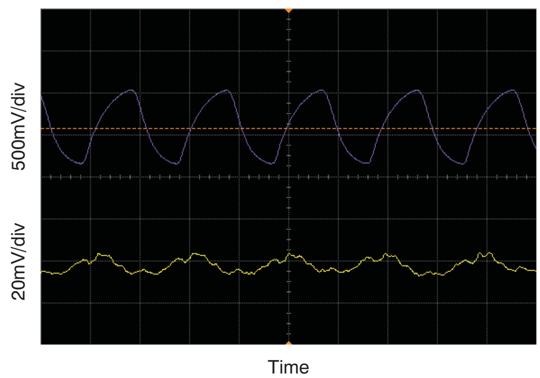

Figure 3. Output Signal (Top) and Power-Supply Voltage (Bottom) on a Clipped Sine Wave Driving Buffer Without Supply Stabilization

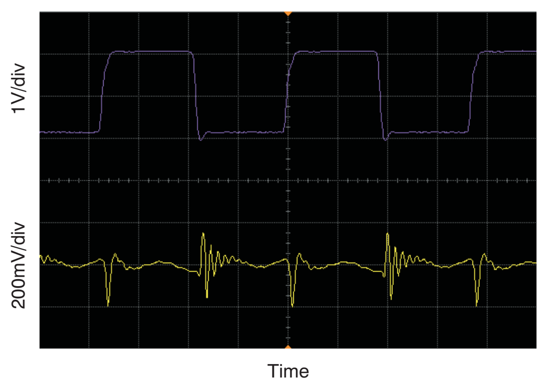

Figure 4. Output Signal (Top) and Power-Supply Voltage (Bottom) on a Rectangular Switching Buffer Driving into 50 Ω Without Supply Stabilization

6 Summary

As we have noted, there are many points to consider when selecting a waveform type for clock transmissions. Both rectangular and sinusoidal waveforms offer several advantages and disadvantages.

The selection of the waveform used for clock transmissions depends greatly on the specific requirements of the application. In reality, there is rarely a pure sinusoidal waveform used. The two signal types most often used are the rectangular and the clipped sine wave.

In most non-portable applications, the rectangular waveform is used. The longer transmission lines in these types of applications are more susceptible to noise. Additionally, power is not as much of an issue as it is for portable applications.

The clipped sine wave is a good compromise between EMI performance and fast rising/falling edges. In portable systems, this type of wave is very popular because the short line lengths in these applications are less susceptible to noise. On the other hand, the possibility of reducing the number of external components required for power filtering, as well as the reduced EMI signature of these signals, is a very positive factor.

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