Improving the signal integrity for an HCMOS crystal oscillator

Introduction

For a high-performance system, an ideal clock is an essential condition. Therefore, a robust crystal oscillator is chosen as an excellent clock source. However, an improper PCB layout or an incomplete consideration of circuit design could cause an unexpected system degradation given that the transmission line effect appears to dominate the integrity of the clock signal. Any long PCB trace would behave like a transmission line rather than just a simple short trace when high-frequency components of the clock signal are traveling along that transmission line. Even a clock signal of several MHz or KHz potentially embeds harmonic components of hundreds MHz to several GHz to form sharp rising and falling edges of the waveform.
If the impedance at both ends of the transmission line is mismatching, the short wavelengths of high-frequency harmonics can cause a tangible reflection phenomenon. After multiple iteration cycles of wave reflection, some harmonic signals with specific frequencies would be unintentionally enhanced due to a parasitic resonant effect of the transmission line.
Moreover, potentially glitches or ringing could appear at the receiver end in the waveform of a clock, causing overshooting or undershooting or extra steps on the edges. These nonideal situations often cause false triggering and extra noise, so that the risk of system's error could occur. In some extreme cases, a devastating malfunction can also likely happen.

A basic solution for the unwanted source reflection of a HCMOS clock source

From a simplified point of view, the HCMOS output of an oscillator merely feeds an input of a receiver or a clock signal distributor. Therefore, a source termination is the most simple and effective way to absorb the reflected wave traveling from a non-terminated load back into the output of the oscillator over the transmission line. By this method, the reflected wave can't build up at both ends of the transmission line so that the parasitic resonant effects can be alleviated.

Note that a source termination does not substantially reduce the amplitude of the waveform at the receiver end and does not increase power consumption. To implement a source termination, a small-value resistor (Rext) is inserted in series between the clock source and transmission line, see the Figure-1. Note that the resistor (Rext) should be placed as close as possible to the output terminal of the oscillator for best prevention of reflections.

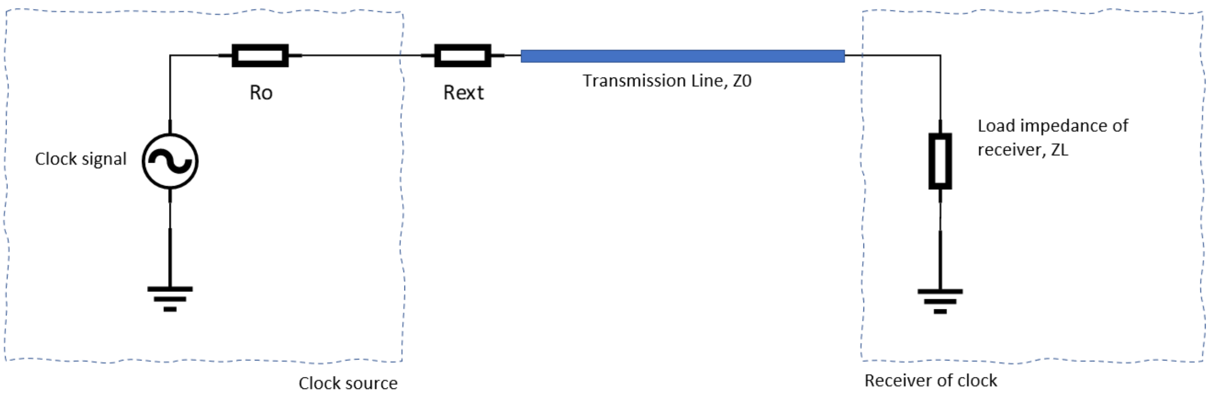

Figure-1 A basic diagram for the solution of unwanted source reflection

Theoretical point of view

The reflection coefficients can be used to determine the ratio of the reflected wave to the incident wave, and it can be calculated from the impedances of the correspondent interface. The source reflection coefficient (Γ_S) is computed by the source impedance (Zs) and the characteristic impedance of transmission line (Z0):

$$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} \quad \text{... eq-1}$$

The source impedance (Zs) in equation-1 is the sum of the output resistance of the clock source (Ro) and the source termination resistor (Rext), therefore, the source termination resistor (Rext) should be placed to the clock source as close as possible.

$$Z_S = R_o + R_{ext} \quad \text{...eq-2}$$

The load coefficient (Γ_L) can also be calculated based on Z0 and the load impedance of receiver (ZL),

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \text{...eq-3}$$

The typical load impedance ZL is obviously higher than the Z0. Hence, a load terminated resistor in parallel is required to decrease the load reflection coefficient (Γ_L). For this reason, an extra current sink is added, whereby the amplitude of the signal is lowered.

It should be noted that adding a current sink or a parallel termination resistor is not recommended for HCMOS compatible circuits, as a termination at the receiver side will change the H and L levels, and signal integrity at the receiver side may no longer be guaranteed.

The intention of a proper termination is to destroy the root of unwanted resonant effects of a transmission line, like ringing or waveform deformation. The most effective method can be implemented by reducing the round-trip reflection (Γ_{LS}) at both ends of transmission line. Intuitively the strength of the round-trip reflections between the two ends is concluded by the multiplication of the factors Γ_L and Γ_S . The round-trip reflection coefficient (Γ_{LS}) can be defined as below,

$$\Gamma_{LS} = \Gamma_L * \Gamma_S \quad \text{...eq-4}$$

We can achieve a zero round-trip reflection coefficient by absorbing the reflection wave at only one end of transmission line through a proper matching.

A method to estimate the output resistance of the HCMOS clock output

The determination of the source terminated resistor (Rext) is essential to decrease the source reflection coefficient (Γ_S). If the characteristic impedance (Z0) of the transmission line is known, Rext can be well chosen by finding out the output resistance (Ro) of the clock source.

Normally, the range of Z0 of a microstrip line structure on the PCB is about 50 ~ 150 Ohms. There isn't a way to measure the Ro directly, but an approximated method can be figured out if the value of Ro is in the range of a few Ohms to a few hundred Ohms.

The recommended procedure is as follows:

1. Mount a crystal oscillator with CMOS output on a simple PCB.
2. Apply power to the VDD of the crystal oscillator.
3. Use an FET active probe to measure the peak-to-peak value (V_L1M) of waveform with an oscilloscope. If the Hi-Z FET probe has a much higher impedance than Ro, the voltage at the FET active probe (V_L1M) can be approximated to the unloaded voltage (V_UL). See the Figure-2.

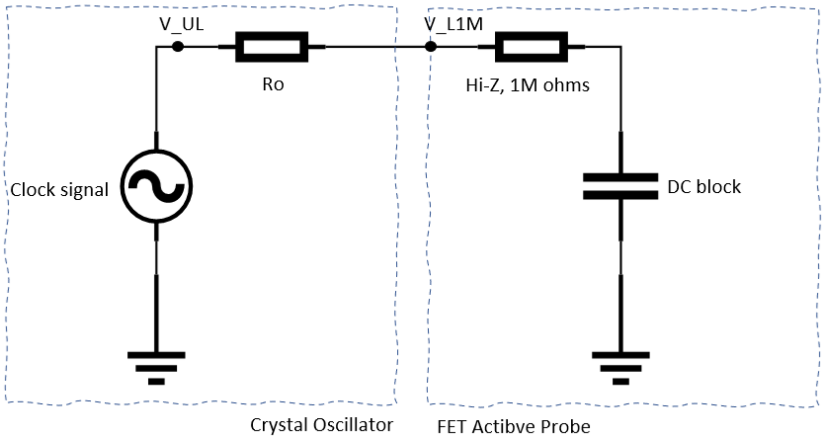

Figure-2 An approximation for the unloaded voltage (V_UL)

4. Use an external DC block component to connect the output of crystal oscillator to a RF cable. (SMA type of interface is suggested.)
5. Directly connect the RF cable to the oscilloscope.
6. Set the input impedance of the oscilloscope to 50 Ohm and measure the peak-to-peak value of 50 Ohm loaded waveform (V_L50). See the Figure-3.
7. The output resistance (Ro) can then be computed by this equation.

$$R_o = 50 * \left(\frac{V_{UL}}{V_{L50}} - 1\right) \cong 50 * \left(\frac{V_{L1M}}{V_{L50}} - 1\right) \qquad \text{...eq-5}$$

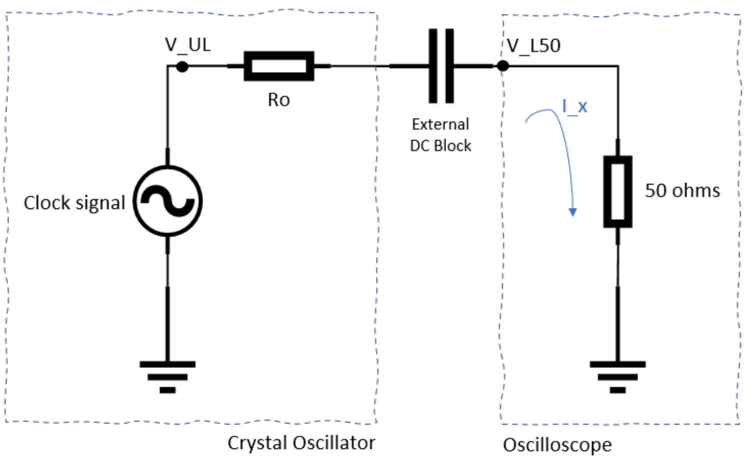

Figure-3 A Measurement for the loaded voltage (V_L50)

Now the proper external resistor (Rext) can be also computed by equation-2 to let the source impedance (Zs) be equal to the characteristic (Z0) of transmission line and minimize the source reflection coefficient (Γ_S).

Appendix- A comprehensive expression of the oscillator's output resistance (Ro)

We use the Figure-3 to understand the ins and outs. According to the ohmic law, we could define the current (I_x) as

$$I_x = \left(\frac{V_{L50}}{50}\right)$$

and the Ro expresses as

$$R_o = \left(\frac{V_{UL} - V_{L50}}{I_x}\right)$$

Then the equation of I_x is substituted into Ro, and a comprehensive equation of Ro can be written as

$$R_o = 50 * \left(\frac{V_{UL}}{V_{L50}} - 1\right)$$

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