Introduction

Crystal drive level is the amount of power dissipated in a crystal which is usually specified in microwatts or milliwatts. It can be calculated by measuring the excitation current flowing through the crystal. The maximum drive level is the most power the crystal can dissipate while still maintaining operation with all electrical parameters guaranteed. Drive level should be maintained at the minimum levels necessary to initiate proper start-up and assure steady state oscillation. Some of the larger crystal packages like HC49 tend to have higher drive level limits while the smaller crystal packages like 5x7mm and 2.5 x 3.2.mm have lower drive level. To ensure that premature aging or damage to the crystal does not occur, drive level should be considered.

Though drive level is specified in most quartz crystal datasheets, at times it is overlooked. Drive level is an important factor when designing or evaluating an oscillator circuit.

Measuring Drive Level

There are multiple ways of measuring drive level. Using a current probe is most reliable which is similar to current flowing through a resistor. Using a FET probe is also common but has disadvantages on an inverter type oscillator, like a Pierce. On an inverter type oscillator, there is phase difference between the signal at the crystal input and output which make it difficult to accurately measure the voltage across the crystal. The equations and examples below will show the requirements for measuring drive level using a current probe.

The drive level can be calculated by using the RMS drive current (Id) and the load resonance resistance (R_L). Refer to equation 1.

$$Power = I_d{}^2 \times R_L \quad (watts) \qquad (1)$$

$Id = \text{RMS drive current}$
$R_L = \text{Load resonance frequency}$

Since R_L varies with load capacitance, equation 2 can be used to calculate R_L.

$$R_L = R_R\left(1 + \frac{C_O}{C_L}\right)^2 \quad (\Omega) \qquad (2)$$

$C_O = \text{Shunt Capacitance}$
$C_L = \text{Load Capacitance}$
$R_R = \text{Resistance at series resonant frequency}$

Combining equation 1 and 2 yields equation 3.

$$Power = I_d{}^2 \times R_R\left(1 + \frac{C_O}{C_L}\right)^2 \quad (watts) \qquad (3)$$

When R_R is at FS (series resonance frequency), R_R is equal to R_1 (Motional Resistance).

$$Power = I_d{}^2 \times R_1\left(1 + \frac{C_O}{C_L}\right)^2 \quad (watts) \qquad (4) \quad R_1 = \text{Motional Resistance}$$
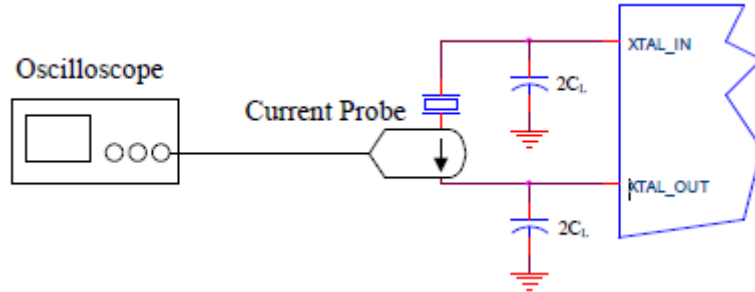
If using a series resonance crystal, C_L goes to infinity.

$$Power = I_d{}^2 \times R_1 \quad (watts) \qquad (5)$$

Example Calculation

For this example, a Tektronix CT-6 probe was used to measure the drive current. When placing the current probe, special attention should be given to the orientation. For inverter type oscillators, the drive current should be measured on the output side of the crystal in order to contain the influence of the oscillator. Refer to Figure 1.
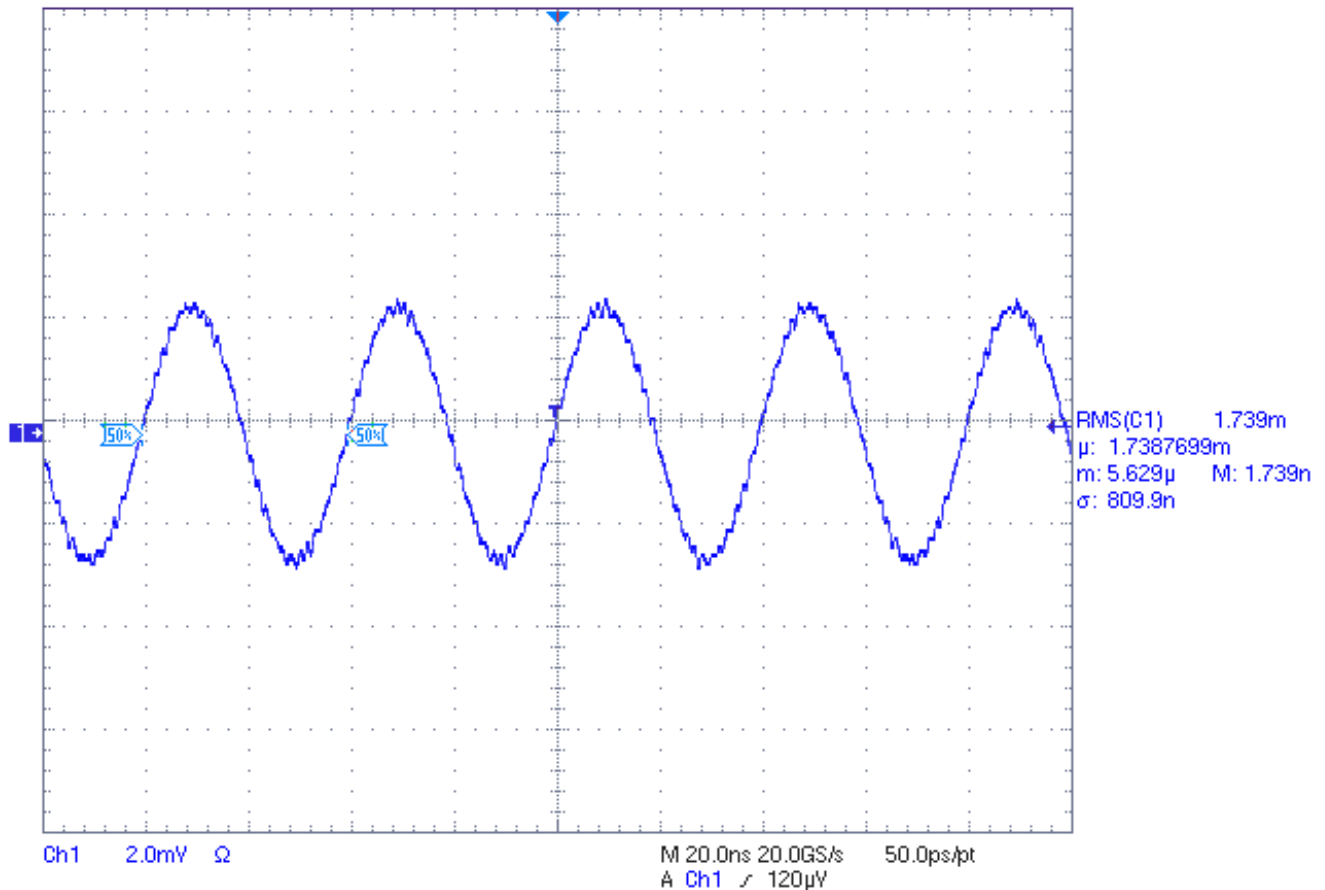
Figure 1. Oscilloscope and current probe connection

Oscilloscopes measure voltage versus time, though the display value is in mV, the current probe converts the electric field to AC current. The voltage can be ignored; in reality it is current. Oscilloscopes can display AC current in peak, peak to peak, or RMS. For most cases, we can assume the waveform is a pure sine-wave, hence the equation 6 applies. Refer to equation 6 and Figure 2.

$$I_{RMS} = \frac{I_{pk}}{\sqrt{2}} = \frac{I_{pkpk}}{2\sqrt{2}} \qquad (A) \qquad (6)$$

Figure 2. Sample AC Current waveform. I_RMS = 1.74mA

Using a Saunders & Associates 250B Network Analyzer, the relevant crystal parameters can be characterized. For this example, a 25MHz, HC49 type crystal was used. Refer to Figure 3.

Figure 3. S&A Crystal Parameters, 25MHz

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Description:   S&A 250B
Reference F: 25,000,000 Hz
Power: 1.00 mW into 25.00 Ohms
CL: 18.00 pF Using: Calculated FL


  RR       RL    C0    C1
Ohms     Ohms    pF    fF

14.0     19.0   2.9   11.4
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Using equation 3 in combination with I_{RMS} from figure 2 and R_L from values in Figure 3 yields the drive level below.

$$Power = I_d^2 \times R_R \left(1 + \frac{C_O}{C_L}\right)^2 = (1.74mA)^2 \times 14\Omega \left(1 + \frac{2.9pf}{18pf}\right)^2 = 57.14uW$$

The drive level contains variables from both the crystal and oscillator; hence both the crystal type and frequency will affect the drive level. When characterizing an oscillator, it should be verified across minimum and maximum frequency, C_L, and R_L. For the example above, the drive level is 57.14µW for a 25MHz, HC49 crystal on this specific oscillator.

This example yielded 57.14µW of drive level. In order to avoid poor aging or crystal damage, this value should be compared to the maximum level recommended by the crystal manufacturer.

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