Application Note: Spread Spectrum Oscillators Reduce EMI for High Speed Digital Systems

Introduction to Electro-magnetic Interference

Design engineers seek to minimize harmful interference between components, circuits, and systems. This interference includes both radiated and conducted radio frequency (RF) emissions. Interference requirements are need to be met in order to satisfy legally mandated domestic and international regulatory requirements and governmental regulations.

Electro-magnetic interference (EMI) is defined as a naturally occurring phenomenon when the electro-magnetic field of one device disrupts, impedes, or degrades the electro-magnetic field of another device via radiated and/or conductive paths. EMI can cause two or more electronic devices to interfere with each other and affect their performance and operation.

Federal Communications Commission (FCC)

EMI is subject to strict regulations by the US Federal Communications Commission (FCC) and other international regulatory bodies whose goals are to limit the amount of EMI electronic devices emit and to prevent damage to the human body and interference between electronic devices. The FCC's Class A regulations apply to industrial applications and the Class B regulations apply to residential or consumer applications.

EMI is a measurement of radiated energy from a frequency source and is typically measured in dBmV/m (decibel-volts per meter) at a given frequency. This parameter is larger for higher amounts of radiated energy. Thus, the more energy emitted from a frequency source, the larger the resulting electric field and EMI.   When defining the frequency spectrum for the EMI measurement, one wants to distinguish between the peak electro-magnetic emissions and the average electro-magnetic emissions. The average emission is defined as the average dBmV/m level over a given frequency spectrum. Peak emission is defined as the maximum dBmV/m level at any frequency over a given frequency spectrum.

Today, FCC regulations are primarily concerned with peak emissions at a given frequency, not the average emissions over a given frequency spectrum. Thus, a circuit designer should focus their EMI design efforts on reducing the peak emissions at a given frequency within the frequency spectrum, not the overall average emissions within the spectrum. Figure 1 shows a FCC Class B plot of power (dBµV/m) versus frequency (MHz) for the peak emission requirements (at ten meters).

Figure 1: FCC Class B Peak Emissions
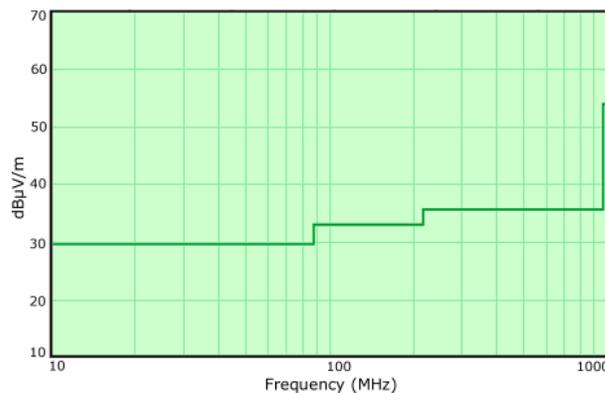
Electro-magnetic Interference and Clock Oscillators

A traditional non-modulated oscillator generates an output signal at the intended output frequency. In addition to the energy emitted at the fundamental frequency, there are large amounts of radiated electromagnetic emissions at its harmonic frequencies. These types of oscillators also generate electric signals at frequencies slightly lower and higher than the intended output and radiate electromagnetic waves over a frequency spectrum. The range of the frequency spectrum is dependent upon the mechanical and electrical design of the oscillator, power supply regulation, output termination, and printed circuit board layout.

High speed frequency sources such as clock oscillators, phase lock loop (PLL) synthesizers, and other types of clock signal generation devices are a major source of EMI in electronic circuits. Therefore, EMI reduction is a major concern for designers utilizing these clock generation devices.

Conventional PCB design and fabrication methods of EMI reduction include multiple ground and power planes, discrete component filtering (suppression), and enclosure shielding (containment). Although these EMI reduction methods are effective, they can have a substantial impact to the overall product cost. An alternative to some of these EMI reduction techniques and the use of a traditional non-modulated oscillator is the inclusion of a spread spectrum clock oscillator in the clock distribution system. The use of such an oscillator can significantly improve EMI and reduce overall system cost.

A spread spectrum clock oscillator has the output frequency intentionally modulated in order to reduce the EMI of the output signal. Spread spectrum clock oscillators are best used in applications that require a reduction of EMI emissions in order to pass FCC EMI regulations.

Spread spectrum oscillators reduce the EMI at the clock source, rather than down-stream in the clock distribution network. By reducing the EMI at the clock source, supplemental shielding enclosures and/or filtering components are not required, reducing assembly costs and improving system EMI performance.

By modulating the output signal, the EMI on the output signal is spread over a larger frequency spectrum. The total amount of energy is still present, but the spreading of the output power over the frequency band results in a reduction of EMI at any one frequency. Regulatory bodies like the FCC have maximum limits for peak EMI emissions (i.e. emissions at any one frequency within the spectrum). Thus, a clock oscillator can be used to pass FCC regulatory EMI test requirements by reducing EMI peak emissions.

EMI Reduction

In order to understand the importance of a spread spectrum oscillator, a thorough understanding of frequency modulation is required. Figure 2 shows a plot of output amplitude (power) versus frequency for a modulated and un-modulated center-spread spectrum clock oscillator. This figure illustrates the significance between the frequency span and the amplitude for a given modulated and un-modulated spread spectrum clock oscillator. By modulating the output frequency over a frequency spectrum (span), a reduction in output amplitude can be achieved. This reduction in output amplitude correlates with a reduction in radiated energy or EMI.

Figure 2: EMI Reduction Plot
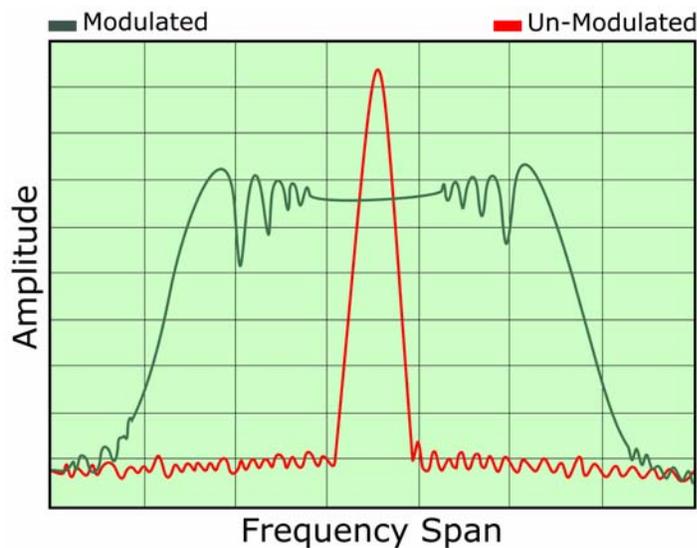
The primary factor that affects the amount of peak EMI reduction for a spread spectrum clock oscillator is the output frequency modulation width. Figure 3 shows a plot of output frequency versus time for an output of a non-linear modulated spread spectrum clock oscillator. The output frequency has a minimum (F_{MIN}), center (F_C), and maximum (F_{MAX}) frequency. The output frequency is swept linearly though a range of frequencies rather than being held at one constant frequency. This range parameter is often called output modulation width, output frequency spectrum, or frequency spread percentage.
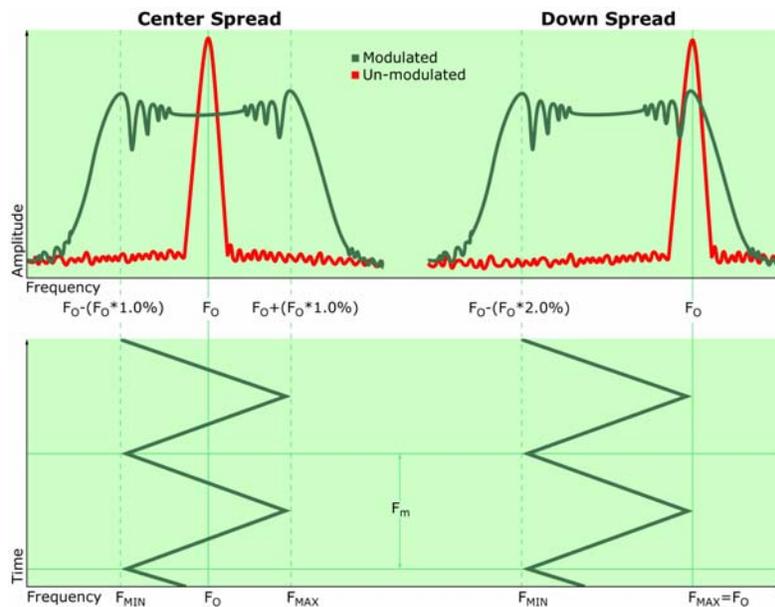
Figure 3: Output Frequency Modulation Width
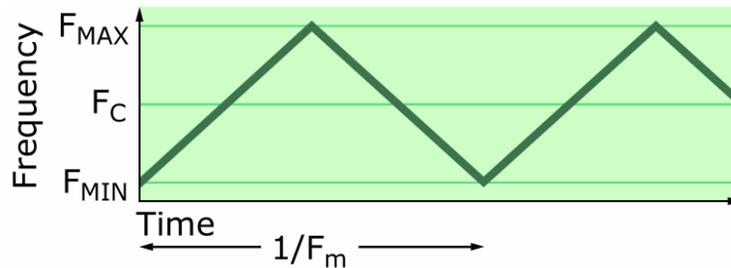
The minimum (F_{MIN}) and maximum (F_{MAX}) output frequencies are often stated as a percentage (%) with respect to the center frequency. Ecliptek clock oscillators offer many output modulation width options. The wider the modulation frequency spread percentage, the larger the bandwidth of frequencies over which the energy is distributed, and therefore the more EMI peak reduction.

As shown in Figure 3, the output modulation frequency (Fm), often called sweep rate, is defined as the inverse of the modulation period. The modulation frequency can be found on the series datasheet.

Center and Down Spread Modulation

Clock oscillators are offered with two standard output frequency modulation options: Center Spread and Down Spread. Figure 4 shows an example of these two options.

Figure 4: Center and Down Spread Options

The instantaneous output center frequency (F_C) is the approximate midpoint between the minimum frequency (F_{MIN}) and the maximum frequency (F_{MAX}). The instantaneous output frequency will therefore always vary between F_{MIN} and F_{MAX}. The instantaneous minimum (F_{MIN}) and maximum (F_{MAX}) output frequencies are stated as a percentage (%) with respect to the center frequency. In Figure 4, the center spread diagram provides an example of a device with a ±1.0% center spread percentage. In this example, if F_O were 100MHz, typical frequencies for F_{MIN}, F_C and F_{MAX} would be 99MHz, 100MHz, and 101MHz, respectively.

When a system cannot tolerate an operating frequency higher than the nominal frequency, then a down spread option should be considered. In Figure 4, the down spread diagram provides an example of a device with a -2.0% down spread percentage. For this example, if a customer was concerned about over-clocking and had a maximum operating frequency requirement of 100MHz (F_O), typical frequencies for F_{MIN} and F_{MAX} would be 98MHz and 100MHz, respectively. The disadvantage of down spread modulation is that the average output frequency will be lower than the nominal output frequency, creating a trade-off between average output frequency, maximum over-clocking, and maximum frequency modulation amplitude.

Spread spectrum clock oscillators can achieve significant reductions in EMI emissions. The oscillator output frequency and frequency spread percentage are factors that determine the amount of system EMI reduction. An estimate of the EMI reduction can be made with the formula below.

$$\textbf{EMI Reduction (db) = 10 log [S * F}_o \textbf{ / RBW]}$$

where: S   = Peak to Peak Spread Percentage
            F_O = Nominal Output Frequency (in MHz)
            RBW = Measurement Resolution Bandwidth (in MHz)