Mobius Microsystems White Paper
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How to Reduce EMI and Improve RF Noise Coupling

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1. Abstract

ElectroMagnetic Interference (EMI) is commonly defined as unwanted and noise-inducing harmonics in the frequency spectrum. System designers aim to reduce EMI in order to comply with wireless regulations and limit any interference with nearby devices.

This White Paper introduces Mobius' patented MM8512 Spread Spectrum Clock Generator (SSCG), a high performance, easy-to-use, and cost effective device designed to reduce system-level EMI. It works by dithering the clock frequency by a controlled amount, i.e. spreading the frequency over a wider spectral bandwidth thus reducing peak energy (EMI).

The MM8512 is based on Mobius' patented CMOS Harmonic Oscillator (CHO™) architecture, and is the industry's first fully integrated, all-CMOS Spread Spectrum timing device. The product eliminates the need for both quartz-based crystals and Phase Locked Loop (PLL) ICs.

The device is produced on a single piece of silicon, with programming options that allow setting various output frequencies and spread spectrum modulation depths. The MM8512 thereby offers system designers a single, highly accurate frequency source with best-in-class phase noise and jitter performance at very low power consumption. It therefore represents a compelling choice to reduce EMI and improve RF noise coupling in systems.

2. Introduction to Spread Spectrum Clocking

Because an electronic device can generate undesirable electromagnetic interference (EMI) and thereby disrupt nearby radio and wireless communications, all electronic equipment must meet Electromagnetic Compliance (EMC) standards.

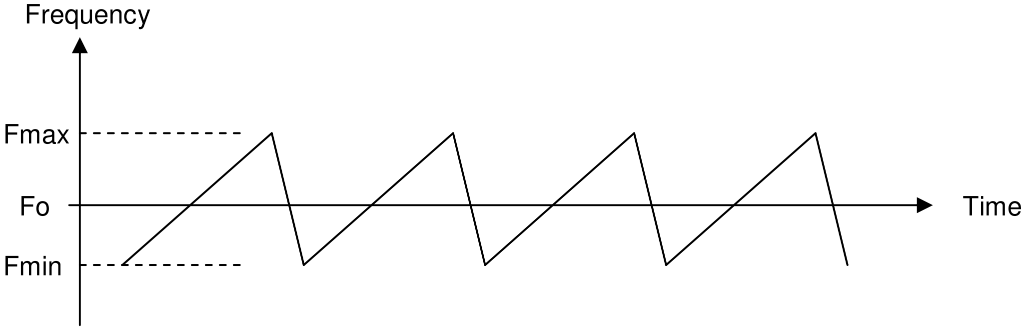
EMI is caused by fast changing currents inside the electronic device. These currents usually come from the clock sources, data and address buses, and other switching signals. Higher frequency signals get emitted into the air more effectively, and therefore higher order harmonics are usually the main sources of EMI. Engineers traditionally spend significant effort minimizing EMI in their designs in order to achieve compliancy certification and reduce the RF interference. This task is further complicated as each new design generation demands increased wireless capability, and operates at higher clock frequencies to meet the bandwidth requirements of today's multimedia-rich applications.

Common methods to reduce EMI include metal or ferrite shielding on Printed Circuit Boards (PCB), PCB layout improvement (occasionally requiring more PCB layers), shielding cables, etc. Unfortunately, these usually add cost to the system.

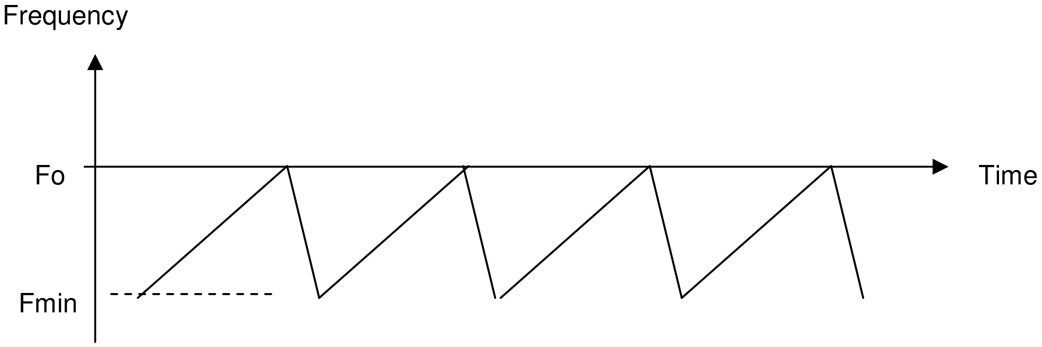
To deal with this design concern, SSCG is used extensively in many electronic devices, from multi-function printers to digital TVs and monitors. It is required for JEDEC's buffered memory modules and SATA-IO's Serial ATA specification. Utilizing SSCG, EMI can be reduced by up to 10-12 dB in the critical frequency bands deterministically, thereby reducing engineering iterations considerably, and improving RF noise floor

For many systems, EMI can be significantly improved by Spread Spectrum Clocking (SSC) technology. In an SSC system, the main clock frequency is modulated, or "spread," such that it does not remain for any extended period in any particular frequency. Figure 1 below illustrates the typical variation of the frequency of a spread spectrum clock signal vs. time. Since all switching signals in the system are derived from the main clock source, these switching signals and their harmonics are also spread in frequency.

Figure 1



“Center-spread” option where the frequency is modulated above and below a desired target “center”.



“Down-spread” option where the frequency is modulated such that it never exceeds a predetermined level of maximum frequency.

A few other qualifying specifications for Spread Spectrum clocks are “Spread Rate” which define how fast the frequency dithering pattern repeats per second; and the “Spread Magnitude”, which is the difference between the highest and the lowest frequency. In a linearly spread clock frequency, if the Spread Rate is significantly smaller than the Spread Magnitude (which is usually the case), the theoretical reduction of EMI energy by spreading the clock is given in Equation 1 below:

$10\log_{10} (D*F_o/BW)$.

In this case, the Spread Magnitude (D) is defined as the ratio of Spread Magnitude to the non-spread center frequency; F_o is the frequency of the interfering harmonic; BW is the bandwidth of the receiver that is being interfered.

For example, assume a system having a 10MHz main clock is interfering with an FM radio signal of 100MHz <u>on</u> its 10th harmonic. If a +/-1% linear spreading clock is used, the average EMI energy reduction is 11.2dB (consider that FM radio has a 150KHz signal bandwidth). For higher harmonics, the EMI reduction will be more significant. For instance, the SSCG clock in the above example will have 21dB of EMI reduction for a 1.8GHz GSM cellular phone signal that has a 300KHz signal bandwidth.

3. MM8512 Description

The MM8512 builds upon the standard SSCG techniques of frequency modulation, but uses Mobius' patented CHO architecture to replace both the quartz crystal and the PLL ICs with a monolithic CMOS die, thereby generating clocking signals without the need for an external resonator.

Eliminating quartz crystals offers significant space savings on the PCB, and allows for more integrated systems which lower the Bill of Materials (BOM) count and cost

In addition to quartz crystals, eliminating the PLL IC or internal circuit for SSCG improves performance by minimizing any increase in phase noise and jitter which are critical timing specifications, and also by reducing power consumption significantly. The typical jitter performance of the device, which is based on an LC (inductor-capacitor) resonator technology, is $3ps_{RMS}$ and phase noise is <-140dBc/Hz under typical conditions at 1MHz offset from the carrier.

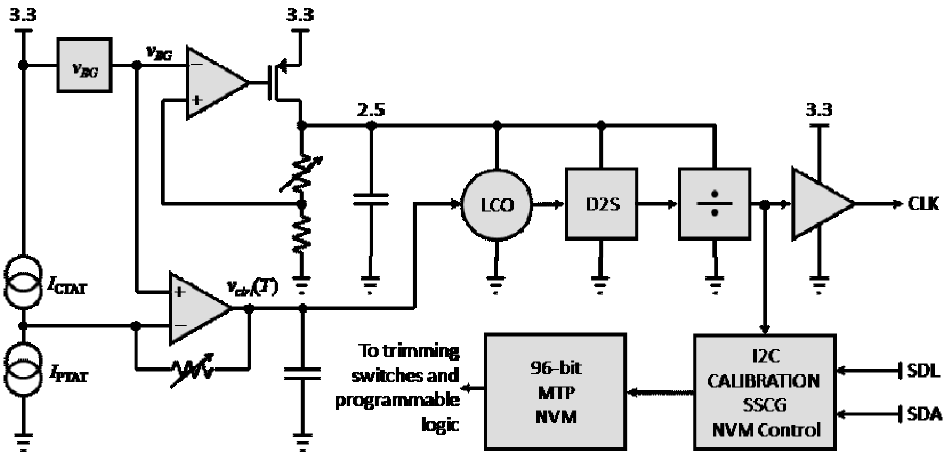
Mobius' CHO technology generates the required frequencies internally at accuracy levels that are sufficient for common interface applications such as USB 2.0 HS, S-ATA and PCIe. The all-CMOS implementation benefits from a well established manufacturing infrastructure and shortens order lead times to best respond to the fluctuating demands of the consumer electronics market.

The MM8512 offers a wide selection of Spread Magnitudes from 0.25 to 6 percent, which enables optimal EMI reduction without sacrificing system timing accuracy. Both center- and down-spread spectrum options are supported. The MM8512 is assembled in a 5x3.2 mm standard package which is designed as a 'drop-in' replacement for leading Spread Spectrum crystal and PLL IC products, with multiple sources available in the market. The device operates from a 3.3V supply and can be used as a fully integrated clock generator with output frequencies that range from 6MHz to 100MHz. Additionally, the MM8512 offers an industry-leading start-up time of ~300µs which allows for quick boot-up and reset.

4. Spread Spectrum Clocking with MM8512

A representative block diagram of the MM8512 device is shown in Figure 2 below.

Figure 2



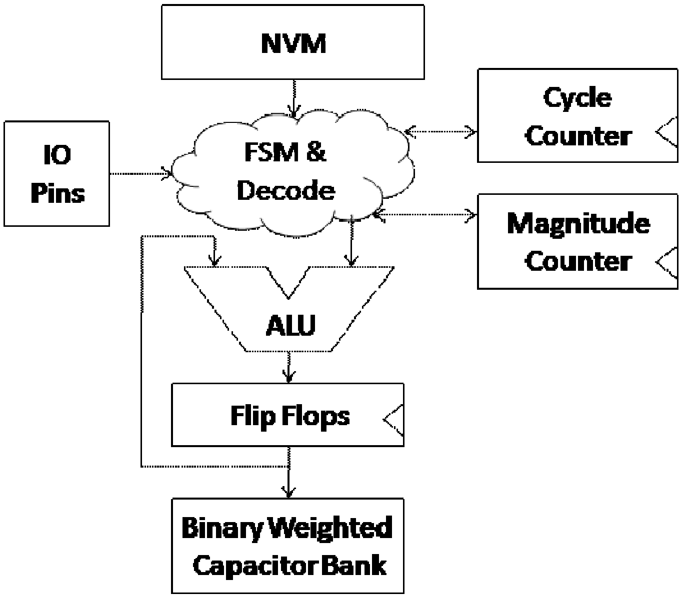
The core of the MM8512 device is the LC Oscillator (LCO) circuitry. The LCO is a free-running oscillator with temperature compensation and process correction. A full and detailed description of the LCO is beyond the scope of this White Paper, but is discussed fully in [ISSCC-08]. A voltage regulator provides a clean power supply for the LC Oscillator (LCO) and other bias and compensation circuitry. The LCO is followed by a differential-to-single ended converter (D2S) and a configurable CMOS divider that provides the variable output frequencies discussed previously.

Temperature compensation for the LCO is provided via the temperature dependent voltage (vctrl) applied to varactors (voltage dependent capacitors) in the LC tank circuit. This voltage is trimmed to modify the capacitance in the LCO to cancel out any change in L due to temperature changes and therefore keeping the oscillation frequency constant. An additional capacitor bank in the LCO is needed to provide for process correction on a part to part basis. This bank is made up of binary weighted thin-film capacitors and is automatically calibrated through the digital interface. The remainder of the control interface is used for implementing the SSCG functionality, managing the multiple time programmable (MTP) non-volatile memory (NVM), and other test and calibration tasks. The NVM is used to store all part trimming data, as well as frequency and spread profile configuration.

A simple block diagram of the Spread Spectrum Clocking architecture of the MM8512 is given in Figure 3 below. The implementation of the SSCG functionality takes advantage of the binary weighted process correction capacitor bank of the LCO to adjust the output frequency in a regular manner. It does so by varying the capacitance an extremely small amount at very fine, discrete time intervals. The capacitance change and frequency of changes sets the modulation depth and rate for the spread profile. A spread profile typically utilizes a 30kHz modulation rate and a 0.25% to 6% modulation depth – i.e., “spread magnitude.”

The control logic also takes special steps to ensure that when spreading is disabled from I/O control, the spread module completes the current cycle so the process correction capacitor bank ends at the original (non-spreading) control word. To assist with Automated Test Equipment (ATE), the entire SSCG control module has built in self-testing (BIST) to verify the module operates as expected.

Figure 3



5. Measuring the Output Spectrum

The EMI reduction effect of the MM8512 may be observed by setting the center frequency of the spectrum analyzer to the nominal frequency of the clock, and then setting the Resolution Bandwidth (RBW) of the analyzer to the desired value. The RBW is the frequency range the analyzer takes each time it steps the center frequency of analysis, and is equivalent to a radio receiver's channel selection bandwidth. The Video Bandwidth (VBW) selection may be accomplished via the automatic setting mode. The resulting setup will produce a nice, smooth plot of the frequency spectrum of the clock signal. The averaging function of the signal analyzer may then be activated while making sure the type of averaging is set as RMS.

Figure 4 shows the comparison of the EMI spectrum of the MM8512 before and after the spread spectrum is turned on. The spreading factor of this particular sample was configured at +/-0.25% (D=0.005). In this test, the 10th harmonic of the 25MHz output is measured; the resolution bandwidth of the analyzer is set to 100KHz; and the reduction is approximately 11dB, very close to the theoretical 10.97dB.

Figure 4

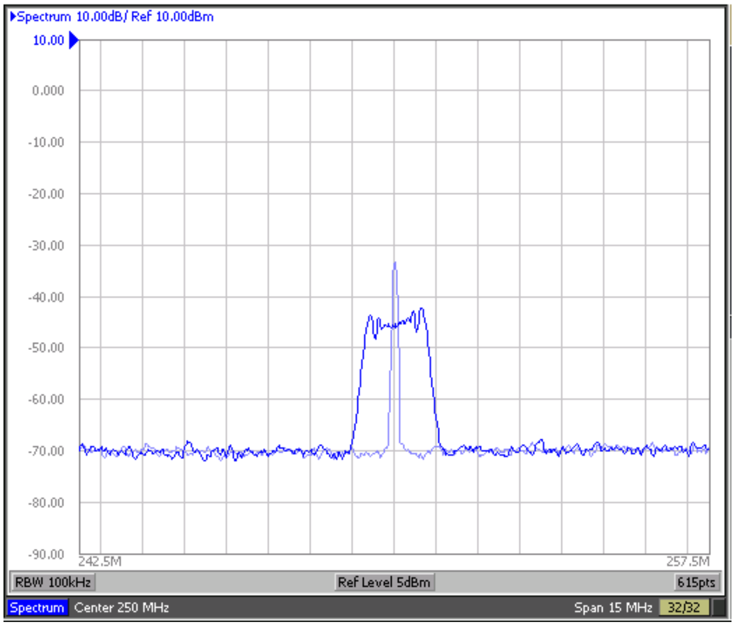
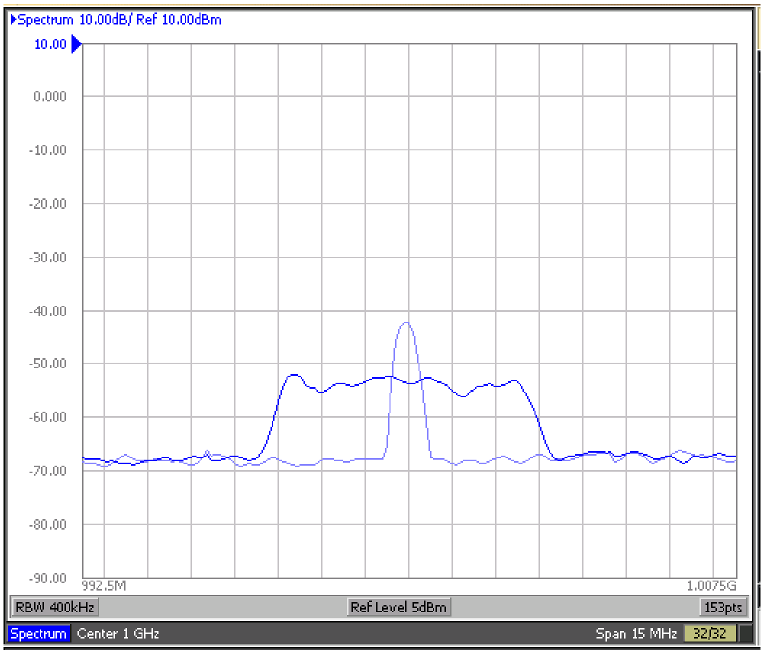


Figure 5 shows the same component measured at its 40th harmonic. The analyzer resolution bandwidth is 400KHz. Again, the measured 10dB EMI reduction is very close to the theoretical value of 10.97dB.



6. Benefits of CMOS Harmonic Oscillators

As discussed above, the MM8512 is designed to reduce peak EMI by spreading the clock frequency over a wider spectral bandwidth. There are many consumer applications which utilize this method today including printers, TVs and computation devices.

In these applications, each new model may be different in terms of its EMI signature, and thus designers need to optimize the EMI reduction methods specifically for each new product, with the sensitivity depending on such parameters as chassis design, number of PCB layers, system complexity, and the length of traces that carry clock and high frequency signals.

One of the key advantages of a programmable and flexible SSCG such as the MM8512 is its capability of reducing EMI at the point of the frequency source deterministically, without the need for extensive trial and error testing. An SSCG can generate reference frequencies with many different spread spectrum magnitudes and rates, appropriate for a given system.

The MM8512 draws about 12mA from a 3.3V supply, and may save power compared to a typical crystal plus PLL IC implementation of SSCG. As mentioned, one of the key differences between traditional devices and the MM8512 is the latter's use of an LC based oscillator internally, which produces very low output jitter compared to ring-oscillator type PLL ICs. The device also offers programmable output drive strengths for added reductions in EMI. Lastly, the MM8512 features a very low current (200nA) standby mode which can be used for added power savings.

Since EMI reduction is a common problem in numerous applications, besides printers, TVs and computation devices, the MM8512 may also be used to clock PCI buses and memory interfaces as well as to act as a reference frequency source for primary microprocessors.

7. Conclusions

EMI has long posed a problem for designers of electronic products and systems who need to reduce RF interference in order to pass compliancy requirements. And never has this been more pressing than now as rapidly succeeding product generations incorporate more features, such as greater wireless capability.

Spread Spectrum Clock Generation (SSCG) has been the industry's traditional approach to dealing with the issue, relying on quartz crystals and PLL ICs to generate clocking signals.

Just introduced, the Mobius MM8512 Spread Spectrum Clock Generator (SSCG) is the industry's first fully integrated, all-CMOS Spread Spectrum timing device meant to reduce system-level EMI. Based on Mobius' patented CMOS Harmonic Oscillator (CHO) architecture, it replaces quartz crystals and PLL ICs with a monolithic CMOS die, for use in products ranging from printers to digital TVs, as well as for buffered memory modules

The high performance, cost effective device works by dithering clock frequency a controlled amount to reduce peak energy. Programming options let the system designer set various output frequencies and spread spectrum modulation depths. The result is a single, highly accurate frequency source with best-in-class phase noise and jitter performance.

By removing quartz crystals and PLL ICs, the MM8512 not only improves performance, it also permits smaller PCBs, thus lowering the count and cost of the Bill of Materials. In addition, using industry-standard CMOS technology facilitates shorter lead times to meet the tight time-to-market demands of the consumer electronics market.

8. Call to Action

Order samples or an evaluation kit for Mobius' MM8512 Spread Spectrum Oscillator to achieve reductions in EMI in your design. Further information may be found at http://www.mobiusmicro.com. For any specific inquiries, please contact Mobius Microsystems at applications@mobiusmicro.com by email or call +1-408-329-5000.

Mobius Microsystems is located at Murphy Square, Suite 210, 111 West Evelyn Avenue, Sunnyvale, CA 94086 USA.

9. References

[1] Michael S. McCorquodale, Scott M. Pernia, Justin D. O'Day, Gordy Carichner, Eric Marsman, Nam Nguyen, Sundus Kubba, Si Nguyen, Jon Kuhn and Richard B. Brown, "A 0.5–480MHz Self-Referenced CMOS Clock Generator with 90ppm Total Frequency Error and Spread Spectrum Capability," IEEE International Solid State Circuits Conference (ISSCC) Dig. of Tech. Papers, San Francisco, CA 2008.