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APPLICATION NOTE 3512

Automotive Applications for Silicon Spread-Spectrum Oscillators

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Abstract: Digital-electronics systems enrich our lives in many ways, but digital clock signals also act as a source of conducted noise (via cables) and radiated electromagnetic interference (EMI). Because the potential noise problems are substantial, all of today's electronic products are tested to ensure compliance with recognized EMI standards. But it's not just about EMI compliance. . . The use of spread-spectrum (SS) oscillators is increasingly attractive for use in automobiles, where the benefits are seen not just by instruments, but also by the driver and passengers—in clean performance of the electronic automotive subsystems.

Automotive Advantages

Benefits of the SS approach go well beyond its efficacy in meeting certain FCC and regulatory requirements for EMI compliance. The benefits perceived for EMI compliance depend mostly on the bandpass specification of your measurement technique. SS techniques do minimize concentrations of peak energy, and the resulting distribution of this energy into the noise floor does reduce the need for filtering and shielding, but they can provide other benefits as well.

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The increasing number of high-performance multimedia, audio, video, and wireless systems deployed in today's automobiles compels designers to pay special attention to any unwanted RF energy present at frequencies to which these subsystems are sensitive. For high-quality radios and wireless data systems, the elimination of RF energy peaks can determine whether a system is usable or not.

For years, radios have utilized a method known as frequency parking to avoid interference from power-supply switching noise. Such radios actually communicate with the power supply, commanding it to alter its switching frequency as necessary to shift energy peaks out of the tuner's input band. With the increasing number of interference sources in a modern automobile, however, you cannot always anticipate how the systems will work together. The situation is further complicated by the use of antenna diversity systems, and by restrictions on the placement of new subsystems.

Other benefits of the SS oscillator can be found in digital audio and in the factory-installed, hands-free interface. These systems commonly use a codec to increase audio quality by providing a digital interface

to the cell phone or other telematic interface. The use of a dithered (spread-spectrum) oscillator as clock source to the codec eliminates the generation of annoying idle tones during otherwise silent intervals. This technique is also common in multimedia applications that incorporate switched-capacitor codecs. Besides eliminating the idle tones, an SS oscillator pushes energy peaks into the noise floor, which reduces (for example) the possibility of landing on channels used by a frequency-hopping wireless network.

Virtually all subsystems in the next-generation automobile are likely to include areas in which SS-clocking techniques can provide significant benefits in performance and EMI compliance. For that purpose, vendors such as Maxim/Dallas offer all-silicon oscillators that have reliable startup characteristics and are not affected by vibration. They are cost competitive with ceramic resonators, and cover a range from kilohertz to over sixty megahertz.

General Considerations

Controlling EMI remains a challenge for the electronics designer. A look at the origin of EMI often shows the largest contributor as a digital system clock, which follows for several reasons: the clock often has the highest frequency in the system, it is usually a periodic square wave, and clock traces are often the longest traces in the system. The frequency spectrum for such a signal consists of a fundamental tone and lower-amplitude harmonic tones, whose amplitudes diminish with increasing frequency.

Other signals in the system (those on the data and address buses) are updated at the same frequency as the clock, but they occur at irregular intervals and are generally uncorrelated with each other. The result is a broadband noise spectrum of much lower amplitude than that of the clock. The total energy in this spectrum is much larger than the clock energy, but it has little effect on the EMI tests. Those tests look at the highest spectral amplitudes; not the total radiated energy.

You can control EMI with filtering, shielding, and good PCB layout. But filtering and shielding add cost, and a precise layout takes time. Another approach is to attack the noise source itself—most commonly, the clock oscillator. You can easily lower the amplitudes of the fundamental and overtones by making the clock frequency vary with time. Because the energy of the clock signal remains constant, a varying frequency that broadens the overtones necessarily lowers their amplitudes.

A simple way to generate such a clock is to modulate a voltage-controlled oscillator (VCO) with a triangle wave. The resulting spectrum becomes broader as the triangle-wave amplitude increases. How fast should this triangle wave repeat? A slow sweep (in the audible range) can couple through power supplies to analog subsystems. A sweep that's too fast, on the other hand, may confuse the digital circuitry.

Figure 1 is the block diagram of a clock oscillator based on the approach described above, in which a triangle wave controls the spectral broadening of a VCO output. (The VCO's center frequency is controlled by a DAC and programmable 8-bit divider that allows you to set the frequency anywhere between 260kHz and 133MHz.) The IC of Figure 1 is controlled by a 2-wire interface, and settings are stored in an on-board EEPROM. Such devices can operate in stand-alone mode when pre-programmed to the desired frequency, and their frequency can be updated on the fly—an advantage in low-power applications.
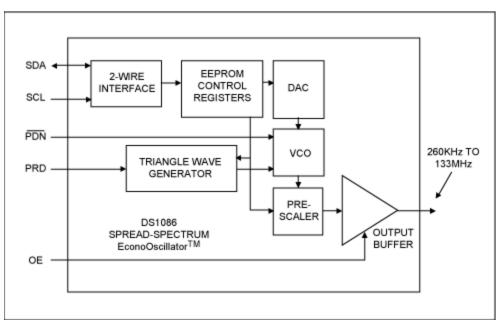
Figure 1. The core of the DS1086 programmable clock generator is a VCO controlled by a triangle wave. The frequency is preprogrammed over a 2-wire interface and stored in an onboard EEPROM.

Figure 2 compares the spectrum of an ordinary crystal oscillator with that of the spread-spectrum clock oscillator. Setting the triangle-wave amplitude to broaden the spectrum by 4% lowers the peak amplitude nearly 25dB below that of the crystal clock oscillator.
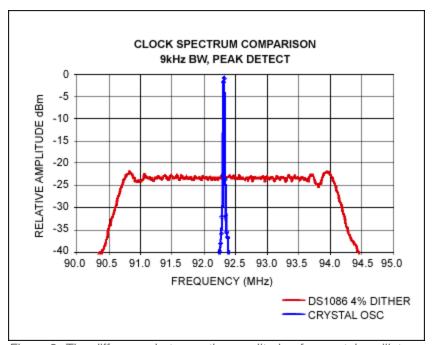

Figure 2. The difference between the amplitude of a crystal oscillator and the amplitude of the DS1086 with 4% spreading is close to 25 dB.

When using the spread-spectrum oscillator as a clock source for microprocessors, be sure the µP can cope with tolerances on the duty cycles, rise and fall times, and other parameters associated with

frequency variation in the source. For applications in which the oscillator is used as a reference (real-time clocks and real-time measurements, for example), the varying frequency may add quite a bit of error.

Portable consumer products can include radio functions such as cellular phones, and spread-spectrum techniques are applicable to the switching power supplies found in those products. The radio circuitry (especially the VCO) is susceptible to noise on the power supply. Switching supplies are needed to maximize battery life, but they unfortunately have noise spectra similar to those of clock oscillators. That noise can limit performance by coupling directly into the radio circuitry.

A step-up converter with external synchronization pin (such as the MAX1703) lets you control its frequency with a spread-spectrum clock. It is instructive to compare the noise spectra of a free-running step-up converter (**Figure 3**) to one that is synchronized to a spread-spectrum clock (**Figure 4**). Overtones of the free-running stepup converter are visible all the way out to 10MHz, whereas spread-spectrum broadening (Figure 4) pushes the tones into the noise floor. Note that the noise floor in this plot has risen because the overall energy is constant.
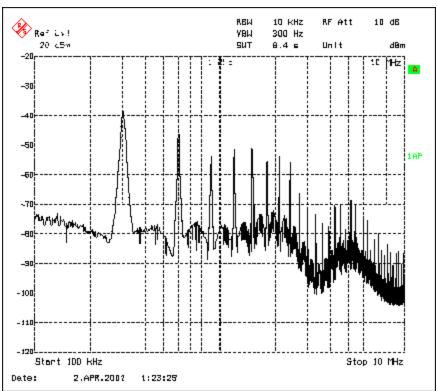

Figure 3. The spectrum of the MAX1703 step-up converter shows the fundamental at 300kHz, the free-running switch frequency. Overtones are visible all the way up to 10MHz.
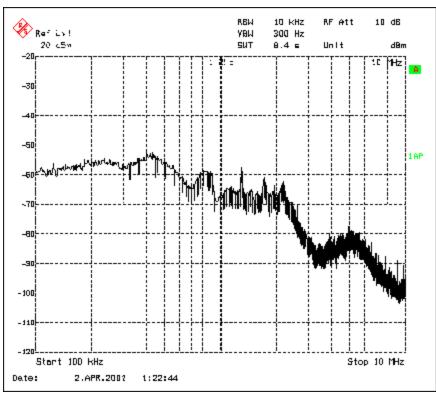
Figure 4. Synchronizing the MAX1703 step-up converter to a spread-spectrum oscillator removes the peaks and causes the noise floor to rise.

To implement a dithered clock source, one needs the answers to several questions: What should be the dithering shape to reduce the narrow-band spectral energy? How is the maximum clock-frequency shift related to the narrow-band spectral energy? How does dither rate effect the narrow-band spectral energy? What limits the dithering rate being used? Those questions are addressed in the following sections.

Dithering Shape

To ensure that the clock signal remains usable, the dithering amplitude is generally small (<10%). Thus, dithering is similar to narrow-band FM modulation. The theory for such modulation offers a simple relationship between dither shape and the resulting spectrum.

Theory shows that the "probability density function" of the clock frequency has the same shape as the spectrum of the dithered clock output. (Probability density function describes, as a function of frequency, the percentage of time the system dwells on any one frequency.) The sawtooth waveform, a commonly used dithering shape, visits each frequency exactly twice in one dither cycle. Because each frequency appears for the same percentage of time, the probability density function versus frequency is constant, creating a uniform distribution (see Figure 1).

The spectrum for this type of dither shape is the same—narrow, uniform band of spectral energy located between the minimum and maximum frequencies produced by the dither. This shape is optimum for the amount of dithering allowed (Fmax -Fmin), because the narrow-band spectral energy is the lowest possible at any frequency.

This spectrum is also produced by pseudo-random-frequency dither, another popular dither shape. It is usually generated as a long sequence of frequencies that repeats in a regular cycle, but includes each

frequency only once per cycle. The frequencies have a pseudo-random order of occurrence, and are easily generated with shift registers. Becuause each frequency occurs only once per cycle, its probability density function is also uniform, like the triangle distribution shown above. As discussed below, these methods differ considerably in other areas.

Spectral Attenuation

The measure of a dithering scheme is how much the narrow-band spectral energy has been reduced with respect to that of a single-tone clock. This section derives the relationship for optimum shaping of a uniform dither distribution.

Two points help in understanding spectral energy: First, in going from a single tone to a dithered clock, the clock energy is conserved. Wideband energy is the same, but spread over a wider frequency band after dithering. Second, the spectrum of a cyclically dithered clock consists of separate spectral tones spaced at intervals equal to the dithering frequency (F_d). We now equate single-tone power to power in the total dithered-tone band:

$$V_{RMS} \text{ (dB)} = 20\log[sqrt(\{(F_0 * a)/F_d\}*V_u^2)]$$
$$= 10\log[\{(F_0 *a)/F_d \}]+ 20\log[V_u],$$

where F_0 is the clock un-dithered frequency, a is the percentage dither about the un-dithered frequency, and V_u is the uniform RMS voltage of each spectral tone in the dithered band. The reduction in narrow-band spectral energy is the ratio of V_u to the left-hand term (V_{RMS}).

$$\text{Spectral attenuation} = 10\log[\{(F_0 *a)/F_d\}].$$

The above equation states that the more spectral tones you can generate in an allowed dither bandwidth $a*F_0$ (i.e., the lower the dither frequency), the lower will be the energy in small increments of bandwidth within the spectrum. This intuitive explanation fits the equation. As an example based on this expression, consider a dithering scheme for the DS1086 programmable clock generator, in which a = 0.04, F_0 = 100MHz, and F_d = F_0/2048. Thus, the DS1086 spectral attenuation is = 19.1 dB.

Note that increasing the dither percentage (a) has the same effect as lowering the dither-rate frequency on the narrow-band spectral energy. Also, note that this equation works both for the triangle dither and the pseudo-random dither shape, because they have the same distribution. The next question is how far can we push the two reduction parameters, and what is the implication of each.

Dithering Limits

The limits on spectral attenuation are set by practical considerations. First, the frequency instability due to dithering varies the timing in a system. The system therefore provides a definite limit of the value of "a."

The circuit that generates the dithered clock also limits the dither rate. For systems that employ phase-locked loops or other control loops (as does the DS1086 family), the bandwidth of the control loop limits the dither frequency. The dithering control voltage is limited by the loop's bandwidth. Otherwise, the dither control's distribution function would be distorted to a more Gaussian shape. In turn, that shape would produce a spectrum with larger spectral energy near the un-dithered clock frequency than would be present for a more uniform distribution.

The triangle dither pattern has its primary frequency component at the dither rate, but the pseudo-random pattern requires a bandwidth wider than the dither pattern rate. Frequency can jump from

minimum to maximum in the pseudo-random pattern, but only between small consecutive increments of frequency in the triangle pattern. The approximate relationship for loop bandwidth to dither rate is:

Loop BW > 3(triangle pattern frequency), and
Loop BW > 3(pseudo-random pattern rate)(pattern length).

For a fixed amount of loop bandwidth, the triangle pattern can support a larger dither frequency. Because the dither rate must be faster than the narrow-band detection of an interferer (to appear as frequency dithering), the triangle looks more dithered than does the pseudo-random pattern for the same detection time.

Thus, dither-detection time influences how low the dither frequency can be. Because the bandwidth of an interference victim varies with the application, the dither frequency has no hard lower limit (unfortunately). The other consideration on the dither frequency's lower limit is out-of-band noise from the dither rate itself. For a linear system, the triangle dithering system has no tones at the dither rate or its near harmonics. The pseudo-random scheme has some lower-level version of the pseudo-random pattern spectrum at the dither rate. If this clock signal is picked up by a non-linear circuit, however, there exists the unwelcome possibility of mixing the low dither rate into a desired band.

Spread-spectrum techniques do not replace the traditional EMI-lowering techniques of filtering, shielding, and good layout practice. They can provide a substantial benefit, however, especially in systems for which certain subassemblies or peripheral equipment are sensitive to energy peaks at particular frequencies. They are extremely useful in minimizing radio/TV interference in automotive and home-entertainment systems. Good PCB layout is essential for proper functioning of digital and analog systems, but a spread-spectrum clock can aid EMI certification and lower costs by reducing the amount of filtering and shielding needed.

Maxim produces a family of spread-spectrum oscillators suitable for a wide range of applications. For further information, please see EconOscillator Timing Products.

References

1. Ott, H. W., Noise Reduction Techniques in Electronic Systems, 2nd edition, chapters 10 and 11. Wiley-Interscience, New York, 1988.
2. Maxim application note 232, "Using the DS1086 as a Microcontroller Clock to Reduce EMI" 2003.

Related Parts		
DS1086	Spread-Spectrum EconOscillator	Free Samples
DS1086L	3.3V Spread-Spectrum EconOscillator	Free Samples
DS1087L	3.3V Spread-Spectrum EconOscillator	Free Samples
DS1089L	3.3V Center Spread-Spectrum EconOscillator™	Free Samples
DS1090	Low-Frequency, Spread-Spectrum EconOscillator	Free Samples
DS1094L	Multiphase Spread-Spectrum EconOscillator	Free Samples

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