Digital Programmable Oscillator Is Smaller, Sturdier and More Versatile than Crystal Oscillators

by Albert Huntington

Introduction

Open just about any electronic gadget these days, and you will find a crystal oscillator driving a microcontroller, providing a timebase or clocking any number of discrete time circuits. Crystal oscillators provide a reasonably priced, and highly stable time base. They are relatively easy to use, and are available in increasingly smaller packages. Thus, the venerable crystal oscillator has become the defacto timebase solution. Designers often do not even consider asking if it is the best solution to a problem, when, in fact, crystal oscillators are not without their drawbacks. They can be power hungry, inflexible, board space hogging, and above all, *shock sensitive* components.

Enter the LTC6903 and LTC6904. These programmable oscillators provide a smaller, more reliable and vastly more versatile clocking solution. In a small MS8 package, the LTC6903 and LTC6904 use less board space than almost all crystal oscillators. Whereas crystal oscillators contain a quartz crystal and are sensitive to mechanical shock, the LTC6903 and LTC6904 are a fully electronic devices, and relatively insensitive to vibration and mechanical shock. While crystal oscillators output a set frequency, the LTC6903 and LTC6904 are fully programmable between 1kHz and 68MHz. The frequency is set by a 16-bit control word via a serial port and is typically accurate to within 1.1%, with a resolution of 0.1% or better.

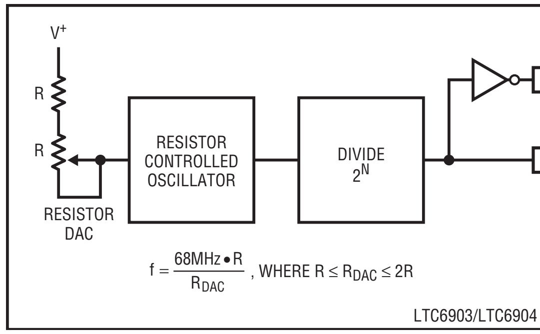

Figure 1. LTC6903 and LTC6904 conceptual block diagram. The LTC6903 and LTC6904 consist of a resistor controlled oscillator coupled to a serial port controlled resistor DAC and output divider.

Device Description

The LTC6903 and LTC6904 are resistor controlled oscillators, similar to the popular LTC1799. These new oscillators offer an integrated serial resistor DAC and a set of digital frequency dividers, as shown in Figure 1.

The LTC6903 takes commands via an SPI-compatible 3-wire serial port, and the LTC6904 communicates through an I^2C-compatible 2-wire serial port. The serial port bit maps are shown in Figure 2. Ten DAC bits control the resistor DAC, four OCT bits control the output dividers, and 2 MODE bits control the outputs. The LTC6904 can respond to one of two different serial port addresses (set by the state its ADR pin).

The resistor DAC ranges linearly in value from R to 2R, where R is trimmed to give the oscillator a frequency range of 34MHz to 68MHz:

$$f = \frac{68MHz \bullet R}{R_{DAC}}, \text{ where } R \le R_{DAC} \le 2R$$

The oscillator frequency is inversely proportional to the resistance of the DAC. At frequencies just above 34MHz, the step size is 16.6kHz. At frequencies immediately below 68MHz, the step size is 66.4kHz. The step size ranges between 0.05% and 0.1% of the frequency. The output frequency divider divides the internal oscillator frequency by 2^N, where N ranges from 0 to 15. N is calculated from the OCT bits of the control word, and is simply the complement of those bits. Higher values of N (lower values of OCT) yield lower output frequencies. The combination of the OCT and DAC bits into a single 14-bit control word provides a simple and consistent interface where higher control codes always result in

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
OCT3	OCT2	OCT1	OCT0	DAC9	DAC8	DAC7	DAC6	DAC5	DAC4	DAC3	DAC2	DAC1	DAC0	MODE1	MODE0
4-Bit Control Divider 2^N				10-Bit Control DAC										2-Bit Control OUT and $\overline{OUT}$	

Figure 2. LTC6903 and LTC6904 serial port bitmap. OCT[3:0] controls the octave, DAC[9:0] controls the frequency setting within an octave, and MODE[1:0] sets the active output.

Table 1. Choosing the OCT code

Minimum Frequency	Maximum Frequency	OCT Code
34.05MHz	68.03MHz	15
17.02MHz	34.01MHz	14
8.511MHz	17.01MHz	13
4.256MHz	8.503MHz	12
2.128MHz	4.252MHz	11
1.064MHz	2.126MHz	10
532kHz	1063kHz	9
266kHz	531.4kHz	8
133kHz	265.7kHz	7
66.5kHz	132.9kHz	6
33.25kHz	66.43kHz	5
16.62kHz	33.22kHz	4
8.312kHz	16.61kHz	3
4.156kHz	8.304kHz	2
2.078kHz	4.152kHz	1
1.039kHz	2.076kHz	0

higher frequencies. Across all control codes, the LTC6903/LTC6904 is guaranteed to be completely monotonic.

The output pins are controlled by the output control bits MODE1 and MODE0. Either of the outputs can be disabled through these bits. When both outputs are disabled through the mode control bits, the internal oscillator is also disabled. The OE pin can also be used to asynchronously disable either output without shutting down the oscillator entirely.

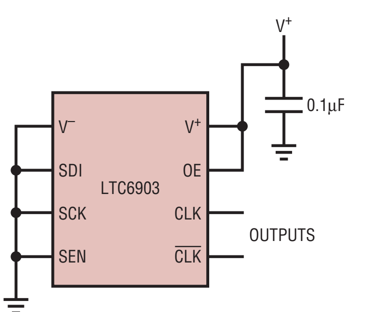

Figure 3. LTC6903 minimal circuit. The LTC6903 and LTC6904 have a simple external interface—the only required external component is a bypass capacitor.

Applications Example

A Minimal Circuit

The LTC6903 and LTC6904 require no external components other than a small power supply bypass capacitor. For best performance, this capacitor should have low series resistance and be mounted directly adjacent to the power supply pins. The minimal circuit shown in Figure 3 results in an oscillator frequency of 1.039kHz upon power-up. The LTC6903/LTC6904 incorporates power on reset circuitry which sets the control code to all zeros when power is first applied. Other frequencies may be set through the serial port.

Calculating the Frequency Code

In order to set a frequency, an OCT code and a DAC code must be calculated. The OCT code may be chosen from Table 1 or it may be calculated as:

$$OCT = 3.322 \log \frac{f}{1039}, \qquad (1)$$

where f is the desired frequency in Hertz.

When using the equation, it is necessary to round the OCT code *down* (truncate) to the nearest integer.

The DAC code is:

$$DAC = 2048 - \frac{2078(Hz) \bullet 2^{10+OCT}}{f},$$

where f is the desired frequency in Hertz and OCT is the previously determined OCT code.

Round the DAC code to the nearest integer value, up or down. The frequency may be calculated from the OCT and DAC settings through the formula:

$$f = 2^{OCT} \bullet \frac{2078}{\left(2 - \frac{DAC}{1024}\right)} \qquad (2)$$

For instance, to set a frequency of 1.00MHz, first chose the OCT code from Table 1 or calculate OCT from equation [1] above.

$$OCT = 3.322 \log \frac{1 \bullet 10^6}{1039} = 9.91$$

Round down (truncate) for an OCT code of 9. Next, calculate the DAC code:

$$DAC = 2048 - \frac{2078(Hz) \bullet 2^{10+9}}{1 \bullet 10^6} = 958.53$$

Rounding to the nearest integer, the DAC code is 959.

Verify the calculations by plugging the result back into the formula [2] for frequency:

$$f = 2^9 \bullet \frac{2078}{\left(2 - \frac{959}{1024}\right)} = 1.00 \times 10^6$$

In order to determine the 16-bit control word for the LTC6903/LTC6904, values for the mode control bits, MODE0 and MODE1, must be chosen. To enable both outputs, set both MODE0 and MODE1 to "0".

The control word is composed of the OCT, DAC and MODE control bits:

$OCT \bullet 2^{12} + DAC \bullet 2^2 + MODE,$

or,

$9 \bullet 2^{12} + 959 \bullet 2^2 + 0 = 40{,}700,$

or in binary,

1001111011111100.

Figure 4 shows that frequency resolution over the entire range of the control word is roughly proportional to the set frequency.

Writing the Control Code

The LTC6903 can be configured through its SPI-compatible serial port. Similarly, the LTC6904 can be

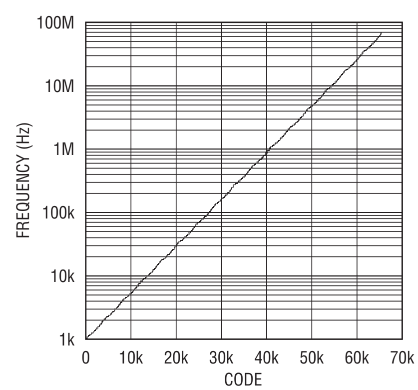

Figure 4. Frequency vs control code. The LTC6903 and LTC6904 achieve 0.1% resolution across all specified frequencies with a smooth, monotonic transfer function.

OCT = 9				DAC = 959										MODE=0	
D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
1	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**

Figure 5. Setting the frequency to 1MHz and choosing a mode after calculating OCT and DIV codes. The codes must be translated into a binary number and written to the LTC6903 or LTC6904 through its serial port.

addressed through its I^2C-compatible 2-wire serial port. Both serial ports are set up so that the serial transfer is accomplished in 8-bit chunks, the MSB being transferred first. Therefore, writing just a single byte to the serial port will result in the most significant byte being changed. Additionally, the bytes are written to the registers as they are received, so a pause between writing the first and second bytes may temporarily result in an unintended frequency output.

Driving Loads

The LTC6903 and LTC6904 output drivers present a low output impedance of 45Ω, and are capable of driving substantial resistive and capacitive loads of as much as 1kΩ and 100pF at frequencies up to 1MHz. At higher frequencies, two effects must be taken into account. First, the impedance presented by the capacitive load becomes a substantial factor in the shape of the output waveform. At the maximum operating frequency of 68MHz, in order to achieve full swing, an output load of 5pF or less is recommended. Second, the current drawn through the output drivers at high frequencies becomes excessive with capacitive loads. This results in greatly increased power dissipation, and will contribute to frequency inaccuracy at frequencies above about 1MHz. Under a 5V power supply, the output drivers each draw 1.7mA at 68MHz for every 5pF of load. This is simply a calculation of the energy necessary to charge and discharge the output load capacitance to 5V at 68MHz, following the formula:

$$I_S = C_{LOAD} \bullet V_{SUPPLY} \bullet F_{CLK}$$

The recommended 5pF load is equivalent to two HC CMOS logic inputs, and is substantially less than the 12pF–15pF of a standard oscilloscope probe. It is also recommended that the connection to the output of the LTC6903/LTC6904 be kept shorter than 5cm in order to reduce ringing and reflections from transmission line effects.

Jitter

Crystal oscillators traditionally excel in frequency accuracy with low jitter. The LTC6903 and LTC6904 do not reach the level of a crystal oscillator by those measures, but it is comparable enough to make it a good choice in most applications, especially when size, cost and durability are important.

Frequency accuracy is trimmed in at <0.75% at 1kHz under nominal power supply and temperature conditions. DAC variation over frequency settings adds an additional 0.35%, while temperature variation across 0°C–70°C adds 0.9%, for a total variation of 2% over temperature and setting. Power supply variations, mostly at the upper end of the supply range, account for an additional 0.25% inaccuracy, leading to 2.25% over all conditions.

Due to the large number of dividers used when operating at low frequencies, the LTC6903 is able to provide typical peak-to-peak jitter of less than 0.1% at frequencies up to 500kHz, and less than 0.4% at frequencies up to 8.5MHz. At 68MHz, jitter increases to just under 3% because the averaging effects of the dividers are absent. These specs are acceptable in all but the most demanding precision timing applications.

A Tunable Lowpass Filter

The LTC6903 and LTC6904 are uniquely well suited to interface with switched capacitor devices such as filters and data converters. The tunable lowpass filter of Figure 6 is a typical example. Using the LTC6903 in combination with an LTC1569-7 tunable filter, it is possible to generate a lowpass frequency response anywhere from 94Hz to 300kHz with a 0.1% resolution, using a circuit consisting of only two small integrated circuits and no external components other than two 10% resistors and power supply bypass capacitors.

By tuning the LTC6903 over a frequency range of 3kHz to 9.5MHz at 5V power supply using the equations presented earlier, a corner frequency of between 94Hz and 300kHz may be set. The current draw of the combined circuits is typically 10mA, the majority of which is in the LTC1569-7 tunable lowpass filter.

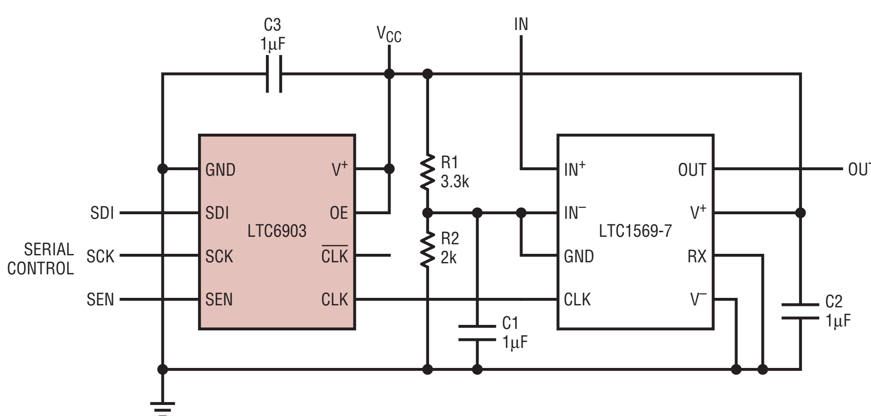

Figure 6. This simple circuit can generate a lowpass frequency response anywhere from 100Hz to 200kHz with a 0.1% resolution.

continued on page 30

such that the desired output voltages ramp characteristic is achieved. The gate pullup currents are controlled via the FB^+ and FB^- pins.

Figure 4 shows coincident tracking for a system operating with +12V and –12V supplies as per the circuit in Figure 2. The circuit in Figure 2 is easily converted to work with –5V and +12V supplies by simply changing R3, R9 and R11 to 12.4kΩ. The new coincident tracking behavior is shown in Figure 5. Ratiometric tracking is sometimes preferable, especially in signal processing applications. Figure 6 shows this mode of operation, obtained by changing only R3 and R11 to 12.4kΩ. Note that in this case the supply ramps are made to start and finish at the same time.

Short-Circuit Protection

Current limiting provides protection for the output MOSFET devices. The current limit for either supply is set by sense resistors R_S^+ and R_S^- (Figure 2). The voltage across the sense resistor is regulated by the current limit circuitry to 50mV for conditions where foldback current limiting is not enabled. The TIMER pin provides a means for setting the maximum time the LT4220 is allowed to operate in current limit. Whenever the current limit circuitry becomes active, by either the positive or negative sense amplifier operating in current limit, a pull-up current source of 60uA is connected to the TIMER pin and the voltage rises with a slope of $dV/dt = 60\mu A/C_{TIMER}$. If the overload is removed, a small 3μA pulldown current slowly discharges the timer pin. If the timer succeeds in charging to a 1.24V threshold, an internal fault latch is set and the $\overline{\text{FAULT}}$ pin is pulled low. Both MOSFETs are quickly turned off while the TIMER pin is slowly discharged to ground.

The power dissipation will be high in the output MOSFET devices when the output is shorted with zero ohms. To prevent excessive power dissipation in these pass transistors the current limit on each supply is reduced as the output voltage falls. This characteristic, commonly referred to as "current foldback", reduces the fault current as the output voltage drops and reaches the lowest level into the short. The foldback current limiting reduces short circuit MOSFET dissipation by a factor of 2.5. The FB± pins effectively measure the MOSFET V_{DS} voltage and control the appropriate current limit sense amplifier input offset to provide the foldback current limit.

Automatic Restart

Normally the LT4220 latches off in the presence of a fault. Nevertheless, by removing R15 in Figure 2, you can connect the $\overline{\text{FAULT}}$ and ON^+ together to enable automatic restart. $\overline{\text{FAULT}}$ pulls the ON^+ pin low allowing an automatic restart to be initiated once the TIMER pin ramps below 0.5V.

Conclusion

The LT4220 combines all of the functions necessary for split supply Hot Swap control in one small 16-lead SSOP plastic package. This device is adaptable to applications covering a wide range of positive and negative supply voltages, ramping profiles, capacitance and load currents, including optical/laser, audio and ECL systems.

LTC6903/LTC6904, continued from page 9

Conclusion

Though crystal based oscillators have dominated the timing and clocking market for many years, the LTC6903 (I^2C) and LTC6904 (SPI) offer solutions that are smaller, more flexible, more robust and lower power. Selecting a frequency from the 1kHz–68MHz frequency range is simple through the serial ports, and both devices operate over a wide range of supply voltages.

LTC3205, continued from page 23

Both of these features are required to keep the LTC3205 in direct-connect mode as long as possible.

Conclusion

The LTC3205, designed specifically for portable backlighting applications, provides all of the necessary current regulation, power circuitry and control logic to deliver efficient and accurate power to a large number of LEDs in a portable product. To further reduce board level complexity, it uses only four 0603 sized ceramic capacitors keeping the total solution height under 1mm. A straightforward serial interface reduces the number of wires needed to control all of the LEDs. Given its feature set, the LTC3205 packs an amazing amount of backlighting horsepower, flexibility and performance into a very small 4mm × 4mm footprint.

For more information on parts featured in this issue, see http://www.linear.com/go/ltmag