

Keywords: RTC, oscillator, crystal, battery current, low power

APPLICATION NOTE 4247

Oscillator Design Considerations for Low-Current Applications

Jan 26, 2011

Abstract: This application note describes how low-frequency oscillator design and crystal selection affect operating current. When running the oscillator from a limited-capacity supply, such as a lithium coin cell or super capacitor, minimizing the operating current increases the operating time.

Introduction

Maxim has a large portfolio of low-power, battery-backed real-time clocks (RTCs). A primary consideration when Maxim designs an RTC is minimizing the power requirements of the oscillator when the RTC is running from the backup supply, so as to maximize the life of the backup source. Crystal oscillators provide reasonable accuracy, and development efforts for many years have focused on minimizing power consumption.

Oscillator design goals include the following:

- Provide enough current and gain to start and maintain oscillation
- Provide a wide operating-voltage range
- Minimize the influence of external noise on accuracy

Key Crystal and Oscillator Parameters

Figure 1 presents an equivalent circuit of a crystal resonator. A crystal has two frequencies of zero phase, as shown in **Figure 2**. The lower frequency is the series resonant frequency. At the series resonant frequency, L1 and C1 cancel, and the impedance is determined by R1.¹ The second, higher, frequency is the parallel resonant frequency. At parallel resonance, resistance is at a maximum.

A parallel resonant oscillator circuit (**Figure 3**) uses a crystal that is designed to operate with a specified load capacitance. This results in a circuit that operates at a frequency between the series resonant point and the parallel resonant point. A change in the load capacitance causes a change in the oscillator frequency.

Crystal equivalent series resistance (ESR) tends to shift upwards after going through SMT reflow, so an SMT crystal that is otherwise similar to a through-hole package crystal may have a higher maximum ESR specification. Likewise, smaller tuning-fork crystals will usually have higher ESR specifications than larger ones.

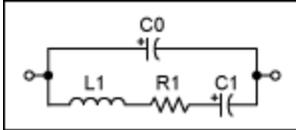


Figure 1. Equivalent circuit of a crystal resonator.

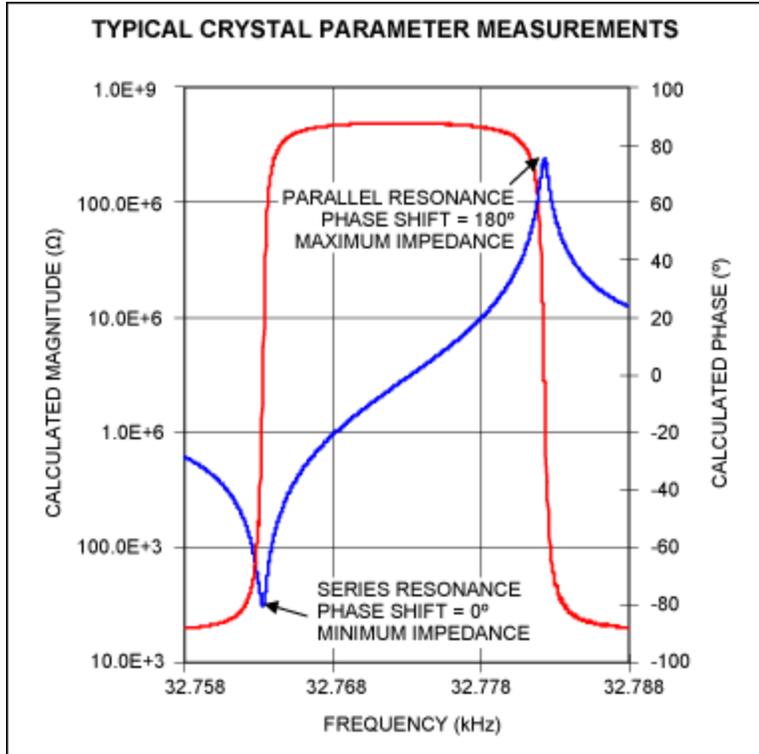


Figure 2. Crystal phase and impedance response.

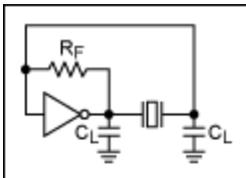


Figure 3. Pierce-type (inverter variation) oscillator circuit.

Oscillator Current

As Eric Vittoz has observed, when both load capacitors in a crystal oscillator circuit (Figure 3) are of equal value, the minimum current for oscillation (or critical transconductance) can be approximated by the equation below.²

$$g_{\text{m,crit}} \approx 4\omega^2 \times C_L^2 \times R_{\text{ESR}} \quad (\text{Eq. 1})$$

Where ω is the frequency in radians, C_L is the equivalent capacitive load, and R_{ESR} is the ESR of the crystal. The oscillator is assumed to be a CMOS device operating in weak inversion.

Vittoz also determines that the oscillator amplitude and bias current are related by the following equation:

$$\frac{I_O}{I_{Ocrit}} = \frac{x}{2} \times \frac{I_{B0}(x)}{I_{B1}(x)} \quad (\text{Eq. 2})$$

Where $x = \frac{|V_1|}{nU_T}$ and I_{B0} and I_{B1} are zero- and first-order modified Bessel functions.

We can therefore show the relationship between oscillator current at a given oscillator voltage with different values of ESR and C_L , as shown in the following example. Assuming that $V_1 = 400\text{mV}_{P-P}$, $nU_T = 26\text{mV}$, $\text{ESR} = 35\text{k}\Omega$, and $C_L = 6\text{pF}$, then $\frac{I_O}{I_{Ocrit}} \approx 4$, and

$$\begin{aligned} I_O &\approx 4\omega^2 \times C_L^2 \times R_{\text{ESR}} \times nU_T \times 4 \\ &\approx 4 \times (32,768 \times 6.283)^2 \times (6\text{e-}12)^2 \times 35\text{e}+3 \times 0.026 \times 4 \\ &\approx 22.2\text{nA}. \end{aligned}$$

Table 1 shows the relationship between both C_L and ESR on oscillator current, using the values for V_1 and nU_T above.

Table 1. Crystal ESR and C_L versus Oscillator Current

ESR (Ω)	C_L (pF)	I_O (nA)
35,000	6	22.2
70,000	6	44.4
35,000	12.5	88.9
70,000	12.5	177.8

Since in the equation for $g_{m\text{crit}}$ the C_L term is squared, doubling the load capacitance has the effect of increasing oscillator current by four times. Increasing the crystal ESR by two times causes the required oscillator current to double. Note that this is the minimum estimated oscillator current, which does not include current consumed by additional circuits for amplifying the oscillator output, nor does it include currents in the devices used to divide the frequency down to 1Hz.

Oscillator Design Requirements

An oscillator should be designed so that it has sufficient gain to operate over the entire operating temperature and voltage range. The amplitude must always be sufficient to drive the following gain and buffer stages under operating conditions. To minimize oscillator current requirements, for a given oscillation voltage, a low C_L is desired. Lower C_L , however, will increase an oscillator's susceptibility to the influence of external noise. Poor availability of low C_L crystals may make selection of a crystal with a higher C_L necessary, at the cost of increased oscillator current. Likewise, if a design requires a small crystal package, an oscillator design that will drive a high ESR crystal is needed, increasing the necessary oscillator current.

Additionally, circuits used to add desirable functions, such as glitch filters to improve oscillator noise immunity, or circuits to detect when the oscillator has stopped, will add to the circuit's overall current consumption.³

Conclusion

There are a number of tradeoffs to be considered when designing an oscillator for a low-power RTC. Increasing C_L will increase noise immunity and may provide a larger selection of crystal models to choose from, at the expense of oscillator current. Likewise, designing an oscillator so that it will run with relatively high ESR crystals requires higher oscillator currents. Adding a glitch filter or oscillator stop detection circuit also adds beneficial functions, but draws additional current.

References

1. Ecliptek Corporation, "Glossary of Terms for Crystals," www.ecliptek.com.
2. Eric A. Vittoz, "High-Performance Crystal Oscillator Circuits: Theory and Application," *IEEE Journal of Solid-State Circuits*, Vol. 23, No. 3 (June 1988).
3. See the Oscillator Stop Flag (OSF) bit description in the DS1337, DS1338, DS1339, DS1340, DS1341, DS1388, DS1390/91/92/93, and DS1318 data sheets.

Related Parts		
DS12885	Real-Time Clocks	Free Samples
DS12R885	RTCs with Constant-Voltage Trickle Charger	Free Samples
DS12R885	RTCs with Constant-Voltage Trickle Charger	Free Samples
DS1302	Trickle-Charge Timekeeping Chip	Free Samples
DS1305	Serial Alarm Real-Time Clock	Free Samples
DS1306	Serial Alarm Real-Time Clock	Free Samples
DS1307	64 x 8, Serial, I ² C Real-Time Clock	Free Samples
DS1308	Low-Current I ² C RTC with 56-Byte NV RAM	Free Samples
DS1315	Phantom Time Chip	Free Samples
DS1318	Parallel-Interface Elapsed Time Counter	Free Samples
DS1337	I ² C Serial Real-Time Clock	Free Samples
DS1337	I ² C Serial Real-Time Clock	Free Samples
DS1338	I ² C RTC with 56-Byte NV RAM	Free Samples
DS1339	I ² C Serial Real-Time Clock	Free Samples
DS1339	I ² C Serial Real-Time Clock	Free Samples
DS1339A	Low-Current, I ² C, Serial Real-Time Clock	Free Samples
DS1340	I ² C RTC with Trickle Charger	Free Samples
DS1341	Low-Current I ² C RTCs for High-ESR Crystals	Free Samples

DS1342	Low-Current I ² C RTCs for High-ESR Crystals	Free Samples
DS1343	Low-Current SPI/3-Wire RTCs	Free Samples
DS1344	Low-Current SPI/3-Wire RTCs	Free Samples
DS1371	I ² C, 32-Bit Binary Counter Watchdog Clock	Free Samples
DS1374	I ² C, 32-Bit Binary Counter Watchdog RTC with Trickle Charger and Reset Input/Output	Free Samples
DS1388	I ² C RTC/Supervisor with Trickle Charger and 512 Bytes EEPROM	Free Samples
DS1390	Low-Voltage SPI/3-Wire RTCs with Trickle Charger	Free Samples
DS1391	Low-Voltage SPI/3-Wire RTCs with Trickle Charger	Free Samples
DS1392	Low-Voltage SPI/3-Wire RTCs with Trickle Charger	Free Samples
DS1393	Low-Voltage SPI/3-Wire RTCs with Trickle Charger	Free Samples
DS1500	Y2K-Compliant Watchdog RTC with NV Control	Free Samples
DS1501	Y2K-Compliant Watchdog Real-Time Clocks	Free Samples
DS1558	Watchdog Clocks with NV RAM Control	Free Samples
DS1670	Portable System Controller	Free Samples
DS1672	I ² C 32-Bit Binary Counter RTC	Free Samples
DS1673	Portable System Controller	Free Samples
DS1677	Portable System Controller	Free Samples
DS1678	Real-Time Event Recorder	
DS1678	Real-Time Event Recorder	
DS1685	3V/5V Real-Time Clock	Free Samples
DS17285	3V/5V Real-Time Clocks	Free Samples
DS17485	3V/5V Real-Time Clocks	Free Samples
DS17885	3V/5V Real-Time Clocks	Free Samples

More Information

For Technical Support: <http://www.maximintegrated.com/support>

For Samples: <http://www.maximintegrated.com/samples>

Other Questions and Comments: <http://www.maximintegrated.com/contact>

Application Note 4247: <http://www.maximintegrated.com/an4247>

APPLICATION NOTE 4247, AN4247, AN 4247, APP4247, Appnote4247, Appnote 4247

© 2013 Maxim Integrated Products, Inc.

Additional Legal Notices: <http://www.maximintegrated.com/legal>