Compensation of Systematic Error due to Sampling Rate versus Temperature Dependency utilizing a Dual-Mode Crystal Oscillator

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Abstract. *The paper describes a novel approach of the system clock frequency versus temperature dependency compensation. Realized digital signal processing system reduces the systematic error due to sampling frequency versus temperature dependency below ± 0.15 ppm over a temperature range between -45°C and +95°C. The system clock signal is derived from a dual-mode crystal oscillator. Since all the necessary temperature information are obtained directly from a crystal itself rather than from an external sensor, temperature offset and lag effects are eliminated.*

Keywords: Dual-Mode Crystal Oscillator, Sampling rate, Frequency stability, DSP

1. Introduction

In a digital signal processing (DSP) often the sampling rate (i.e. sampling frequency) is derived from the quartz crystal oscillator that forms the system clock. In general, when only the nominal sampling frequency is assumed, then the frequency versus temperature (f-T) dependency of the system clock introduces a systematic error into the DSP. The systematic error can be reduced if the nominal sampling frequency is replaced by an evaluated actual sampling frequency. In many cases of DSP the automatic actualization of sampling frequency can be implemented. Of course, with assumption only nominal value of the sampling frequency the DSP is much more simple.

2. The system description

Realized DSP, which is illustrated in Fig. 1, automatically reduces the systematic error that is introduced with the system clock f-T dependency.

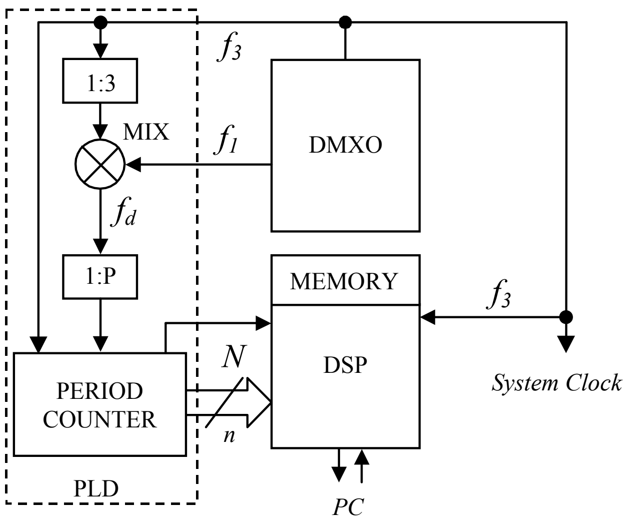


Fig. 1. Block diagram of the realized DSP with automatic actualization of system clock frequency

The DSP incorporates a crystal self-thermometry using a dual-mode crystal oscillator (DMXO). The DMXO, which excites fundamental and 3rd overtone slow-shear acoustic modes (i.e. c-modes) of the quartz crystal, has been originally published in [1]. Processing of actual frequencies of the both acoustic modes enables prediction of their frequency shifts due to ambient temperature changes over a wide range.

A design of DMXO circuit depends on parameters of the crystal that is considered. We have selected a high quality 10-MHz fundamental c-mode frequency SC quartz crystal. The crystal fundamental and 3rd overtone c-modes are free of significant anomalies in the wide temperature range (at least between -45°C and +95°C). Due to relatively low equivalent series resistances of the c-modes, a double gain loop emitter degenerative type DMXO circuit we have selected. The schematic diagram of such DMXO is shown in Fig. 2 and its detail description has been published in [1], [2].

An actual system clock frequency f_3 depends on the crystal actual 3rd overtone c-mode series resonant frequency (Fig. 3a). The DMXO simultaneously produces also the auxiliary signal with actual frequency f_1 that depends on the crystal actual fundamental c-mode series resonant frequency (Fig. 3b).

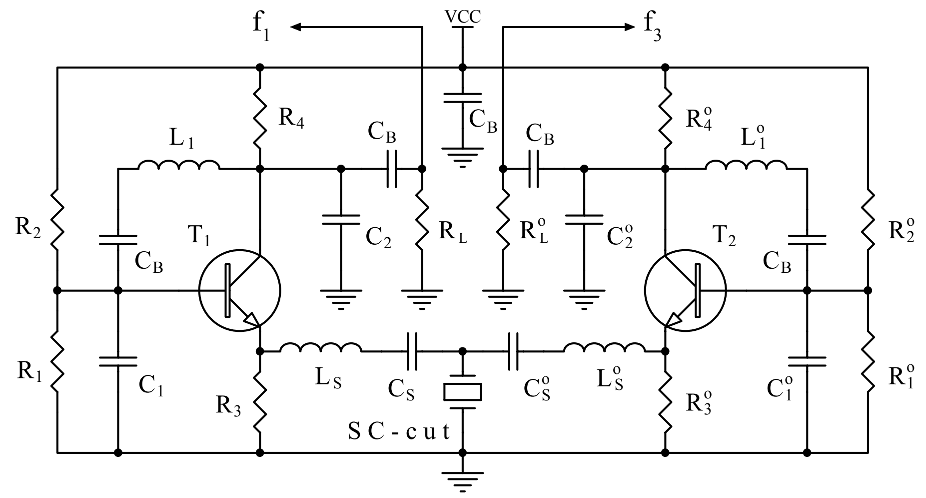
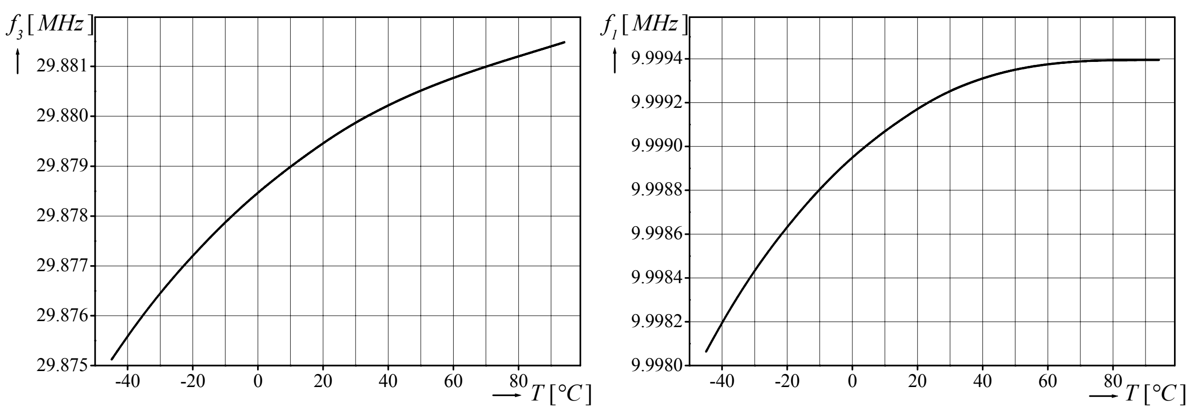
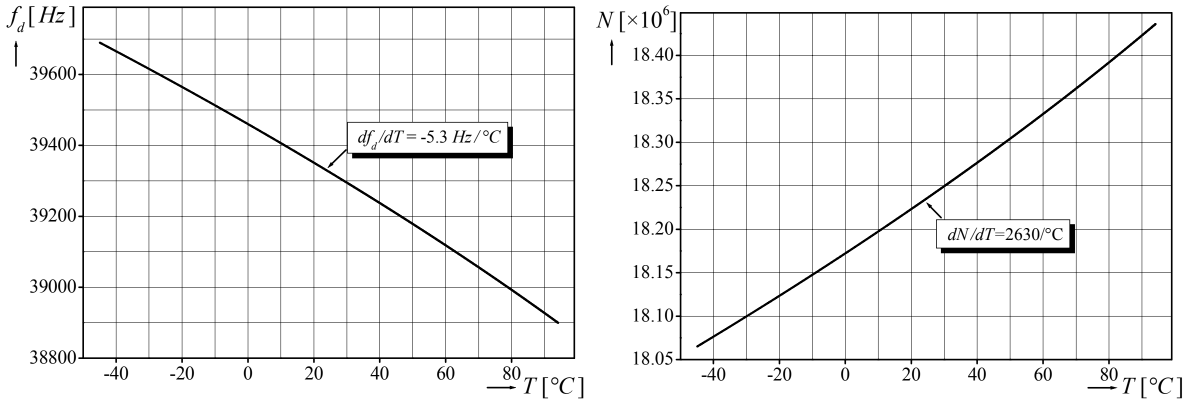


Fig. 2. Schematic diagram of the utilized DMXO



a) b)

Fig. 3. a) SC crystal 3rd overtone c-mode series resonant frequency versus temperature; b) SC crystal fundamental c-mode series resonant frequency versus temperature



a) b)

Fig. 4. a) Difference frequency versus temperature; b) Temperature number versus temperature; P=24000, $N(25°C)$=18236200

At the output of digital mixer is available the difference signal with frequency that can be expressed by following equation:

$$f_d(T) = f_1(T) - \frac{f_3(T)}{3} \ , \tag{1}$$

where T represents an actual temperature of the crystal in DMXO. The difference frequency versus temperature is shown in Fig. 4a.

The period counter is cleared at each compensation cycle begin. The amount of clock pulses accumulated during P periods of the difference signal in the period counter can be expressed by following formula:

$$N(T) = \frac{f_3(T)}{f_d(T)} P = \frac{f_3(T)}{f_1(T) - \frac{f_3(T)}{3}} P \ . \tag{2}$$

Temperature number (i.e. the amount of accumulated pulses) versus temperature is shown in Fig. 4b. Actual shift of the temperature number is given by following equation:

$$\Delta N(T) = N(T) - N(25°C) \ . \tag{3}$$

Actual frequency of the clock signal can be calculated by solving a K^{th} order polynomial that approximates f_3 versus ΔN dependency:

$$f_3(\Delta N(T)) = \sum_{i=0}^{K} a_i \cdot (\Delta N(T))^i \ . \tag{4}$$

The coefficients of the polynomial are derived from a least squares curve-fitting routine using the data collected during a temperature calibration run. The calibration process requires an external precise frequency counter, a controllable chamber and a personal computer (PC). PC controls the temperature in the chamber and records the calibration data (f_{3m}-data are read from the external counter and N-data are read from the period counter of the system). When the temperature-run is complete, PC performs the curve fitting. Finally PC sends determined coefficients of the polynomial to the DSP system.

3. Results

When the coefficients of the 9th order approximation polynomial were derived from least square curve-fit according to a complete set of f_3 versus ΔN data, which was collected over the temperature range between -45°C and +95°C, the approximation gives the maximal error approximately ± 0.15 ppm; it is shown in Fig. 5.

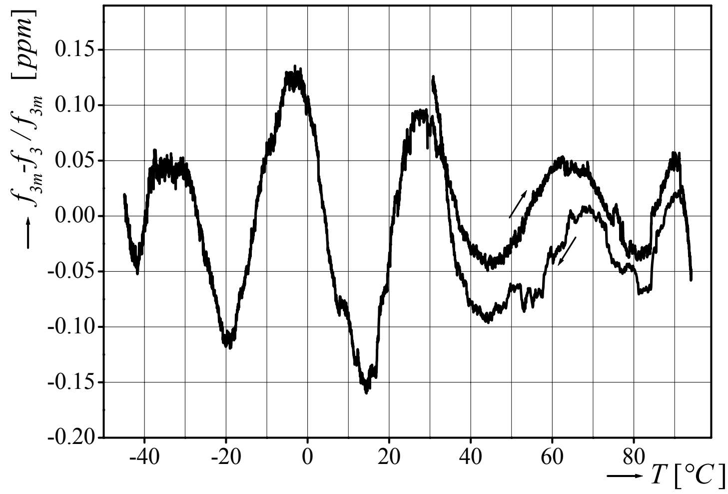


Fig. 5. Error of calculated system clock frequency versus temperature; the f_{3m} is measured clock frequency

Long-term stability of the system mostly depends on the ageing of the used crystal in DMXO. Ageing of approximately -6×10^{-8} per a year of the used crystal has been identified [3].

4. Conclusions

Over the wide temperature range the systematic error due to sampling frequency versus temperature dependency can be essentially reduced utilizing DMXO.

The compensation method does not require a tuning of crystal oscillator frequency. Since all the necessary temperature information is obtained directly from a crystal itself rather than from an external sensor, temperature offset and lag effects are eliminated.

SC crystal within the realized system also may be utilized as a temperature sensor with an excellent sensitivity [4].

References

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