NOVEL IMPROVED APPROACH OF DIGITAL FREQUENCY SYNTHESIS

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ABSTRACT

In this paper a method of frequency synthesis incorporating digital compensation of frequency versus temperature (f-T) dependency of the reference crystal oscillator (the system clock of the synthesizer) is presented. The frequency instability of the generated signals is less than ±0.15ppm over wide temperature range (-35°C to +85°C). The main contribution of this approach is that the synthesizer uses entirely digital temperature compensation of its own system clock.

INTRODUCTION

It is known as a rule, that a frequency stability of a system clock determines a frequency stability of synthesized signals. A quartz crystal oscillator often generates the reference clock. However, if an evaluation of frequency tuning words of a direct digital frequency synthesizer (DDS) is done according to actual frequency of the system clock, then the f-T dependency of the synthesized signals should be reduced.

CONCEPT OF THE SYNTHESIZER

Figure 1 shows a block diagram of the synthesizer we have used in our experiments. Self-temperature-sensing of the crystal using dual mode crystal oscillator (DMXO) has been implemented in the synthesizer [1].

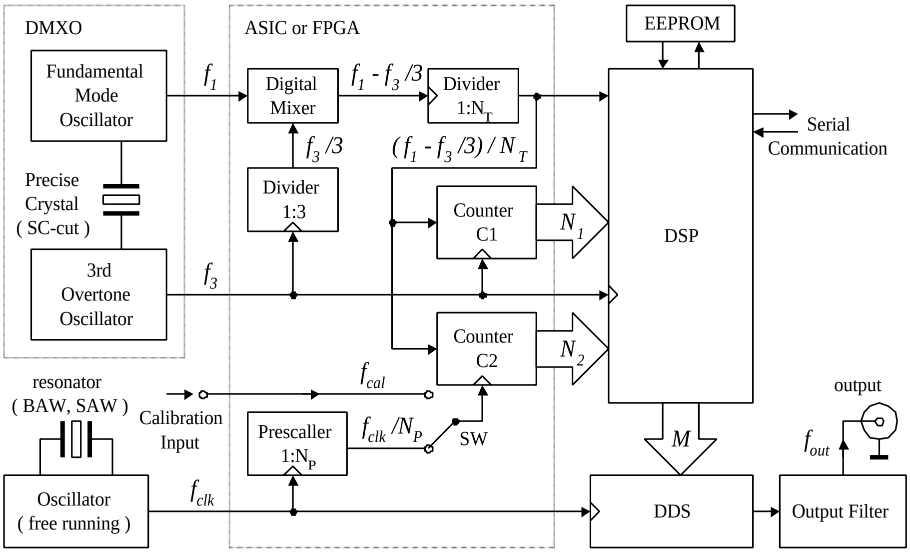

Fig. 1. Simplified block diagram of the synthesizer

The compensation cycles are repeated in regular intervals, several times per second. In each compensation cycle, the number N_1 at the output of the counter C1 represents an actual temperature of the SC-cut crystal, without need of an external temperature sensor [3]. N_1 can be expressed as the ratio of the two frequencies applied to the counter C1 (1).

$$N_1 = \frac{f_3}{f_1 - \frac{f_3}{3}} \cdot N_T \tag{1}$$

In (1) the N_T represents a constant frequency division ratio.

Equation 2 shows the 7th-order polynomial that is used for estimation of the actual frequency f_3 of the SC-cut 3rd overtone [3].

$$f_3 = \sum_{i=0}^{7} a_i \cdot N_1^{\,i} \tag{2}$$

The a_i coefficients of the polynomial (2), which are need in compensation process, are at first evaluated in the calibration process of the system, when the external signal with known and stable frequency f_{cal} drives the counter C2 instead the free running crystal oscillator. The a_i coefficients are stored to the EEPROM at the end of the calibration process.

As it is shown in Fig. 1, another oscillator, which is running independently, generates the clock signal of the DDS. The number N_2 at the output of the counter C2 is used for estimation of the actual frequency f_{clk} (3).

$$N_2 = \frac{f_{clk}}{f_1 - \frac{f_3}{3}} \cdot \frac{N_T}{N_P} \tag{3}$$

In (3) the N_P represents a constant frequency division ratio of the prescaller.

Equation 4 express the frequency f_{out} of signal at the DDS output, where n represents the length in bits of the DDS phase accumulator and M is the DDS tuning word.

$$f_{out} = \frac{M}{2^n} f_{clk} \tag{4}$$

The digital signal processor DSP evaluates actual frequency f_{clk}. The DSP also controls the DDS tuning word M according to the required output frequency f_{out} and also according to actual clock frequency f_{clk}. The contribution of this approach is that the value M, which is computed according to (5), automatically incorporates the compensation of the f-T dependency of the free running oscillator (the system clock of DDS).

$$M = \frac{N_2 \cdot 2^n}{N_P \sum_{i=0}^{7} a_i N_1^{i-1}} f_{out} \tag{5}$$

DUAL-MODE CRYSTAL OSCILLATOR

A dual-mode crystal oscillator (DMXO) is the circuit making the simultaneous excitation of two acoustic modes of a crystal. Processing of both modes simultaneously, enable the possibility to predict actual frequencies of these modes. Design of a crystal oscillator circuit usually depends on parameters of the resonator that is considered. Various types of DMXO circuits have been investigated, including the inductorless DMXO [2].

Fundamental and 3rd overtone c-modes of the SC-cut have been selected. Due to low branch impedance at the serial resonance frequencies of the c-modes the emitter degenerative type of crystal oscillator has been selected. This configuration of DMXO has been presented in [1].

THE SC-CUT QUARTZ CRYSTAL

The SC (stress compensated) quartz crystal comprises c-modes (e.g. slow-shear, acoustic modes), which are activity-dip free in the wide temperature range [1]. In comparison with AT and BT cuts, SC cuts have faster warm-up, no frequency overshoot, much smaller 2nd order temperature coefficient, almost zero amplitude-frequency effect, better short-term stability and lower acceleration sensitivity.

The 10-MHz fundamental frequency SC-cut crystal has been selected as the frequency-determining element in the synthesizer [3]. Figure 2 shows the f-T characteristic of fundamental c-mode of the SC cut. The f-T characteristic of 3rd overtone c-mode of the SC cut is shown in Fig. 3. Residuals vs. temperature after fitting the Df_3 vs. N_1 data to a 10-segment 7th order polynomial are shown Fig. 4.

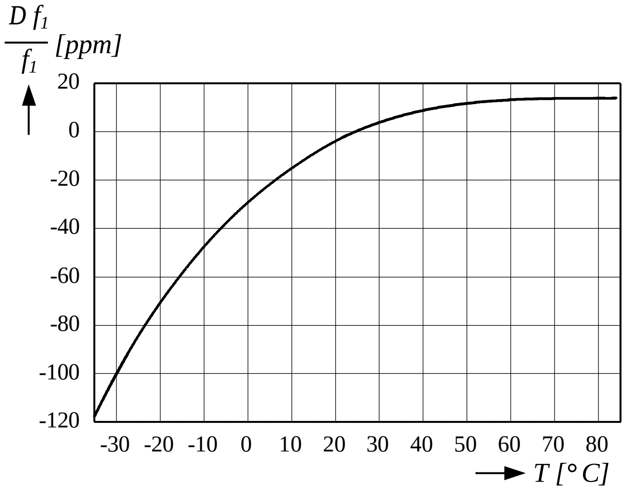

Fig. 2. Frequency vs. temperature characteristic of the SC-cut crystal; fundamental c-mode

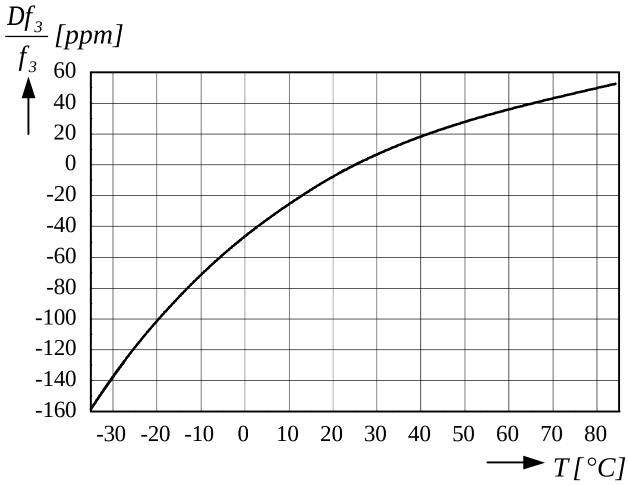

Fig. 3. Frequency vs. temperature characteristic of the SC-cut crystal; 3rd overtone c-mode

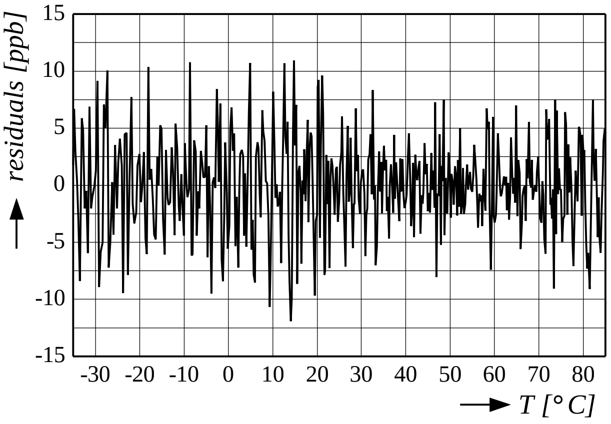

Fig. 4. Residuals vs. temperature after fitting the Df_3 vs. N_1 data to a 10-segment 7th order polynomial

FREE RUNNING CRYSTAL OSCILLATOR

In the interim system a 66MHz HCMOS crystal oscillator in the standard DIP-14 metal package has been constituted as a system clock of the DDS. Figure 5 shows the f-T characteristic of the oscillator. Over temperature range between -35°C and 85°C the oscillator frequency is changing about ±7 ppm. Residuals between computed and measured values of f_{clk} are shown in Fig. 6.

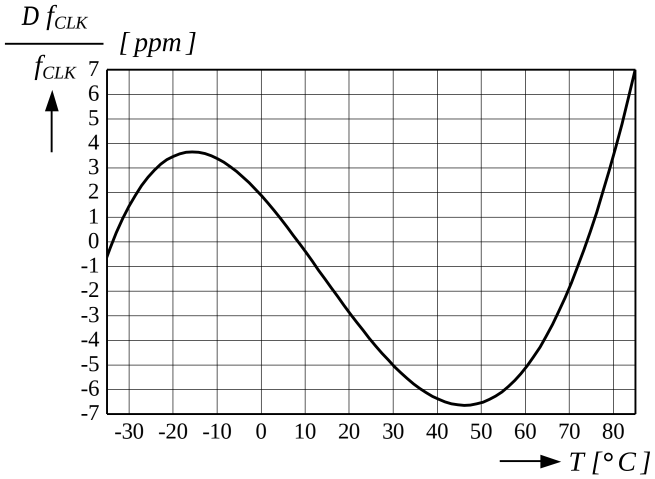

Fig. 5. Frequency vs. temperature characteristic of the free running 66MHz crystal oscillator

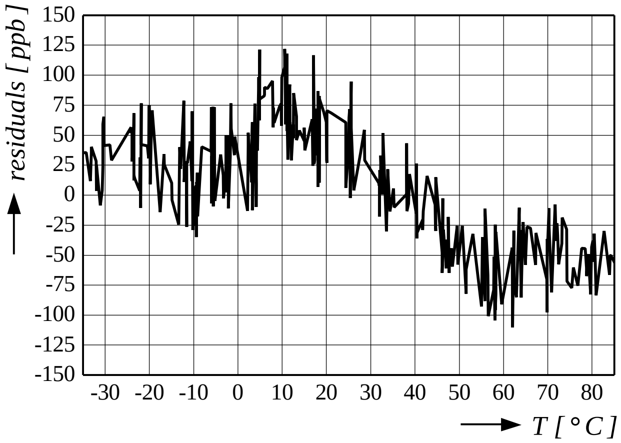

Fig. 6. Residuals vs. temperature between computed and measured values of f_{clk}

CONCLUSIONS

Over temperature range between -35°C and +85°C the f-T instability of the synthesizer has been reduced from ±7ppm to ±0.15ppm implementing the described method without using a temperature stabilization of a reference crystal oscillator. Described approach of frequency synthesis eliminates the need of voltage controlled crystal oscillator; i.e. the method does not require pulling a frequency in reference oscillator and so the one of the hysteresis, aging and noise sources has been eliminated.

REFERENCES

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[3] Stofanik, V., Balaz, I., Minarik M., “Digitally Temperature-Compensated DDS”, *Proceedings of the 2001 IEEE/EIA International Frequency Control Symposium*, pp. 816-819, 2001.