The design high quality reference oscillator for DDS

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Abstract **Direct digital synthesis is used in many applications. There is necessary to use a quality source of the clock signal. One of the best circuits for this purpose is Butler oscillator as emitter follower. By this circuit is possible to design a high frequency oscillator working up to hundred megahertz. In this paper the design of the Butler oscillator by use of a feedback loop analysis in resonance frequency vicinity of the crystal is showed. For non-linear analysis of the oscillator, the harmonic balance method is used.**

Keywords **Butler oscillator, reference oscillator DDS, piezoelectric crystal unit.**

I. INTRODUCTION

Direct digital synthesis is used in many applications. There is necessary to use a quality source of the clock signal. In these special applications, output frequency need to be whole number. This is a problem in the DDS because the output frequency is given by equation:

$$f_{\mathrm{OUT}} = \frac{M \cdot f_{\mathrm{REF}}}{2^n} \qquad (1)$$

f_{out} is output frequency, M is tuning word and n is tuning word with (in bits). Frequency of the clock signal source has to be equal to power number two. The next condition is a high long-term stability and low phase noise. Crystal oscillators perfectly meet these conditions. The cut AT Piezoelectric crystal which is frequently used [1]. Some integrated circuit DDS [2] has internal multiplayer referenced which use a phase lock loop. In this case the output phase noise will be worse. For critical applications where we require higher output frequency is necessary to use crystal oscillator oscillating on an overtone of the piezoelectric crystal unit.

II. THE BUTLER CRYSTAL OSCILLATOR

One of the most widely used crystal oscillators, which operates at the higher harmonic level of the crystal, is the Butler oscillator. There are two connection variants: In the first variant, the transistor operates in connection with the common base (Fig. 1), while the other option involves operation with the common collector (Fig. 2). The oscillation frequency of this oscillator ranges slightly above the crystal series resonance. Here, the crystal behaves as a highly selective resistor. In order to apply the oscillations, we first need to perform correct tuning of the resonant circuit L_1 and capacity divider C_1, C_2. The less frequently used connection of the Butler oscillator with the common collector provides a lower output performance; at the same time, however, the presetting of the direct operating point shows a very low degree of criticality, and there is no spurious oscillation. From the perspective of the alternating signal, the coil L_1 is earthed through the lock-in condenser C_F. Intensive requirements are placed on the transistor T_1; for utilization purposes, its transit frequency f_T ought to be 10 time the amount of the oscillation frequency. Thus, we will achieve not only a neglectable phase shift caused by the transistor, but also the minimization of its effect on the frequency stability. However, with the SB connection, this margin may generate spurious oscillation modes, and that is why the SC connection is more suitable. Spurious capacities of electrodes of the applied transistor as well as the capacities of its semiconductor junctions ought to be minimal so as not to affect to be oscillation condition. Another requirement (which is nevertheless seldom guaranteed by the manufacturer) consists in the minimum noise of the 1/f transistor. This noise increases the phase noise of the crystal oscillator, thus worsening its short-term frequency stability.

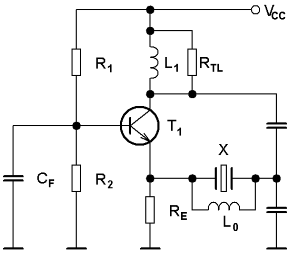

Fig. 1. The Butler oscillator in the SB connection

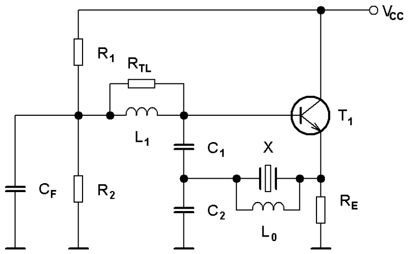

Fig. 2. Butler oscillator in the SC connection

For an easy understanding of the design of individual components of the feedback circuit it is suitable to utilize the voltage transfer $K_U(s)$ of the feedback branch [3]. Inductivity L_0, together with the static capacity of crystal C_0, is tuned into resonance; therefore, we need not assume these components. Resistor R_E shows a value greatly exceeding the output impedance of the emitter follower, which enables us to neglect it. In a contrary situation, the resistor would be paralelly matched with this output impedance. The feedback circuit is shown in Fig. 3.

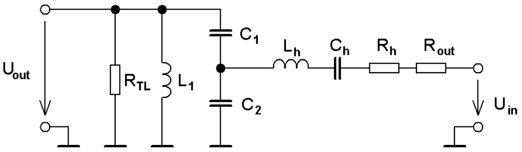

Fig. 3. The feedback circuit

For the transfer of this feedback branch, we derived the following transfer by the help of the SNAP program. The feedback branch amplitude frequency characteristics are shown in Fig. 4; the phase characteristics can be seen in Fig. 5. The parameter is the damping resistance R_{TL}; other components have the initial values. It is obvious that, with the decreasing R_{TL}, the gain margin decreased while the phase characteristic passage through zero increased in steepness.

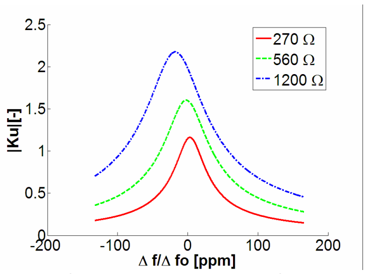

Fig. 4. Amplitude frequency characteristic for parameter R_{TL}

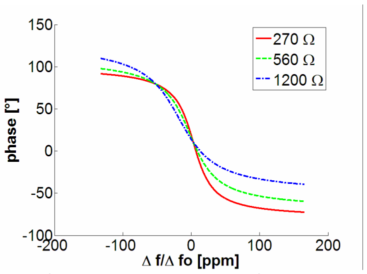

Fig. 5. Phase frequency characteristic for parameter R_{TL}

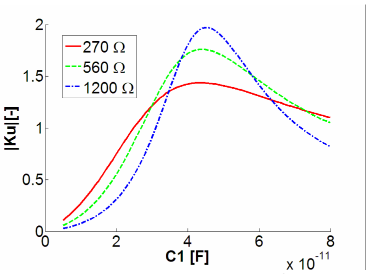

Fig. 6. |*K*u| in realized oscillation condition for parameter R_{TL}

The oscillation condition, with the neglection of phase shift in the transistor, is satisfied if the feedback circuit phase shift equals to 0 °. The aim of the optimization is to achieve the highest possible steepness of phase characteristics during the passage through zero. Furthermore, the value of condenser C_1 was stepped together with several values of the resistor R_{TL}. Fig. 6 shows the dependence of voltage transfer $|K_u|$ with the satisfied oscillation condition; the phase characteristics steepness dependence is given in Fig. 7. The crystal unit resonance frequency is influenced by its power load. Using the Ansoft Designer program (harmonic balance method [4]), we simulated the crystal unit power load on the damping resistor R_{TL}. The result phase noise is near work [5].

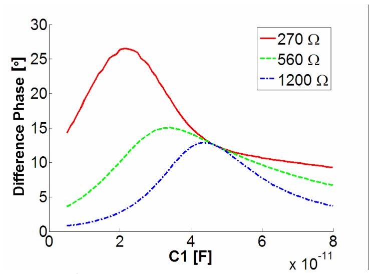

Fig. 7. Difference phase for detuning 5ppm around oscillation frequency

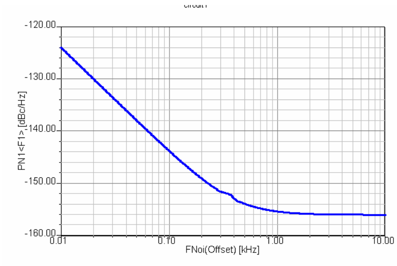

Fig. 8. Phase noise L(f) in the output

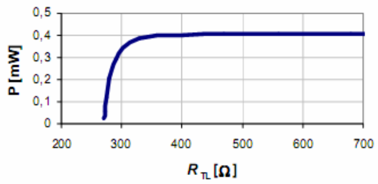

Fig. 9. Power dissipation in the crystal unit

III. CONCLUSION

The Butler oscillator was optimized for the maximum short-term stability and a minimum load of the crystal unit. Reduction of R_{TL} value is causing increase of the frequency stability of the oscillator and decrease of the gain margin.

IV. ACKNOWLEDGEMENTS

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