10 cm range small-size reference microwave oscillator on a coaxial resonator with a PLL and a low level of phase noise

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Abstract: The results of development and modernization of a high-stable small-size reference microwave oscillator with a PLL and a low level of phase noise for use in special purpose equipment with an operating frequency of 3.6 GHz, phase noise (with 2 kHz offset) of -112 dBc/Hz and output power from 0 to 40 mW are presented.

1 Introduction

The constant stringency of requirements for frequency and microwave signal shapers, intended for different special purpose systems, leads developers to look for new technical solutions to achieve high electrical and weight-dimension characteristics. Most of these systems are based on using various types of frequency synthesizers in their composition, the development process of which in each individual case should begin with analyzing a set of requirements for the characteristics of the frequency shaper spectrum in general, the level of phase noise, the frequency range of the output signal, the switching time and the analysis of operating conditions and application areas of the developed equipment as well. As a rule, design, technological and technical solutions are adopted on the basis of these requirements, and components are selected that allow to obtain the required product characteristics.

In particular, in gigahertz frequency range the shapers consist of frequency synthesizers of indirect frequency synthesis, including reference microwave oscillators based on dielectric resonators (DR) or coaxial dielectric resonators (CDR), stabilized by a loop with phase lock loop (PLL), their parameters substantially determine the quality of the system as a whole. The reference oscillator with PLL is composed of: a voltage controlled oscillator (VCO) on CDR, a frequency synthesizer microcircuit, a frequency divider, an integrated directional coupler, microwave signal and DC amplifiers, voltage stabilizers and a loading processor. Considering that microcircuits with sufficient broadband are used in the work, the output frequency of the reference oscillator module is determined mainly by VCO frequency range. The spectral density of phase noise is the most important indicator

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of the quality of microwave active oscillators. Despite the significant number of publications devoted to this issue, the task of implementing the requirements for the phase noise level is still one of the most difficult in the design of active oscillators. One can get good phase-noise characteristics using active devices with low flicker noise and high Q resonators in combination with special circuitry solutions [1]. The VCO spectral power density characteristics of phase noise (NSPD) have a direct impact on the output characteristics of the entire product. Therefore, it will be given special emphasis in this work.

2 Design part

Structurally, the reference microwave oscillator with a PLL is located in a metal case without internal partitions. The external frequency from the reference crystal oscillator is supplied and the output microwave signal is removed through coaxial microwave inputs/outputs, the product is powered via coaxial feeding filters. The case and cover of the product are made of AlMg alloy with subsequent palladium-nickel galvanic plating. The oscillator is sealed with TinIn solder using the “inverted lid” method. The oscillator has dimensions of $63 \times 38 \times 12,5$ mm and weight of 50 g. Figure 1 shows the appearance of the product.

Fig. 1. The appearance of the oscillator.

Due to stringent requirements to the level of VCO phase noise and high generation frequency for CDR VCO, the main directions in its development were the optimization of the oscillator circuit and especially its topology.

All circuitry and topology of the reference microwave oscillator is implemented on a single multi-layer printed circuit board (ML PCB), the conductors of which are connected to the inputs/outputs of the case using bypasses. All add-on components of the circuit are mounted on the upper layer of ML PCB and electrically connected to the topological drawing of the board by the soldering method [2].

Figure 2 presents the ML PCB in cross-section. The four-layer board has a total thickness of 1 mm with a thickness of intermediate layers of 0.25 mm. The copper metallization thickness of each layer of the board is $18 \mu\text{m}$. The finishing coating of the outer layers of the board topology is immersion gold. The signal layers of the board are separated from each other by a dielectric. ML PCB has plated-through metalized holes necessary for mutual switching of the elements of the board topological drawings, which are located in different ML PCB layers.

Fig. 2. ML PCB in cross-section.

This design of the board allows to minimize the mutual influence of the circuit individual parts on each other, providing an improvement in NSPD indicator of the microwave oscillator and simplifying the case design.

The VCO circuit is fully implemented on elements with lumped parameters. The most suitable option turned out to be the traditional Colpitz circuit, the advantages of which are the simplicity of realization and high repeatability of parameters. When selecting active and passive components special attention was paid to characteristics, required for use in circuits with extremely low level of phase noise.

The CR Quality factor at the level of 500 with a typical frequency tuning of no more than 0.5% makes it possible to obtain a rather low level of NSPD. However, with frequency increase the geometric dimensions of the resonator decrease disproportionately and at the same time its Q-factor also decreases dramatically. The sharp decrease in CDR geometry is due to the increasing influence of the board topology parasitic elements, the values of which at frequencies of 3 GHz and above become significant (fig. 3).

Fig. 3. The emergence of parasitic capacitances in ML PCB topology.

Taking into account that the selected active components have the parameters necessary for implementation of high-frequency oscillators, the CDR loaded with a VCO circuit becomes the most critical element from the point of view of providing NSPD and VCO tuning parameters. The TCF (temperature coefficient of frequency) is also the most important characteristic of a resonator when creating oscillators of this type. The use of CDR with a given TCF characteristic largely determines the possibility of narrowing VCO electrical tuning range and, consequently, reducing NSPD values. At the same time CDR oscillators have sufficient adaptability and under certain conditions their assembling can be fully automatic.

In the process of research it was found out, that the main contribution to the parasitic capacitive and inductive component of the oscillatory circuit of the active oscillator is made by communication strips, located in transistor base circuit, which provide a connection

between the circuit active part and resonant circuit on CDR, which determines the oscillation frequency. To solve this problem an area is formed under the topological pattern of the microwave oscillator board, directly in the board itself by milling, there is no shielding metallization within this area (fig.4). In this case, the thickness of the substrate in this place with a part of the microwave oscillator topology, located on it, is reduced to 0,2 mm. The application of this method made it possible to reduce the coupling capacitance value of the CDR oscillator active part and the varactor diode by an order of magnitude (up to 0.1 pF), thereby ensuring preservation of the maximum Q-factor of the tunable resonant circuit and consequently a lower NSPD value as compared to the traditional approach.

Fig. 4. The sampling circuit in ML PCB.

Figure 5 and figure 6 shows VCO NSPD values at the offset of 10 kHz from the carrier of 3.6 GHz, measured by Agilent N9030A spectrum analyzer with sampling (Figure 5) and without sampling (Figure 6).

Fig. 5. VCO NSPD value at the offset of 10 kHz from the carrier 3.6 GHz without sampling.

Fig. 6. VCO NSPD value at the offset of 10 kHz from the carrier 3.6 GHz with sampling.

In order to analyze the behavior of CDR VCO under study during its operation as a part of the PLL loop, preliminary calculations of the loop parameters were carried out using the ADIsimPLL [3] program and in-situ measurements of a real product sample were made. To synchronize the VCO frequency with the frequency of the reference crystal oscillator a PLL loop was used on HMC704 frequency synthesizer microcircuit, operating in the mode with an integer division coefficient [4]. To achieve the lowest possible level of NSPD, the microcircuit frequency-phase detector worked at the maximum possible comparison frequency of 100 MHz, equal to the frequency of the reference crystal oscillator. As a reference oscillator a temperature-compensated crystal oscillator with a phase noise level of -155 dB/Hz at 1 kHz offset was used. The width of the obtained PLL loop was 100 kHz.

Figure 7 shows a graph of NSPD calculation for an oscillator covered by PLL loop performed using ADIsimPLL program. The calculation was carried out for the case with a frequency divider of 2 in the oscillator output circuit. This divider is not a part of the PLL loop feedback circuit. Figure 8 shows the result of measuring a real sample of the product covered by the calculated PLL loop with a similar inclusion of a frequency divider 2 in the output circuit.

Fig. 7. The dependence of NSPD value calculated in ADIsimPLL program with offset up to 1 MHz of the oscillator stabilized by the PLL loop with frequency division by 2.

Fig. 8. The dependence of NSPD value obtained with offset up to 1 MHz of the oscillator stabilized by the PLL loop with frequency division by 2.

Based on the results obtained, it follows that NSPD value of the real sample of the module of the reference microwave CDR oscillator, covered by a PLL loop is close to the calculated NSPD value limited by noises of PLL circuit components and reference oscillator, which indirectly confirms the optimal choice of VCO circuit values.

3 Conclusion

Method of reducing the CDR VCO phase noise due to reducing the absolute value of spurious elements of the topology of a multilayer board which have a negative effect on the quality factor of the oscillatory circuit has been experimentally confirmed. This HIC has successfully passed tests for vibration strength (sin 2g, 25 Hz) and vibration stability (sin 5g, 20-500 Hz). As a result of this work a highly stable, small-sized reference CDR microwave oscillator with an operating frequency of 3.6 GHz, stabilized by a PLL loop was developed. The reference oscillator has a low level of phase noise, -112 dBc/Hz at 2 kHz offset, spurious components level of less than or equal to -70 dBc and an output power of 0...40 mW. The reference oscillator is a finished product and is intended for use in special purpose equipment.

References

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