

Development of the Compact Low Phase Noise Voltage Controlled Oscillator Using Integrated High-Q Resonator

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論 文 内 容 の 要 旨

The recent exponential growth of wireless communication systems has promoted a great demand for compact, low cost, and low power consumption. Therefore, high-performance frequency generation technologies of quasi-millimeter and millimeter (mm-) wave have attracted increasing interest and developed rapidly. The main challenge in designing a low phase noise CMOS voltage-controlled oscillator (VCO) is to improve the low quality (Q-) factor of the conventional spiral inductor, which is due to the stringent size limitation of the metal layers and the lossy substrate.

This dissertation focuses on the analysis, design, and implementation of high-Q integrated CMOS resonators technology for quasi-mm-wave and mm-wave VCO applications. There are two main categories of high-Q resonators are proposed in this dissertation. The first category is the defected ground structure (DGS) resonator. This type of resonator is proposed to be implemented in the LC oscillator instead of the conventional LC tank resonator. A novel two-branch DGS resonator is designed and investigated. The proposed two-branches DGS resonator doesn't only have a higher Q-factor than the conventional spiral inductor but also performs better than the DGS resonator's predecessors. In the V band, the Q-factor of the proposed novel DGS resonator is around two times higher than those conventional resonators and is expected to improve the phase noise characteristic of mm-wave VCO applications.

The second resonator category discussed in this dissertation is called substrate integrated waveguide (SIW) resonator. This type of resonator is proposed as the post design of the DGS resonator. The SIW-based resonator is a "closed" structure compared with the DGS resonator thus less affected by

adjacent circuit components. In the dissertation, a novel miniaturization method of SIW resonator is proposed to realize the implementation of SIW resonator in CMOS technology. The proposed miniaturization method is extremely effective and reduces the area of the SIW resonator to 0.3% compared with the full-mode SIW resonator. The proposed miniaturized SIW resonator is transformed to the bandpass filter (BPF) applications, which is a kind of two ports resonator, with low insertion loss. These two ports resonators are projected to be implemented in future W band (75-110 GHz) VCO designs. One of the proposed BPF is realized with an extremely compact size ($99\text{ }\mu\text{m} \times 99\text{ }\mu\text{m}$, $0.054\lambda_g \times 0.054\lambda_g$). The measured insertion loss ($|S_{21}|$) of 2.26 dB at 84.4 GHz. A weak coupling coefficient problem between CMOS SIW resonators is figured out and analyzed as well. A novel coupling method that couples two SIW resonators through a DGS is proposed as the solution to this problem. The second W band BPF is designed using this novel coupling method and fabricated. The measured insertion loss is 3.15 dB at 85.5 GHz. To validate the feasibility of a SIW-base resonator working at a frequency beyond 100 GHz, a two ports bandpass resonator with two transmission zeros is implemented and measured. The active size of the proposed bandpass resonator without pads is $309\mu\text{m} \times 275\mu\text{m}$ ($\sim 0.1\lambda_g \times \sim 0.09\lambda_g$), and the measured insertion loss ($|S_{21}|$) is 2.06dB. This is the first time that a SIW resonator/BPF is implemented in a commercial Si-based technology successfully, which gives more choice in the future on-chip circuits design.

To evaluate the performance of proposed high Q resonators and verify our design concept of low phase noise VCO, VCO applications using the proposed resonators are designed, fabricated, and measured. The two-branch DGS resonator is implemented in the design of the V band (40-75 GHz) VCO, and the measured best phase noise is -102.58 dBc/Hz at a 1-MHz offset with a carrier frequency of 49 GHz. This is the first time that the DGS resonator is implemented in the VCO which works at a such high frequency. After this, the proposed two-branches DGS resonator is optimized and implemented in a K band (18-27 GHz) VCO to realize the wide tuning function. The K band VCO using optimized two-branches DGS resonator is possible to achieve a 19.8% tuning range and the best phase noise performance of -109.43dBc/Hz at 1-MHz offset with the carrier frequency of 18.51GHz. Finally, experimental research of the relationship between interconnects and phase noise of the K band VCO is given.