DEVELOPMENT OF FBAR BASED ULTRA LOW PHASE NOISE RADIO FREQUENCY OSCILLATOR

張, 国強

https://doi.org/10.15017/1398545

出版情報：九州大学, 2013, 博士（学術）, 課程博士
バージョン：
権利関係：全文ファイル公表済

氏名・(本籍・国籍)	チョウ　コク キョウ 張　　国　強（中　国）
学位の種類	博士（学術）
学位記番号	シ情博甲第５１９号
学位授与の日付	平成25年10月31日
学位授与の要件	学位規則第４条第１項該当　システム情報科学府　電気電子工学専攻
学位論文題目	DEVELOPMENT OF FBAR BASED ULTRA LOW PHASE NOISE RADIO FREQUENCY OSCILLATOR（超低位相雑音高周波FBAR発振器の開発）
論文調査委員	（主　査）教　授　ポカレル　ラメシュ （副　査）教　授　吉　富　邦　明　　准教授　金　谷　晴　一

論　文　内　容　の　要　旨

Wireless communication applications such as mobile, wireless sensor network and wireless local area network, have an explosive growth in recent years. With the rapid growth, the requirement of low cost, high performance, extremely low power and high integration radio frequency (RF) integrated circuits (RFIC) is also increasingly higher. In the past decades, complementary metal-oxide-semiconductor (CMOS), a low cost technology for constructing integrated circuits (IC), has been employed by RFIC researchers and a number of high integration RFICs such as RF transceivers which integrate phase lock loop (PLL) or voltage controlled oscillators (VCO), filter, mixer, power amplifier (PA), low noise amplifier (LNA), variable gain amplifier (VGA), analog to digital converter (ADC), digital to analog converter (DAC), and have both transmission and receiving functions, have been designed successfully.

However, despite the characteristics of low cost, high integration, CMOS technology also reveals thin metals, high loss substrate disadvantages, which brings challenges in the design of high quality (Q) factor inductors and filters, low phase noise VCO, and high efficiency PA.

In recent years, micro electro-mechanical systems (MEMS) technology has become a new solution to compensate the demerits of CMOS. High performances RF-MEMS devices, such as RF-MEMS switches, variable capacitors, filters, resonators and have been reported and several approaches for integrating MEMS with CMOS have been published, which makes monolithic MEMS-CMOS RFIC possible and become the trend of development of RFIC in the future.

Oscillators which are used to generate local oscillation signals such as voltage controlled oscillator or to generate reference frequency signals such as quartz crystal oscillators are one of the most important building blocks of RF transceivers. To realize a high performance RF transceiver, a high accuracy frequency reference and a VCO which has the features of low phase noise, low power consumption and small area are required. For frequency reference, quartz crystal oscillators are usually adopted as the low phase noise and high accuracy. But the frequency of quartz crystal oscillators is very low and they cannot be integrated because of the incompatibility of the silicon substrate and the large size of quartz crystal. For VCOs' design, two main topologies, which are usually adopted, is inductor-capacitor (LC). However, since the low quality (Q-) factor of on- chip inductors, the phase noise of LC-VCOs has always been an issue, normally about -120 ~ -130 dBc/Hz at 1

MHz offset frequency. Thus, it is necessary to find other solutions to create a kind of oscillators which have low phase noise that consumes extremely low power and is able to be integrated with CMOS technology.

Film bulk acoustic resonators (FBAR) have very high Q-factor around 1000 or even more. Using them to replace the low Q-factor on-chip inductors to design low phase noise GHz-range oscillators, has been of great interest and some FBAR-oscillators which have low phase noise around -140 dBc/Hz at 1 MHz offset frequency is able to obtain by some published papers . Based on the introduces above, it can be shown that FBAR-oscillators have the potential to satisfy the low phase noise and integration requirement, but the challenges to design FBAR-oscillators are multi-frequency, differential output, the further improvement of phase noise, low frequency instability and monolithic integration. The low phase noise potential and those challenges give the motivation for this research.

In the beginning of this thesis, the demand of low cost, high performance and high integration of RFIC and the poor phase noise and high power consumption of the normal Ring-oscillator and LC-oscillator are emphasized. In order to solve these problem of current oscillator, researcher are trying using high Q-factor FBAR resonator to design low phase noise oscillator. Then the structure and equivalent circuit model of FBAR and the oscillator theory including Barkhausen criteria, negative resistance and phase noise model which can also be used in FBAR oscillator are presented to provide the theoretical foundation of FBAR oscillator design. In the realization of FBAR oscillator, at first the Pierce FBAR-DCO and the inverter based FBAR-DCO are designed because of the simplicity in design. The oscillation condition of these two FBAR-DCOs is analyzed and the simulation result demonstrates that the FBAR-DCO is able to obtain a phase noise which is 20 dB lower than the phase noise of normal LC-oscillator. Then the second kind of FBAR-VCO in this thesis employed cross-couple architecture. Two methods to mitigate low frequency instability are proposed, which the first method employs a capacitor and while the other one employs a series inductor-capacitor. By considering the effect of transistors' size on the Q-factor and impedance of FBAR, excellent phase noise and high loop gain are obtained. Furthermore, based on the designed cross-coupled FBAR-VCO core, a multiband FBAR-VCO operating at 0.65 GHz, 0.98 GHz, 1.96 GHz and 3.92 GHz is presented. Although the traditional divider and multiplier are employed, the possibility of a multiband VCO using FBAR-VCO as a core circuit has been developed. Finally, in the last part of this thesis conclusion, new applications of the developed FBAR-VCO and recommendation for future works are summarized.

論 文 審 査 の 結 果 の 要 旨

本研究は，圧電薄膜共振子（FBAR: Film Bulk Acoustic Resonator)を用いた超低位相雑音発振器設計手法を提案するものである。更に、CMOSウエハー上へのFBARの集積化に成功することによって超低位相雑音を有する発振器を開発するとともにその優れた実用性能を実証したもので、電気電子工学上価値ある業績である。