DESIGN AND IMPLEMENTATION OF A LOW POWER MEMS BASED RECONFIGURABLE VCO

H. P. Le and J. Singh

Centre of Telecommunications and Microelectronics
Victoria University
P.O.BOX 14428, Melbourne, MC8001, Victoria, Australia
Email: Hai.Le@vu.edu.au

ABSTRACT

This paper presents the design and implementation of a low power reconfigurable VCO for a multi-standard receiver. The designed VCO employs MEMS components to replace the passive components to attain lower system power consumption and better performance. Results show that the reconfigurable MEMS-based VCO achieves a frequency tuning ranges of 1.86GHz to 1.94GHz, 3.6GHz to 3.78GHz and 4.18GHz to 4.50GHz for the three communication standards, namely GSM900, DCS1800 and WCDMA. It consumes an average power of 3.8 mW at a supply voltage of 1.2V. Results also indicate that a 50% reduction of power consumption is achieved when the MEMS components are employed to replace the passive components. This characteristic makes the VCO a better candidate for wireless communication applications where power consumption is the major factor.

1. INTRODUCTION

In the last decade there has been significant growth in the wireless market with recent surge in applications of radio frequency (RF) transceivers. The new applications are accompanied with strict design goals such as low cost, low power dissipation and small form factor. The large capacity and range of new applications are the driving force for development of various wireless data standards such as Global System for Mobile (GSM), Digital Cellular System (DCS) and Wideband Code Division Multiple Access (WCDMA) standards. The switching of mobile from one standard to another is the most important aspect of modern personal communication systems, used to provide access to different network technologies and multiple cells. The switching need of a mobile, forces the use of a reconfigurable RF front end design. The major challenges in developing such multistandard compatible devices are to limit the additional hardware and reuse maximum number of building blocks for the multiple modes of operation [1].

The recent multistandard wireless receiver architecture supports more than one standard, by providing multiple parallel receivers. A voltage controlled oscillator (VCO) is the most important part of multi-band frequency synthesizer with dual control options such as band control and fine-tuning. There have been many attempts to achieve multi-band or wide tuning range VCO using switched capacitor array [2], variable inductors and combination of both [3]. The wide band design of VCO with fixed inductor and switched capacitor or variable inductor and fixed capacitor are not sufficient for very large tuning requirements. In addition, the efforts to increase tuning range have adverse effect on the phase noise and power performance. There is, therefore, a continued search for architectures and circuit techniques enabling VCO architectures to attain lower power dissipation, better performance and better tuning range.

Existing research results indicate that MicroElectro Mechanical Systems (MEMS) based RF systems will play a significant role in designing new products. By using MEMS based RF components, the footprint of RF circuits can be greatly shrunk by including all the off-chip components into on-chip components. At the same time, the performance of RF circuits is improved as a result of reducing signal delay and noise. The availability of MEMS based passive components and circuitry opens promising new integration options for wireless systems. These advantages and promising applications of MEMS components for RF design is the driving motivation for RF and MEMS integrated front-end of a mobile receiver [4]-[5].

This paper presents the design and implementation of a low power MEMS based reconfigurable VCO. Depending on which communication standard has been selected, the VCO automatically reconfigures its operating parameters to switch to the desired standard in order to meet the different requirements of the desired communication standard. In addition, the designed VCO employs MEMS components in place of the passive components to attain lower system power consumption and improved performance.

The paper is organised as follows. Section 2 discusses the direct conversion receiver architecture and the reconfigurable algorithm. The handover scenario is also discussed in Section 2. Section 3 presents the design and implementation of a reconfigurable VCO using CMOS and MEMS technology, its advantages and typical components for wireless communication are discussed. Results are presented in Section 4 and finally conclusions are drawn in Section 5.

2. RECONFIGURABLE DIRECT CONVERSION RECEIVER ARCHITECTURE

2.1. Reconfigurable Direct Conversion Architecture

Recently published papers [1]-[6] on the standard transceivers prefer the choice of direct conversion receiver (DCR) architecture for reception. The main advantage of this structure is the high level of integration that can be achieved, permitting from the low noise amplifier to the input of the analog to digital converters (ADCs) to be built on one chip with very few internal and external components. In addition, this type of architecture uses single down conversion mixer to convert the input RF frequency signal to the zero frequency. Moreover, the receiver directly de-modulates the signal into baseband operation and does not go through an intermediate Frequency (IF) stage. Other advantages of the DCR architecture includes: Image frequency problem does not exist so image filter is not required and monolithic implementation is possible.

The proposed multi-standard DCR architecture suitable for GSM900, DCS1800 and WCDMA is presented in Fig. 1. The multi-standard architecture employs a reconfig-urable VCO, reconfigurable Low Noise Amplifier (LNA), Programmable Low Pass Filter (LPF) and programmable bank of Band Pass Filters (BPFs). Depending on which communication standard has been selected, the frequency band controller at baseband will initiate signals to reconfigure the VCO, LPF, LNA and BPFs to operate at the desired communication standard. The designed reconfigurable algorithm is presented in Fig. 2. A desired communication standard is decided based on the actual received power at the mobile terminal from adjacent base stations. To justify the need of a multi-standard mobile receiver, a handover scenario between different communication standards will be discussed in the next section.

2.2. Handover scenario for Multistandard Receiver

The most important aspect of modern personal communication systems is mobility, which allows users to travel from one area to another while keeping a continuous connection. In order to achieve this mobility, one of the most important concepts used is handover. As a single base station only can cover a specific area, the basic operation of handover is dynamic change in serving base station based on the quality of the link between the base station and the mobile terminal. Based on the received power at the mobile terminal from adjacent base stations, an existing connection between the mobile terminal and the current base station can be terminated and replaced by a new connection in the new cell (target cell).

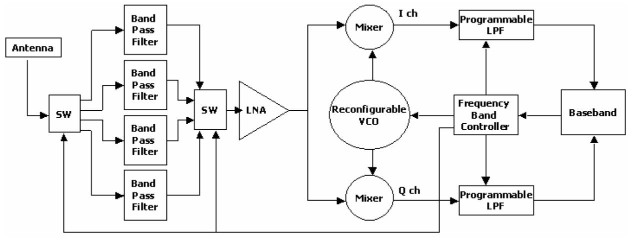

Figure 1. Building Blocks for the Multi-Standard System.

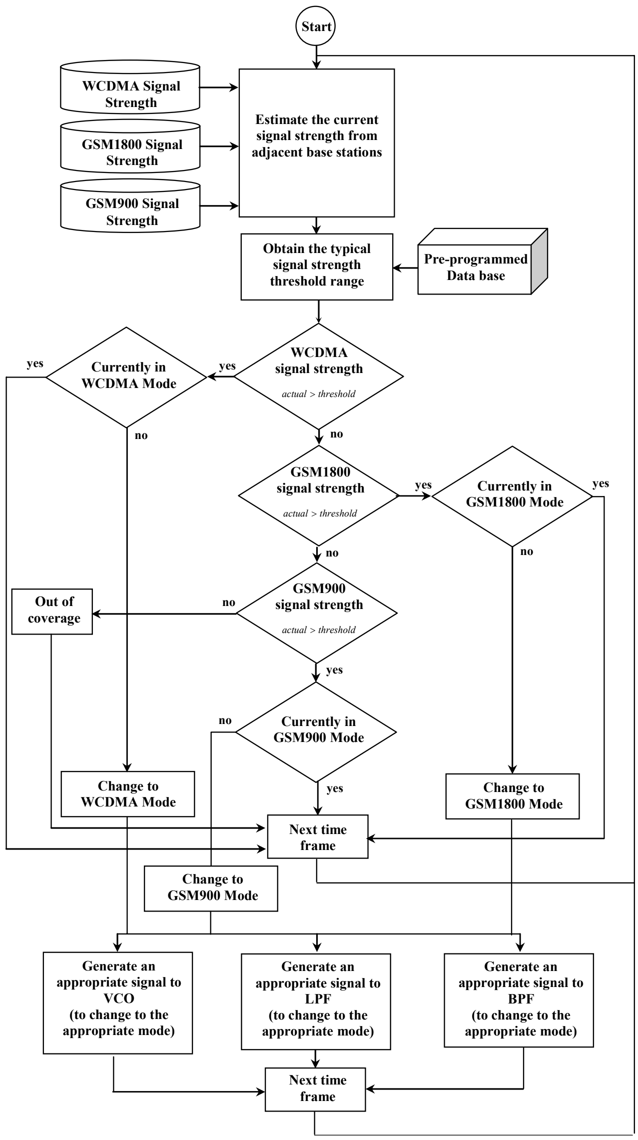

Figure 2. Reconfigurable algorithm flow chart.

There are three different types of handover: hard handover, inter-system handover and soft handover. In hard handover, the connection between mobile terminal also referred as user equipment (UE) and radio access network is disrupted and a new connection is established. The inter-system handover is related to switching between different communication standards, such as between WCDMA and GSM, where the mobile terminal is required to switch between different systems for different operating modes. Soft handover is a Code-Division Multiple-Access (CDMA) specific handover type implemented in the 3rd Generation (3G) network, which occurs when the mobile station is in the overlapping coverage area of two adjacent cells [7].

The handover scenario is studied by using a static handover model in 3G communication network. The model details the path loss calculations and the received pilot signal power at UE when the mobile terminal is traveling through different coverage area of adjacent base stations. The random parameters used are UE initiates a call in 4 km cell, vehicular speed is selected between 8 and 96km/hr and direction is selected to be between 0 and 360 ^{0}. Results of the handover possibility to another cell are as shown in Fig. 3 and Table 1 respectively. Results show that if a user is making call for 5 minutes there is a 40% chance of handover. There is, therefore, a large chance that the mobile terminal requires the switching between the different communication standards for regular call time. This justifies the requirements of a multi-standard receiver, which can reconfigure its operating parameters and architectures for different communication standards [7].

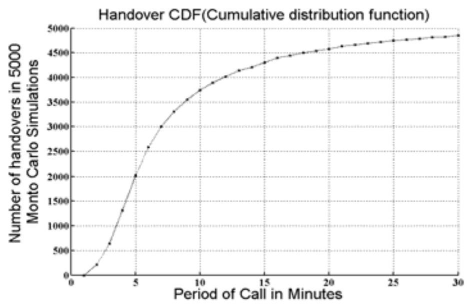

Figure 3. Probability of handover in single cell [7].

Table 1. Handover Probability

Call time (Minutes)	**Handover Probability (%)**
3	12
5	40
10	75
15	85

3. IMPLEMENTATION OF THE RECONFIGURABLE MEMS VCO

VCO is considered as one of the most important block in the receiver architecture, as the performance of VCO decides the receiver's performance. Very stringent requirements are, therefore, placed on spectral purity of the local oscillators. A significant amount of research has been carried out on the improvement of VCO performance; however, it is still one of the most challenging components. This section presents the design and implementation of a reconfigurable VCO for the multi-standard receiver architecture, which was discussed in section 2. The reconfigurable VCO is designed for three frequency standards, GSM900, DCS1800 and WCDMA. Table 2 presents the frequency and phase noise requirements of the VCO for the three frequency bands. The VCO frequency is double for all standards in order to incorporate the provision of divide by two which is required to get the I and Q channels.

Table 2. VCO Frequency Band and Phase Noise Specifications

	Band 1 GSM900	Band 2 DCS1800	Band 3 WCDMA
Frequency (GHz)	1.8	3.6	4.2
Tuning Range (GHz)	1.87 to 1.92	3.61 to 3.76	4.2 to 4.34
Phase noise (dBc/Hz) @600KHz @10MHz @15MHz	<- 120 - -	<- 120 - -	- <-132 <-144

Fig. 4 presents the schematic diagram of the designed reconfigurable VCO. The VCO employs on chip inductors (L_1, L_2, L_3 and L_4), capacitors (C_1, C_2, C_3 and C_4) and NMOS cross coupled differential architecture (M_{N1} and M_{N2}) which generates negative resistance to cancel losses in the tank. The PMOS transistors, M_{P1} and M_{P2}, form a top current mirror. The sizes of the PMOS transistors are selected large enough to reduce 1/f noise. The desired frequency band selection is performed using MMOS switches (SW_1, SW_2, SW_3 and SW_4) to select suitable capacitor and inductor combination, and then fine tuning is performed using V_{tume}. The NMOS transistor (M_{N3}) is added to control the tail current using V_{TAIL}.

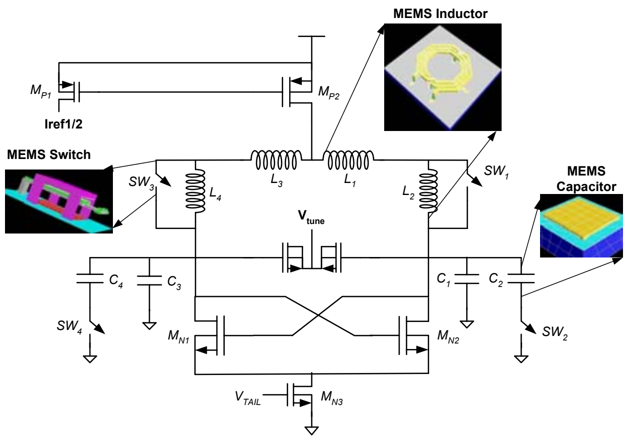

Figure 4. Reconfigurable VCO for a multi-standard system.

In the MEMS reconfigurable VCO, proposed in this paper, the passive components, including inductors (L_1, L_2, L_3 and L_4), capacitors (C_1, C_2, C_3 and C_4) and switches (SW_1, SW_2, SW_3 and SW_4), are replaced by MEMS components, as presented in Fig. 4. Advantages of MEMS devices include small size, high Q factor, low power consumption, high selectivity and compatible fabrication process [4]-[5]. The MEMS inductor is implemented using a simulator that models self-inductance and resistance including skin effects and substrate effects. The modeled differential resonator uses a single balanced octagonal MEMS inductor with a center tap. The quality factor (Q) can be improved by removing substrate underneath the inductor structure. The implemented RF MEMS switch is a derrick-type switch. This topology employs the mechanical movement to make firm contacts during ON state, so these structures avoid the drawbacks of bending presented in typical MEMS beam type switches. Results show that moving metal contacts possess low parasitics at microwave frequencies (due to their small size) and are amenable to achieving low on-resistance (resistive switching) or high on-capacitance (capacitive switching). The variable MEMS capacitor is implemented using electrostatic parallel plate architecture. In the parallel plate approach, the top plate is suspended in a certain distance from the bottom plate by suspension springs. This distance is used to vary in response to the electrostatic force between the plates induced by an applied voltage.

The MEMS components, including inductors, capacitors and switches, were implemented using Conventor design suite. Reduced order models of the MEMS components were extracted using Coventorware's SpringMM-Electrical, SpringMM-Mechanical and InertiaMM analysis in the form of verilog-A codes. The models represent the components' behaviour in both mechanical and electrical domains. The models were then imported to Cadence for co-simulation with the CMOS section of the VCO.

4. RESULTS

Two reconfigurable VCOs, with and without the MEMS components to replace passive components, have been implemented in Cadence RFSpectre using AMI 0.6-micron CMOS process. Simulation has been performed when the designed VCOs are switching between the three desired communication standards, namely GSM900, DCS1800 and WCDMA. Table 3 presents a performance summary of the designed reconfigurable VCO with and without the MEMS components. The design also incorporates the provision of divide by two to get the I and Q channels. The results also indicate that the phase noise requirements for the standards are also met.

5. CONCLUSIONS

This paper presents the design and implementation of a low power reconfigurable VCO for a multi-standard mobile receiver architecture using MEMS components. The VCO is designed for three different communication standards, namely GSM800, DCS1800 and WCDMA. It achieves a frequency tuning ranges of 1.86GHz to 1.94GHz, 3.6GHz to 3.78GHz and 4.18GHz to 4.50GHz for the three desired communication standards. It consumes an average power of 3.8 mW at a supply voltage of 1.2V.

Results show that a 50% reduction of power consumption is achieved when the MEMS components are employed to replace the passive components. This VCO characteristic, therefore, enhances the efficiency of a multi-standard mobile receiver.

Table 3. Performance Summary of the two reconfigurable VCO

Parameters	Reconfigurable VCO without MEMS component	Reconfigurable VCO with MEMS components
Operating standards	GSM900, DCS1800, WCDMA	GSM900, DCS1800, WCDMA
Operating frequency	1.8GHz, 3.6GHz, 4.2GHz	1.8GHz, 3.6GHz, 4.2GHz
Tuning Ranges	1.86GHz to 1.94GHz 3.6GHz to 3.78GHz 4.18GHz to 4.50GHz	1.86GHz to 1.94GHz 3.6GHz to 3.78GHz 4.18GHz to 4.50GHz
Power Consumption	7.6 mW	3.8 mW
Supply Voltage	1.2V	1.2V
CMOS Technology	AMI 0.6 micron process	AMI 0.6 micron process
Phase Noise		
GSM900 @600KHz @1MHz	-122 (dBc/Hz) -134 (dBc/Hz)	-125 (dBc/Hz) -140 (dBc/Hz)
DCS1800 @600KHz @1MHz	-123 (dBc/Hz) -136 (dBc/Hz)	-125 (dBc/Hz) -140 (dBc/Hz)
WCDMA @10MHz @15MHz	-146 (dBc/Hz) -150 (dBc/Hz)	-150 (dBc/Hz) -152 (dBc/Hz)

6. ACKNOWLEDGMENT

H. P. Le and J. Singh acknowledge the contribution made by Mr. Vibhute in this paper.

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