Frequency Modulation and Control in Quadrature Ring Oscillator for Multiband FM/FSK Transmitters

Md. Mahbub Reja, Kambiz Moez and Igor Filanovsky

Department of Electrical and Computer Engineering, University of Alberta

Edmonton, Alberta, Canada

Email: {mreja, igor, kambiz}@ece.ualberta.ca

***Abstract*—A circuit for wide range frequency modulation and control in a quadrature ring oscillator for multiband FM/FSK transmitter is presented. The modulation and control signal are applied to the oscillator transmission gates via the floating current source circuit. The current of this source repeats the input control current that includes two components, one of which tunes the mid-frequency and the other tunes the modulation depth. Each of the control components is set independently. This precise and wide-range frequency control allows one to use it in multiband applications. The proposed circuit is designed in 0.18µm standard digital CMOS process for intended carrier frequencies of two ISM bands (900 MHz, and 2.4 GHz).**

I. INTRODUCTION

The growing demand for low voltage, low power, low cost short range wireless communication systems operating in the ISM (industrial, scientific, and medical) bands (900 MHz, 2.4 GHz, 5.8 GHz) dictates the use of transceiver architecture with minimum circuitry and small chip area. The classical digital frequency modulation/frequency-shift-key (FM/FSK) modulation is used in many applications such as cordless phones, radio telemetry, building automation, remote keyless entry, consumer electronics, and wireless integrated sensor networks. Using FM/FSK modulation technique has the advantage of deploying simple transmitter architecture to generate FSK signals, leading to considerable reduction of the die area.

In recent years, a number of CMOS FM/FSK transmitters including FM/FSK voltage-controlled oscillators (VCO's) with direct frequency modulation have been reported [1-4]. The complex circuits of [1, 2] consisting of a phase splitter for quadrature local oscillator (LO) signals generation, two mixers and *I-Q* generator for data signals lead to a large chip area. On the other hand, the core of the transmitter in [3, 4] is a cross-coupled *LC* oscillator, where *L* is the on–chip passive inductor and *C* is the metal-oxide-semiconductor (MOS) varactors (variable capacitors). On-chip *L* takes a large chip area and the achievable coil quality factor, *Q*, is not high (about 3-5) in digital CMOS processes [5]. It is also difficult to realize a linear control characteristic with MOS varactor, and the size of the varactor transistor is also very big. Moreover, it is also difficult to generate and control high frequency oscillation with wide tuning range at low power and low chip area design required for multiband applications.

In this paper, a design approach of generating high frequency FM/FSK signals in a quadrature ring oscillator for multiband applications is presented. This frequency modulation and control is achieved using a floating current source, and dividing control signal in two independent components.

The circuit is designed and simulated in 0.18µm standard digital CMOS process.

This paper is organized as follows. In Section II, a brief review on the architecture of the proposed circuit is discussed. The design approach is presented in Section III. The simulation results are discussed in Section IV.

II. FREQUENCY MODULATION CONTROL IN QUADRATURE RING OSCILLATOR

The overall architecture of the proposed quadrature ring oscillator with control circuit for multiband FM/FSK transmitters is shown in Fig. 1. Here, the digital data control (FSK control generating two distinct frequencies) signal and analog control (FM control tuning carrier frequency) signal define the value I_C of a current-source in the control circuit. The floating current source, I_{CF} mimics the current I_C and is used as the direct modulating signal for the oscillator.

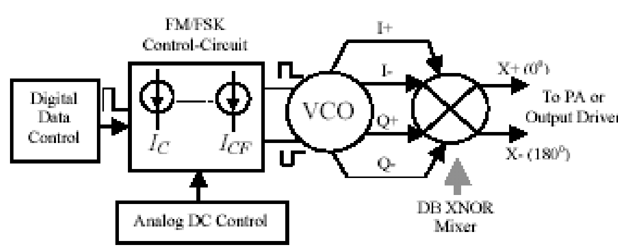


Fig.1 The architecture of the quadrature ring oscillator with control circuit for multiband FM/FSK transmitters

The floating current source allows one to obtain two out of phase (0-180^0) voltage signals, which are then applied to a quadrature VCO to generate FM/FSK signals. Two control signals (analog and digital) may be applied separately or simultaneously to the controlled current-source, I_C either to generate discrete frequencies (mark frequency, f_m, and space frequency, f_s), or to control and tune the carrier frequency or mid-frequency, f_c=(f_m+ f_s)/2. Hence, analog control sets the DC level of two phase-shifted voltage signals to tune the carrier frequency in a wide range, while digital signal generate discrete FSK frequencies. Quadrature signals: I+ (0^0), Q+ (90^0), I-(180^0), and Q-(270^0) from the oscillator are applied to a fully double-balanced (DB) exclusive NOR (XNOR) gate mixer as shown in Fig.2. The mixer generates two out of phases double-frequency FM/FSK signals (*X*+ and *X*-), ready for transmission if followed by a power amplifier (PA) or output driver (not shown in Fig. 1 and 2). In multiband applications, lower frequency band signal is taken directly from the quadrature oscillator outputs (I+, I- or Q+, Q-) through a buffer. The higher frequency band signal is taken from the NOR gate mixer output. Hence, using analog control and inputs or outputs signals of NOR gate mixer one can use the signal (f_c) of one band or another, while using digital control one can set the FSK signals (f_m, f_s) in the corresponding band. Hence, a universal multiband (two or more bands, if a parallel circuit is used) transmitter becomes feasible.

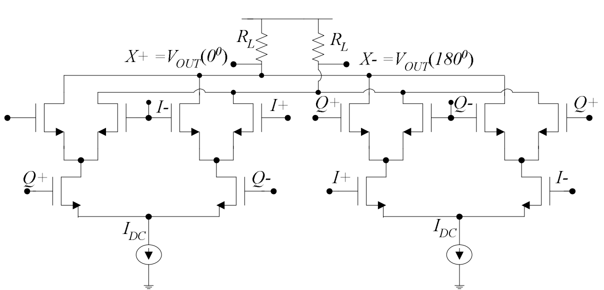


Fig.2 Fully double-balanced (DB) XNOR gate mixer

III. DESIGN APPROACH

A brief review of different direct modulation methods and their drawbacks is given in [6]. Modulating the *LC*-tank MOS varactor of the VCO [3, 4] does not provide linear control (because of the MOS capacitance nonlinearity), and it is relatively slow. The direct modulation of the frequency by variation of active device parameters is better suitable for a fast frequency change of a local oscillator.

A wide tuning range and fast voltage swing VCO has been reported in [7], [8]. In this VCO, a transmission gate (TG) precedes each stage inverter and the frequency of oscillation is tuned by varying the resistance of the TG (a voltage controlled variable resistor) with two opposite DC control voltages.

Then, a wide tuning-range four-stage CMOS ring oscillator with quadrature outputs (I and Q) has been reported in [9]. Using the direct modulation capabilities of the ring oscillators in [7-9], we arrived to a novel oscillator with four quadrature outputs (I+, I-, Q+, Q-) as shown in Fig. 3. When combined control signals, $V_{CTN}(0^0)$ and $V_{CTN}(180^0)$ are applied to the gates of the PMOS and NMOS devices of the TGs in this circuit, it turns into FM/FSK oscillator with required properties.

To obtain these combined voltage signals (digital modulating signal at certain DC level), a floating current source [10] is used as shown in Fig.4. Transistor M2 (Fig. 4) constitutes this source, I_{CF}. From this source one obtains two additional current sources (transistors M7 and M8) with minimal and symmetric delay with respect to the floating current source. The current, I_{CF} , is a copy of the current I_{C1} in M1 (assuming matched M1 and M2), because the operational amplifier A_I creates the symmetric operating conditions for M1 and M2. The current mirror MB, M4 provides the summing current, I_C of the input signals to the transistor M1 and the low input impedance of this current mirror eases the summation of the digital and analog control signals. To generate combined control signal I_C, the digital data or modulating signal is applied to transistor MD and analog control signal is applied to transistor MA.

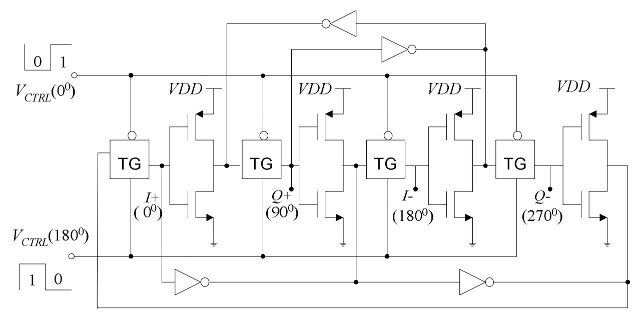


Fig. 3 Direct modulation capable four-stage ring oscillator with quadrature outputs (I+, I-, Q+, Q-)

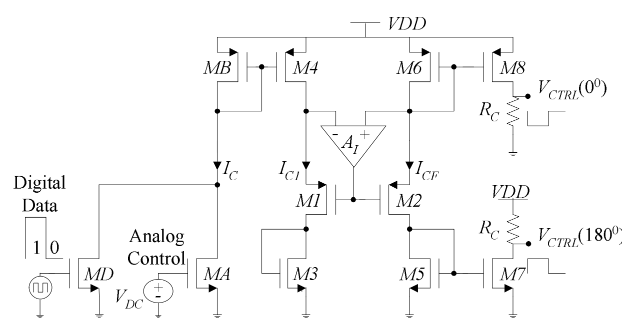


Fig. 4 Floating current-source with digital and analog control

The circuits for generating discrete FSK frequencies (using digital control) or continuous tuning FSK frequencies (using analog control) are represented here by simple transistors but the approach allows one to use other circuits with desirable degree of precision. Analog and digital controls can be simultaneously or separately used. For FSK modulation (discrete frequencies), digital signal may be applied to a MD transistor banks by *N*-bit external switch (here *N* corresponds to the number of MD transistors in parallel) while analog signal (DC) tunes the carrier frequency over a wide range and locates these discrete frequencies in the proper range. The complete circuit for the proposed high frequency FM/FSK oscillator is shown in Fig. 5. Buffer circuit for taking lower-band frequency output (either I+ & I- or Q+ & Q-) or higher-band from the quardature oscillator are not shown in Fig.5.

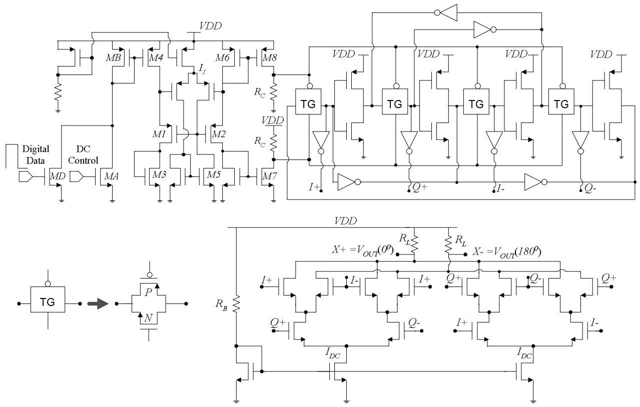


Fig.5 Complete circuit for the proposed FM/FSK oscillator

IV. DESIGN REALIZATION AND SIMULATION

The circuit of Fig. 5 is designed and simulated in CMOS 0.18-um process. Fig. 6 shows the simulation results generating mark (f_m) and space (f_s) frequencies in corresponding with "0" and "1" of digital data signal respectively. Fig. 7 and Fig. 8 show other simulation results for the proposed circuit. Generation of single-frequency (*f*) from the oscillator and its double-frequency (*2f*) from the DB XNOR mixer is shown in Fig.7 (a). The quadrature outputs (I and Q) from the oscillator as shown in Fig. 7(b) show the 90^0 relationship (174ps phase difference in 687ps period signal). Fig.8 shows wide-range changing of output frequencies (f_s and f_m) with respect to different control voltages. For higher-band frequency output (from DB XNOR mixer) at analog control voltage of 450mV, mid-frequency 2.63GHz is achieved and at 850mV control, mid-frequency 1.83GHz is achieved (Fig.8). At control voltage of 620mV, mid-carrier frequency 2.46GHz is obtained (one of the ISM bands). Hence, for 2.4GHz ISM band, frequency can be tuned from 1.83 to 2.63GHz with 800MHz tuning range. Lower-band frequency output (I+ I- or Q+ Q-), varies from 915MHz to 1.315GHz while analog control voltage varies from 850mV to 450mV.

Increase control voltage to 920mV further down the lower frequency-band to 860MHz. Hence, for 900MHz ISM band, frequency can be tuned from 860MHz to 1.315GHz with 455 MHz tuning range). Table 1 summarizes the simulation results for intended carrier frequency of 2.4 GHz.

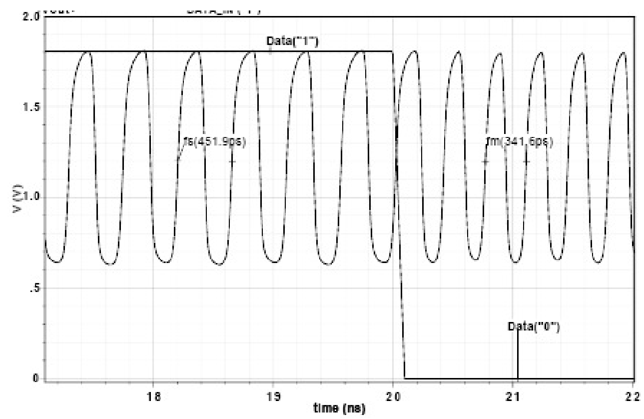
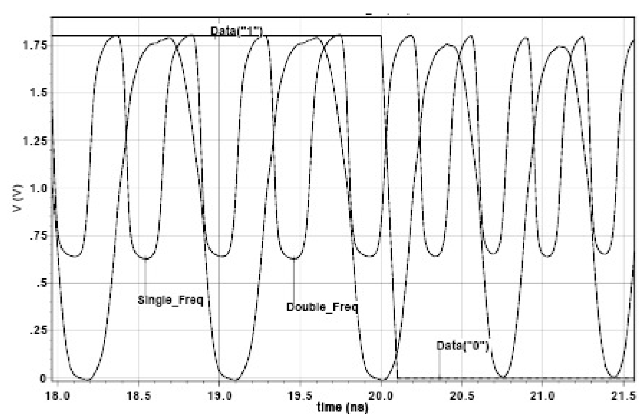
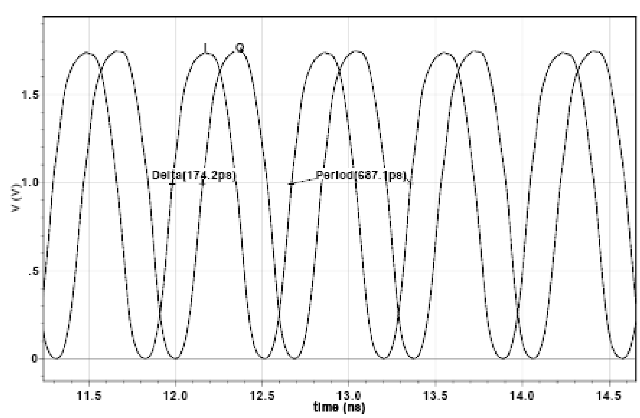


Fig.6 Simulated results: mark and space frequencies in correspondence with "0" and "1" of digital data signal



(a)



(b)

Fig.7 Simulated results: (a) single (*f*) and double (2*f*) frequencies; (b) quadrature outputs (I and Q) generation from oscillator

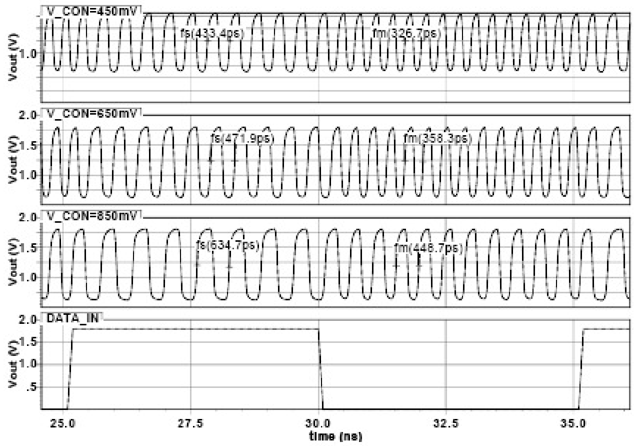


Fig.8 Simulated results: Output frequencies at control voltages (V-CON) 450mV, 650mV and 850mV

Tabel-1: Summary of the simulation results

Intended carrier frequency	2.46 GHz (ISM band)
Mid-frequency tuning range	1.83 to 2.63 GHz
Mark and space frequency V_{dc} (analog-control)=0.62V	f_s=2.17GHz and f_m=2.85 GHz
Frequency deviation ($\Delta f = f_m - f_s$)	± 340 MHz
DC supply voltage	1.8 V
Core oscillator power consumption	1.35 mW

V. CONCLUSION

The proposed FM/FSK generator is designed as an effort to unify the transmission of two different bands. The circuit uses the technique of floating current source that allows one to reduce simultaneous control of two voltages to control of one current where the FM and FSK components can be easily separated. Using frequency doubling allows one to create a transmitter for two different bands in one circuit. The architecture does not need any on-chip bulk passive components. Therefore, it can be realized in a standard digital CMOS process.

The circuit design assumes that frequency of oscillation does not vary widely with process and temperature.

REFERENCES

[1] Melly T., Porret A.-S., Enz C. C., and Vittoz E. A. Eason, "An ultralow-power UHF transceiver integrated in a standard digital CMOS process: transmitter," *IEEE Journal of Solid-State Circuits*, vol. 36, no. 3, Mar. 2001, pp. 467-472.

[2] Germa D., Giry A., Manastretta D., Belot D., and Pache D., "1W 900 MHz direct conversion CMOS transmitter for paging applications," *2001 IEEE Radio Frequency Integrated Circuits Symposium*, May 20-22, 2001, pp. 191-194.

[3] Neihart N. M., and Harrison R. R., "Micropower circuits for bidirectional wireless telemetry in neural recordings applications," *IEEE Transactions on Biomedical engineering*, vol. 52, no. 11, Nov. 2005, pp. 1950-1959.

[4] Choi Y. B., Teo T. H., and Yeoh W. G., "A 2.4GHz fully integrated CMOS VCO with direct FM/FSK modulation capability," *2003 IEEE Conference on Electron Devices and Solid-State Circuits*, Dec. 16-18, 2005, pp. 175-178.

[5] Thomas H. Lee, *The Design of CMOS Radio-Frequency Integrated Circuits*, Cambridge University Press, Cambridge UK, 2002.

[6] Melly T., Porret A.-S., Enz C. C., and Vittoz, "A 1.2V, 433MHz, 10dBm, 38% global efficiency FSK transmitter integrated in a standard digital cmos process," *IEEE 2000 Custom Integrated Circuits Conference*, May 21-24, 2000, pp. 179-182.

[7] Retdian N., Takagi S., and Fujii N., " Voltage controlled ring oscillator with wide tuning range and fast voltage swing," *2002 IEEE Asia-Pacific Conference on ASIC*, Aug. 6-8, 2002, pp. 201-204.

[8] Sheu Meng-Lieh, Lin Ta-Wei., and Hsu Wei-Hung, "Wide frequency range voltage controlled ring oscillators based on transmission gates," *IEEE International Symposium on Circuits and Systems*, ISCAS 2005, May 23-26, 2005, vol. 3, pp. 2731-2734.

[9] Grozing M., Philip B., and Berroth M., "CMOS ring oscillator with quadrature outputs and 100 MHz to 3.5 GHz tuning range," *29th European Solid-State Circuits Conference*, Sept. 16-18, 2003, pp. 679-682.

[10] Vadim V. Ivanov, and Igor M. Filanovsky, *Operational Amplifier Speed and Accuracy Improvement*, Kluwer Academic Peblishers, Boston, 2004.