I/Q LC Oscillators with an Octave Tuning Range for TV on Mobile Platforms

Johan van der Tang, Roger Amiot*, Harm van Rumpt*, Dieter Kasperkovitz*, Arthur van Roermund

Eindhoven University of Technology, Mixed-signal Microelectronics (MsM) group
Den Dolech 2, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
j.d.v.d.tang@tue.nl
* Semiconductor Ideas to the Market (ITOM), Breda, The Netherlands

Abstract **Two I/Q oscillators have been realized that cover one octave tuning range, and when combined with a divider and a multiplexer, cover the complete TV band. The realized oscillators embody highly cost-effective key building blocks for tuning systems in consumer ICs for TV on portable platforms. The resonators consist of bond-wires, 8 bits capacitor banks and varactors. One I/Q LC oscillator is realized with integrators, and achieves a tuning range of 412-880MHz (107% of an octave), and its phase noise to carrier ratio $\mathcal{L}(f_m)$ varies from -101dBc/Hz to -110dBc/Hz at 500kHz offset. Its power dissipation is 35mW (at 3 Volt). A second I/Q oscillator is coupled with V/I converters that implement a high-pass function. Its tuning range is 417-836MHz (102%), $\mathcal{L}$(500kHz) varies between -111dBc/Hz and -115dBc/Hz, with a power dissipation of 23mW. Both oscillators are realized in an 8 GHz f_T/0.6μm BiCMOS process.**

I. INTRODUCTION

Mobile phones get more and more feature packed. Apart from its primary function: making phone calls, software extends it functionality to that of organizers, games, etcetera. In addition, a significant number of features that require dedicated hardware have been added over the last years. Examples are cameras [1], FM radios [2, 3], MP3 players [4] and even game consoles [4].

New trends and new applications on the mobile phone platform continue to emerge and first phones with built in analog television are already on the marketplace [5]. However, to make it an attractive feature, significant improvements are required. Especially, power dissipation and the number of external components need to be reduced to give the consumer an acceptable battery lifetime and the phone manufacturer TV functionality with a small footprint and low bill-of-materials (BOM), respectively.

This paper describes the tuning system concept for a no-external component analog TV IC for mobile phones and other portable platforms. The core of the tuning system consist of an I/Q LC oscillator that is realized with bond-wires, a discrete capacitor bank and varactors. Two I/Q LC oscillators have been designed and implemented and are discussed in detail. One is optimized for maximum tuning range and the second is aimed to maximize phase noise performance.

II. TUNING SYSTEM CONCEPT

Figure 1 shows a tuning system that is capable of covering the complete TV band (approx. 50-860 MHz) with just one oscillator.

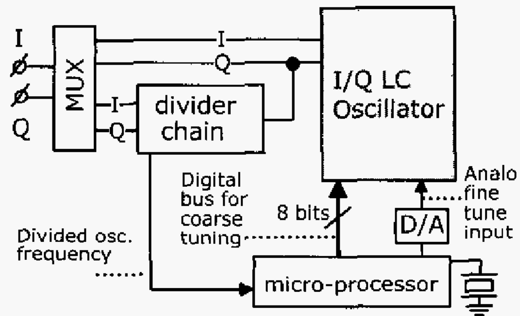

Figure 1. Wide range I/Q signal generation architecture.

The heart of the architecture is the LC oscillator that provides in-phase (I) and quadrature (Q) signals. For the UHF TV band (approx. 470-860MHz), a multiplexer (MUX) selects the outputs of the oscillator. For lower frequencies (VHF bands), the MUX selects the output frequency of the divider chain connected to its input. Provided that the tuning range of the oscillator is more than one octave, any frequency below the highest frequency of the oscillator can be generated. Moreover, as long as the highest frequency of interest can be generated by the oscillator, a shift in center frequency due to process spread can be handled without any problem. This allows the use of inaccurate (but high-Q) resonator elements such as bond wires. As the tuning system generates quadrature signals, it can be used in low-IF and zero-IF architectures.

Tuning to the desired channel is realized with a frequency locked loop (FLL), similar as described in [6]. As shown in Fig. 1, the oscillator signal is divided and interpreted by a tuning algorithm that runs on the micro-processor of the portable platform. The algorithm generates the correct tuning signals for an 8-bits switched capacitor bank and for the D/A-converter that is used for fine tuning, thus closing the frequency lock loop. Note that the I-branch of the oscillator should be loaded by a dummy divider stage in an implementation to maintain symmetric loading of the quadrature

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oscillator. Unlike other tuning concepts that cover the complete TV band using multiple PLLs and oscillators (e.g. see [7]), only one quadrature oscillator is required in this tuning concept.

Now the tuning concept has been described, the rest of the paper is devoted to two implementations of the I/Q oscillator. First, Section 3 discusses coupling options to implement I/Q LC oscillators. Second, the first I/Q LC oscillator is highlighted in Section 4, which uses tuned integrators. Third, Section 5 discussed a second implementation based on coupling with V/I converters with a high pass characteristic. Fourth, design of optimum coupling parameters using AC analysis is briefly touched in Section 6. Finally, Sections 7, and 8 discuss experimental results, and conclusions, respectively.

III. COUPLING METHODS FOR I/Q OSCILLATORS

Like there are many methods to generate I/Q signals, e.g. using dividers [8], a poly-phase filter [9], double loop PLLs [10], and of course I/Q oscillators [11], there are many ways to couple two single-phase LC oscillators.

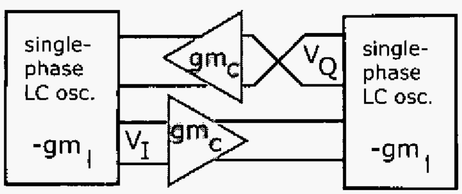

Figure 2. Block diagram of an I/Q LC oscillator coupled with transconductances gm_c.

Figure 2 shows how two LC oscillators with negative transconductance gm_l that are coupled with transconductances gm_c, form an I/Q oscillator. Most straight forward is an implementation of gm_c with transistors connected with their collector or drain to the tank circuit of the single-phase oscillators [12]. This implementation, in which transconductance gm_c is made equal to gm_l, results in a resonator phase shift of 45° in each resonator of the two coupled LC oscillators from Fig. 2, as explained in [12, 13]. Because the effective quality factor of a two-stage I/Q LC oscillator can be written as [11]:

$$Q_{I/Q} = 2 \cdot Q_p cos(\phi_{res}), \quad (1)$$

with Q_p the loaded quality factor of the resonator in a LC oscillator, and ϕ_{res} the phase-shift of this resonator, the coupling methods used in [12] reduces $Q_{I/Q}$. With a phase shift of 45°, $Q_{I/Q}$ is reduced a factor $\sqrt{2}$, resulting in (at least[1]) a 3 dB phase noise penalty.

Optimum coupling (leading to $\phi_{res} = 0$) can be achieved by common-mode inductive coupling [14]. However, this methods requires an on-chip transformer (occupying chip area which should be minimized for consumer products) and it's principle (injection locking) makes it far from trivial to have a robust coupling with this method over the target tuning range of one octave. Alternatively, the coupling transconductances gm_c can be combined with phase shift, such that optimum coupling conditions ($\phi_{res} = 0$) are obtained over the full tuning range of an I/Q oscillator [11]. This approach has been adopted in the designs presented in this paper.

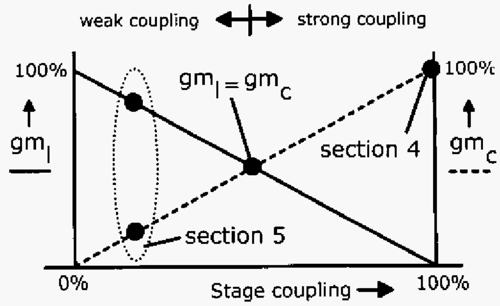

Figure 3. The ratio between gm_l and gm_c determines the strength of the coupling between two single-phase LC oscillators.

Apart from the coupling method, the strength of the coupling between two single-phase LC oscillator is also an important aspect of I/Q oscillator design. Qualitatively, this design aspect is illustrated in Fig. 3. In the middle, reference [12] is indicated (with gm_c equal to gm_l). The coupling strength of the two innovative I/Q stages discussed in the next sections are also marked. In the topology discussed in Section 4, the coupling is 100% and the negative transconductance gm_l from a single-phase LC oscillator is completely removed. The topology highlighted in Section 5 is a case of weak coupling: in other words the dominant transconductance (spending the dominant part of the power budget per section) is gm_l. Clearly, when gm_l is 100%, no I/Q relation will be present anymore. Furthermore, the designer has to pay attention that coupling two stages too weak can result in the highly unwanted multi-oscillation phenomena, as unwanted oscillation modes then may have sufficient loop gain to be triggered under large signal conditions [13].

IV. I/Q LC OSCILLATOR WITH INTEGRATORS

One section of the I/Q oscillator constructed with integrators is shown in Fig. 4.

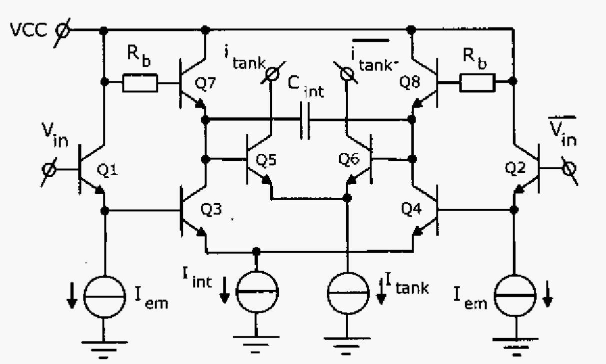

Figure 4. One section of the I/Q LC oscillator with integrators.

Node v_{in} and $\overline{v_{in}}$ are connected to the resonator of the other stage, and outputs i_{tank} and $\overline{i_{tank}}$ inject their current into the LC resonator. The first stage (Q1,Q2) are emitter followers at a low current level

[1]When active device noise in an oscillator dominates, $\mathcal{L}(f_m)$ is proportional to $1/Q^2$. On top of that, the current injected into the resonator by gm_c does not add fully in-phase causing a lower oscillation amplitude compared to the $\phi_{res} = 0$ case.

minimizing loading of the resonator of the previous stage. This is especially important since parasitic capacitance in parallel with the resonator must be minimized to obtain one octave tuning range [13]. Transistors Q3,Q4 and C_{int} realize an integrator that implements the required 90° phaseshift (to realize $\phi_{res} = 0$). The last stage (Q5,Q6) is connected to the resonator and I_{tank} sets the carrier level. Because the total phase shift of the circuit in Fig. 4 without active inductance is larger than 90° in the used BiCMOS technology (8 GHz f_T), active inductances (see [13]), realized by Q7,Q8 (with base resistor R_b), are used to adjust the phase shift. Clear advantages of the circuit are: very low capacitive loading of the resonator and elimination of unwanted oscillation modes (no gm_l). On the other hand, currents I_{em} and I_{int} do not contribute to the carrier, which implies a phase noise penalty compared to designs that use the total power budget to maximize the carrier.

V. I/Q LC OSCILLATORS WITH HIGH-PASS COUPLING

The second oscillator design (see Fig. 5) consist of an AC cross-coupled pair (allowing a large carrier swing) and two transistors (Q1,Q2) plus capacitor C_h that implement V/I conversion with a high pass characteristic having a phase shift close to 90°. Notice that the LC resonator (connected to outputs i_{tank} and $\overline{i_{tank}}$) is now loaded with the input impedance of transistors Q1,Q2, but also by the Miller and collector-substrate capacitance of these transistors. Therefore, if we use the same resonator for this oscillator as for the circuit in Fig. 4, a lower oscillation frequency can be expected.

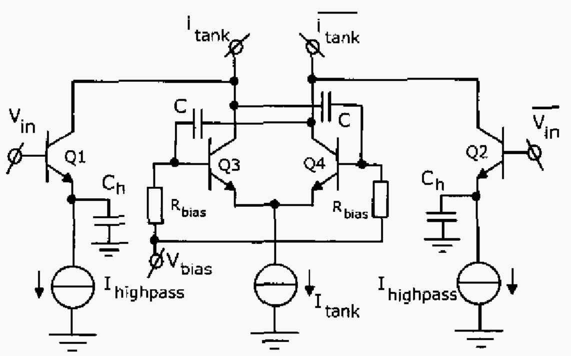

Figure 5. One section of the I/Q LC oscillator with high-pass coupling.

Provided that the current into resonator injected by Q1 and Q2 is 90° shifted in phase with respect to V_{in} and $\overline{V_{in}}$, respectively, these currents add in phase with currents from Q3 and Q4. Therefore, $I_{highpass}$ (2x) and I_{tank} contribute both in an optimal way to the carrier. Optimization and dimensioning of capacitor C_h is addressed in the next section.

VI. COUPLING TESTBENCH

The goal of transistor Q_1 (and Q_2) and C_h in Fig. 5 is to shift the input voltage V_{in} 90° over the whole tuning range (e.g. 450-900MHz). Instead of doing extensive phase noise simulation with SpectreRF, it was found that AC analysis can also be used effectively to dimension C_h. The schematic for the AC simulation is identical to the half circuit of the implementation in Fig. 5, with the addition that I_{tank} is connected to the supply voltage via the (real) impedance of the resonator at resonance. In AC analysis, the transfer function $i_{tank}(j\omega)/V_{in}(j\omega)$ can now be evaluated. For example, Fig. 6 shows the phase of this transfer function for C_h equal to 1pF, 2pF and 5pF. The implemented value of 1pF results in a phase shift closest to 90° across a very wide range. Indeed, SpectreRF confirmed that 2pF and 5 pF leads to worse phase noise performance. It is important to note that much smaller C_h leads to a too weak coupling as the AC gain decreases with decreasing capacitance C_h.

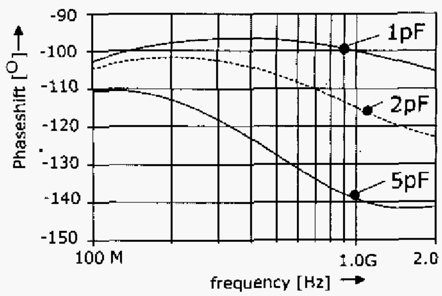

Figure 6. Simulated phase shift of $i_{tank}(j\omega)/V_{in}(j\omega)$ for three values of C_h.

VII. EXPERIMENTAL RESULTS

Figure 7 shows the chip photo of the I/Q oscillator (0.8x1mm^2) from Section 4. The chip photo of the oscillator from Section 5 is quite similar, as they both use identical resonators which dominate the total chip area. The resonators consist of a capacitor bank, varactors for fine tuning, and are constructed with bond-wires as were used in the oscillator in [6]. However, now an 8 bits binary (instead of the 10 bits linear in [6]) capacitor bank is used, reducing the tuning constant (making it less sensitive to noise) of the varactors to a value between 1MHz/V (min. frequency) and 14MHz/V (max. frequency). Worst case quality factor of the resonator (all switches on) is around 4. As can be seen in Fig. 7, the bond-wires of the oscillator are shielded by bond-wires of supply lines.

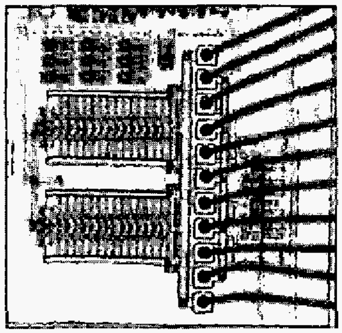
Figure 7. Die photo of the oscillator with integrators. The switched capacitor bank dominates the chip area.

Figure 8 shows the frequency versus code word of the two I/Q LC oscillators. Both oscillators achieve more than one octave tuning range, but clearly the I/Q oscillator with integrators adds the

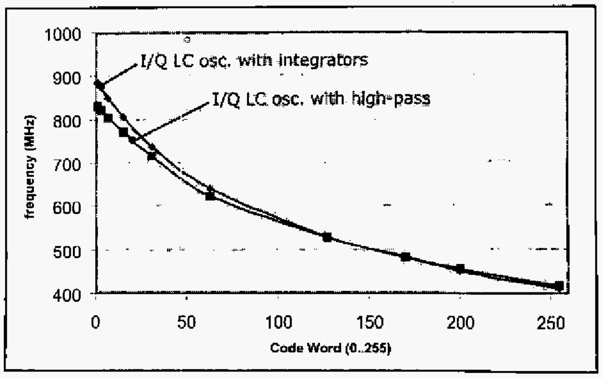

Figure 8. Frequency versus code word of both oscillators, with varactor voltage V_{tune}=1V.

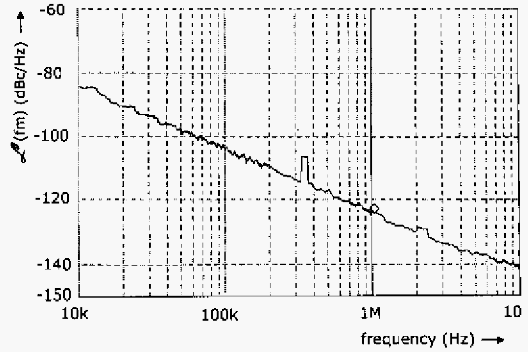

Figure 9. $\mathcal{L}(f_m)$ of the oscillator with high-pass coupling at 417 MHz, measured with a R&S FSIQ

least amount fixed capacitance to the tank circuit. Tuning the varactors from 1V to 0V extends the maximum frequency with approximately 10MHz. To make a fair comparison, both oscillator have exactly the same resonator circuitry. An increase in maximum frequency of the oscillator from section 5 is easily obtained by reducing the value of the switched capacitor bank.

Code	*freq* [MHz]	$\mathcal{L}(500kHz)$ [dBc/Hz]	*freq* [MHz]	$\mathcal{L}(500kHz)$ [dBc/Hz]
1	884	-101.3	831.5	-111.2
3	872.5	-101	822	-111.1
7	848.7	-102.3	803.5	-111.9
15	805.9	-103.2	771	-112.7
31	736.7	-102.8	714.8	-112.9
63	640.3	-104.2	623.3	-113.2
127	527.9	-107.7	529.9	-113.4
255	412	-109.8	417	-115

Table 1. Measured $\mathcal{L}(500kHz)$ of both oscillators.

The third column in Table 1 lists $\mathcal{L}(500kHz)$ of the I/Q oscillator with integrators and the fifth column the measured phase noise of the second I/Q oscillator. In case of the latter oscillator, the coupling method fully contributes to the carrier and at low frequencies (see also Fig. 9) a 10dB improvement is measured compared the first oscillator. Moreover, the oscillator core with integrators dissipates 35mW (at 3V, without buffers), where as the second oscillator dissipates only 23mW (at 3V).

VIII. CONCLUSIONS

The presented I/Q oscillators can be combined with dividers and a multiplexer, to realize a "no-external components" tuning system for television receivers with just one, highly cost-effective, quadrature oscillator. Two I/Q LC oscillators, one with integrators (412-880MHz, 35 mW) and one with phase shifting V/I converters (417-836MHz, 23mW) are realized. Both oscillators achieve more than one octave tuning range and $\mathcal{L}(500kHz)$ levels are better than -101dBc/Hz and -111dBc/Hz,respectively, which is sufficient for high quality analog TV reception.

ACKNOWLEDGMENT

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