

A HIGH DYNAMIC RANGE, DIGITALLY TUNED, Q-ENHANCED LC BANDPASS FILTER FOR CELLULAR/PCS RECEIVERS

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ABSTRACT

A fully-integrated, 850 MHz, 2-pole, bandpass filter with a 2 percent fractional bandwidth is reported. The filter provides digital control of center frequency and Q, and includes a companion on-chip oscillator suitable for master-slave tuning. Prototype measurements show a dynamic range of 75 dB when used in a system with a 1 MHz final IF bandwidth, and an oscillator phase noise of -105 dBc/Hz at 100 kHz offset.

1. INTRODUCTION

Q-enhancement of on-chip spiral inductors has been proposed as a means to realize narrow fractional bandwidth RF filters suitable for use in receiver front-end and first IF circuits [1] [2] [3] [4]. The basic technology has been shown to be theoretically viable for such applications [5], but to-date, reported implementations have realized only moderate dynamic range performance (e.g. 50 dB) and have not addressed manufacturability issues or the need for real-time tuning in practical high-order designs. The implementation reported here is a full fourth-order (2 pole) design operating at 850 MHz with a 2 percent (18 MHz) bandwidth. It achieves a 75 dB dynamic range when used in a cellular or PCS receiver with a nominal 1 MHz channel bandwidth and includes a companion oscillator for use in master-slave tuning.

2. CHIP ARCHITECTURE

The experimental chip architecture is shown in Figure 1. Three fully-differential, on-chip LC resonators are constructed around three 500 μm , 8-turn, center-tapped spiral inductors [6]. Two of the three resonators are identical and form the core of a coupled-resonator filter. The remaining resonator is configured to operate as an on-chip oscillator at a fixed 60 MHz offset from the filter passband. This offset prevents excessive magnetic coupling of the large amplitude oscillator signal into the filter and

allows the oscillator to double as an LO for down-conversion to a 60 MHz IF, while fulfilling its primary role as a tuning reference in a master-slave filter tuning architecture.

To yield a fourth-order response with the desired bandwidth, the filter inductors are magnetically coupled through suitable placement on the die. With ideal inductors, magnetic coupling between filter resonators would result in an induced voltage in one inductor which is in phase quadrature with the current in the opposite inductor, and therefore in-phase with the opposite resonator's voltage waveform. These phase relationships are necessary for a flat passband response. However, with on-chip spiral inductors, inductor currents and voltages are not in quadrature due to the large series resistances present, and significant passband asymmetries result [3]. A coupling neutralization circuit is placed between the two resonators in this design to cancel the undesired effects of the in-phase component of the inductor's I/V relationship. Digital control allows a simple one-time trim of passband ripple to better than 2 dB. Input-output transconductors provide buffering of the resonator circuits to external test equipment used in the prototype chip evaluation. Internal dummy transconductors shown in Figure 1 guarantee matching between resonators, simplifying tuning.

Filter and oscillator frequencies are set through 5-bit digital control words. Use of digital tuning allows high-Q tuning capacitors to be implemented, making resonator starting quality factor (before Q enhancement) primarily dependent on inductor Q. This maximization of starting Q is essential to achieving good dynamic range at acceptable power dissipation [5], and minimizes frequency drift [2]. Within each LC resonator, approximately 80 percent of the total C value originates from the inductor's turn-to-substrate capacitance, with the remaining C contributed by connected I/O buffers, Q tuning cells, and frequency tuning cells. Thus, resonator frequency is largely determined by ca-

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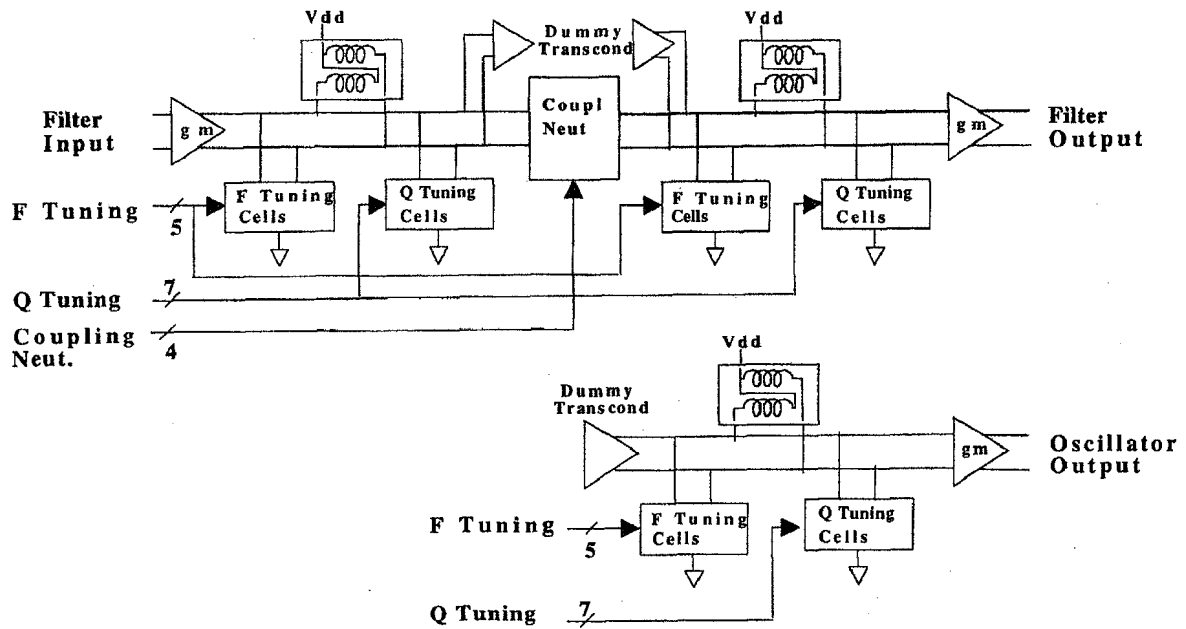


Figure 1. Chip Architecture.

capitance within the inductor, allowing the tuning range to be relatively small in a process with tight oxide thickness tolerances. The prototype design provides a range of 60 MHz with a resolution of approximately 1.8 MHz (10 percent of the nominal filter bandwidth).

Tuning of filter Q is performed through a 7-bit digital control word, yielding the necessary range to compensate for variations in filter starting Q while providing a resolution of 15 percent of the nominal enhanced Q of 70. This Q resolution maps to a resolution of better than 20 percent in filter bandwidth.

As shown in Figure 1, identical controls are present in the companion oscillator circuit so that master-slave tuning can be implemented. Tuning can be accomplished by sensing the oscillator's amplitude and frequency, and constructing a suitable control loop to provide appropriate frequency and Q adjustments using a host system's microprocessor as described in [7].

3. FREQUENCY AND Q TUNING CIRCUITS

The circuit used for Q tuning is shown in Figure 2. The circuit implements a negative resistance used to offset losses within the resonators, raising the effective resonator Q . The core circuit consists of cross-coupled transconductor M1, M2 which provides the negative resistance function, switch M3

to enable or disable the circuit, and pullup M4 to guarantee that when disabled, the circuit remains off in the presence of large signal swings on the inductor. Transistors M5, M6 are used in the LSBs to decrease the effective transconductances below that possible with minimum geometry FETs. The MSB is implemented with 16 copies of the circuit, with transistors M5 and M6 deleted. Lesser significant bits are composed of 8, 4, 2, and 1 copy with M5, M6 deleted, while the two least significant bits use a single copy with M5, M6 included.

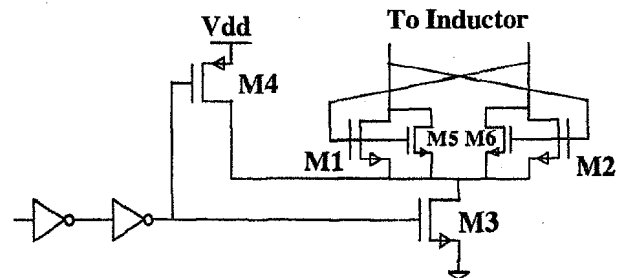
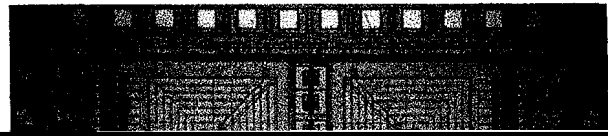


Figure 2. Q tuning cell.

Frequency tuning is performed by switching grounded capacitors in and out of the resonator circuits using suitable arrays of the core circuit of Figure 3. Metal-metal capacitors connected to the inductor are switched to ground on demand

through M1 and M2 which are sized to provide good capacitor Q when on. When M1, M2 are off, minimum geometry FETs M3 and M4 pull the drain of the larger M1, M2 transistors to Vdd -



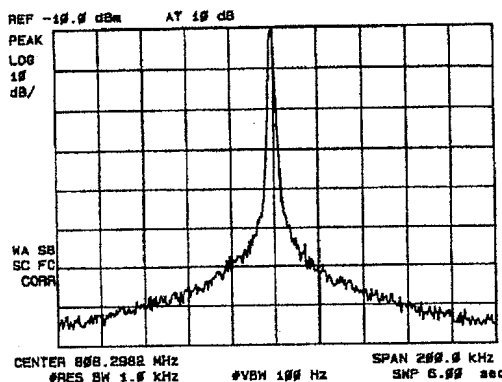


Figure 6. Measured oscillator noise. 1 kHz RBW, 20 kHz/div.

Table 1. Measured Performance

Parameter	Value
Transfer function type	2-pole coupled resonator
Center frequency	840 MHz
Nominal	840 MHz
Min/max	816 MHz / 875 MHz
Open loop frequency drift	-250 ppm / °C
3 dB bandwidth	18 MHz
Midband gain	0 dB
Passband ripple	< 2 dB
Ultimate rejection	> 50 dB
Input 1 dB compression (in-band)	-18 dBm
Input referenced noise floor	
1 MHz final IF bandwidth	-93 dBm
30 kHz final IF bandwidth	-108 dBm
1 dB compression dynamic range	
1 MHz final IF bandwidth	75 dB
30 kHz final IF bandwidth	90 dB
Input third order intercept	
In-band	-10 dBm
40 MHz offset from center	+15 dBm
80 MHz offset from center	+28 dBm
Oscillator offset from filter	62 MHz
Oscillator phase noise	
10 kHz offset	-85 dBc/Hz
100 kHz offset	-105 dBc/Hz
Supply voltage	2.7 - 3.0 V
Supply current (at 2.7 V)	
Filter only	77 mA
Filter plus oscillator	114 mA
Die area (excluding pads)	2 mm ²

designs and implements all filter and oscillator circuits needed for achieving a practical fourth-order response. The technology provides a foundation for implementing high dynamic range, fully integrated receivers in cellular and PCS applications. Future reductions in power consumption through modest improvements in inductor Q could allow the technology to work in portable as well as base/mobile systems.

6. ACKNOWLEDGMENTS

Support for this work was provided by Microtune Inc. The authors thank Hafthor Oskarsson for help in testing of the fabricated circuits.

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