

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 Fig.

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

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 $V_{dd} - V_{th}$, reducing M1, M2 parasitic capacitance and improving linearity. On-off capacitance ratio for the complete circuit is approximately 2:1 and the calculated quality factor of the capacitances is approximately 20 when on and 10 when off. This capacitor Q is found to have negligible effect on the resonator's starting Q when the relatively small fraction of total resonator capacitance contributed by the tuning circuits is taken into account.

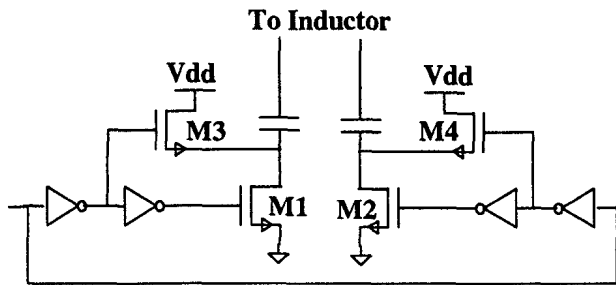


Figure 3. Frequency tuning cell.

4. MEASURED RESULTS

The filter and oscillator circuits described have been implemented in a standard $0.8 \mu\text{m}$ 1-poly, 3-metal, CMOS process. A photograph of the chip layout appears in Figure 4. The filter resonators are located in the upper half of the die while the associated oscillator is positioned at the lower right. The additional inductor in the lower left is part of a test structure for measuring the inductor performance.

The filter transfer characteristic S_{21} measured with external 4:1 impedance baluns is shown in Figure 5. Passband ripple was decreased from a starting value of 8 dB to the level shown using the chip's in-phase coupling neutralization controls. The two curves shown represent the two best neutralization settings. The residual 2 dB ripple could be reduced further with finer resolution controls. The desired 2 percent fractional bandwidth was achieved through appropriate setting of the Q controls and filter dynamic range was then measured as the ratio of the 1 dB compression output power (-18 dBm) to noise output power of -93 dBm measured in a 1 MHz resolution bandwidth, yielding 75 dB at a power dissipation of 208 mW. While this power consumption currently restricts applica-

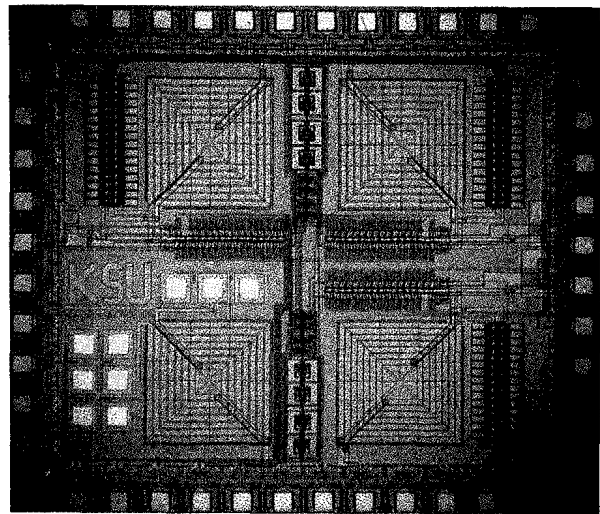


Figure 4. Die photograph.

tions to base/mobile systems, doubling inductor Q (from the current value of 3 to a modest value of 6) could allow this power consumption to be cut by four without sacrifices in dynamic range [5].

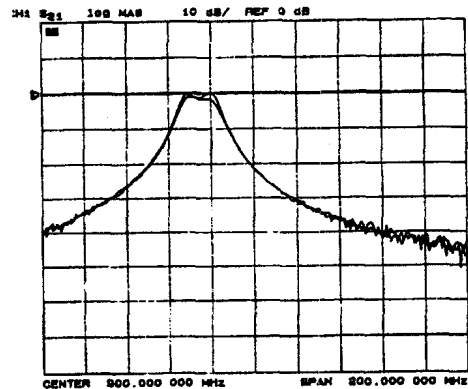


Figure 5. Measured filter response. 900 MHz center, 20 MHz/div.

The phase noise spectrum of the oscillator circuit is shown in Figure 6. Phase noise performance is -85 dBc/Hz at 10 kHz offset and -105 dBc/Hz at 100 kHz offset. The measured offset of oscillator frequency from filter passband center was 62 MHz and feedthrough from the oscillator into the filter was 20 dB below 1 dB compression in the second (output) resonator. Additional performance measurements are summarized in table 1.

5. CONCLUSIONS

The prototype design described in this paper achieves performance exceeding that of previous

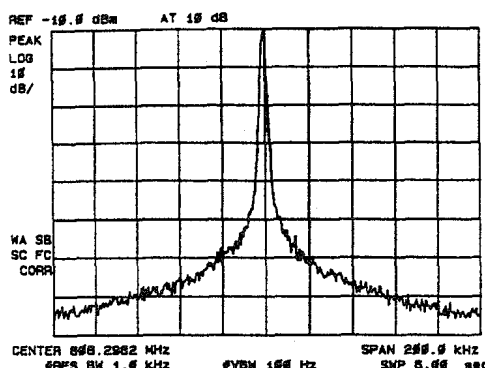


Figure 6. Measured oscillator noise. 1 kHz RBW, 20 kHz/div.

Table 1. Measured Performance

Parameter	Value
Transfer function type	2-pole coupled resonator
Center frequency	
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

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