# CMOS RF Notch Filter for GNSS Receivers

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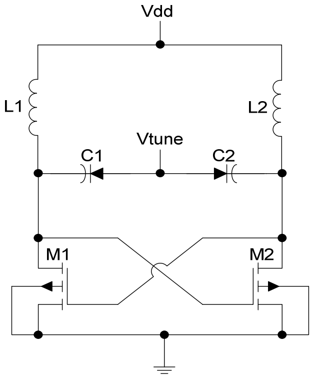
## Introduction

Interference in GPS receivers can come from either spurious harmonic mixing products from adjacent transmitters or from intentional jamming. Therefore, in most practical GPS down-conversion receivers, some sort of filtering is applied at the RF input. In practice, off-chip Surface Acoustic Wave (SAW) filters provide excellent blocking capabilities of unwanted out-of band interference. SAW filters exhibit a narrow passband response of less that 20 MHz and typically attenuate out-of band interferes and other out-of band signals by more that 25 dB. However, such off-chip filters are bulky, expensive and can be lossy, degrading the overall Noise Figure (NF) of the system.

Implementing such narrowband high quality filters on-chip would require excellent inductors. In typical RF CMOS processes, however, on-chip inductors with high quality factors Q are hard to obtain, a critical prerequisite for bandpass filters with sharp magnitude response. Commonly, a technique called Q-enhancement can be applied to improve the Q factor of the on-chip inductors by placing a negative resistance across the inductors. This way, the resistance of the inductors is cancelled at least partially and the effective Q is increased leading to a so-called Q-enhanced resonator [1]. It was shown by Wiser et al. in [2] that Q-enhancement can be successfully implemented to achieve even multi-stage bandpass filters in RF CMOS with arbitrary filter response. In this poster, a new notch filter architecture based on Q-enhanced resonators is proposed that resembles the shape of SAW filters more closely.

## RF notch filter architecture

The filter chosen for this work is based on the simple Q-enhanced technique shown below where the negative resistance of a cross-coupled transistor pair is used to partially cancel the parasitic resistance of the on-chip inductors thus enhancing the inductor Q. The filter consists of several stacked , Q-enhanced LC tanks. The filter topology has a couple of advantages over other filter types. First, the resonance frequency is actually set by two physical passive elements, namely the capacitance from a MOS varactor and the inductance of an on-chip spiral inductor. Due to the small temperature coefficient of MOS varactors, the resonance frequency of the filter can be set almost independently of temperature, which allows a very predictable tuning. In an uncompensated filter, temperature and process variations can change the center frequency of the filter by +/- 10 %. Second, with the Q of the resonant circuit completely dependent on the transconductance of the cross coupled pair, the temperature coefficient of Q is well known and a compensation circuit can be implemented. By introducing a second LC tank circuit, a double notch-type filter response can be achieved leading to a sharp cut-off characteristic. The filter has been developed in a 130nm BiCMOS technology.



$$Q = \frac{R \| (-1/g_m)}{\omega_0 L}$$

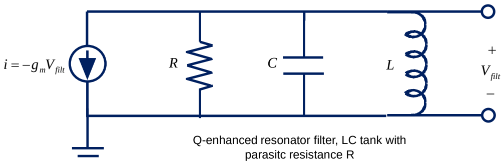
$$= \frac{R/g_m}{\omega_0 L \cdot (1/g_m - R)}$$

Cross-coupled BJT pair with LC tank

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$BW_{3dB} = \frac{\omega_0}{Q}$$

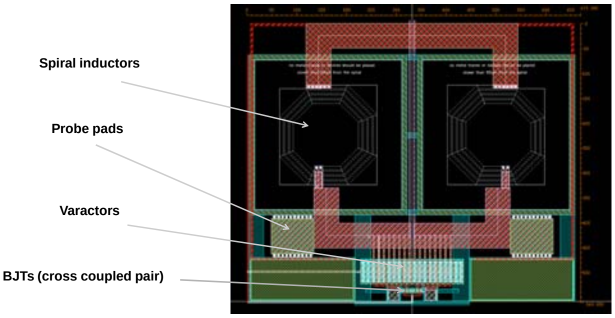
$$R_{Parallel} \approx Q^2 R_{Series}$$



Q-enhanced resonator filter, LC tank with parasitc resistance R

## RF filter layout

The layout of the RF filter is shown in the figure below. A MOSFET varactor diode allows tuning of the LC tank circuit. Care has to be taken in the design of the spiral inductors since the parasitic resistance has to be minimized to achieve a high quality factor.

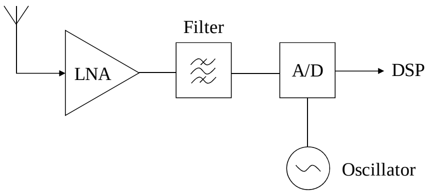


Area of one filter < 0.4mm$^2$

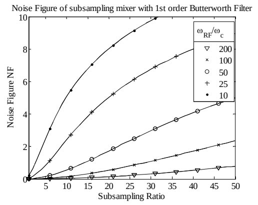
Layout of Q-enhanced resonator filter, LC tank with parasitc resistance R

## Application 1: Direct RF-sampling GNSS receiver

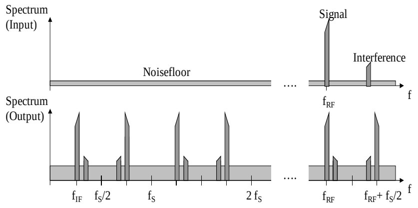
Bandpass sampling architectures, also called subsampling architectures, exhibit several advantages over super-het architectures. First, the complexity of subsampling architectures is significantly lower since no Phased-Locked-Loop (PLL) is required. A direct consequence is that downconversion from RF to IF can be achieved with significant power savings as compared to the super-het architecture. Another significant benefit of such architectures is the capability to process multiple signals at the same time. The property to simultaneously handle multiple carriers make subsampling architectures particularly suited for GNSS applications, as downconversion of multiple frequency bands is required in GNSS environments. With the advent of the new civilian GPS signal L2C and L5 in 2007 and 2009, respectively, and the onset of the new Galileo signal, a receiver that can process multiple signals simultaneously without adding complexity, is highly desired. In fact, a bandpass sampling GNSS receiver front-end made of discrete components was proposed and investigated by Akos et al. [3], [4],; a strategy for determining the optimum sampling frequency for such a GNSS receiver was found by Psiaki et al. [5]. As Psiaki showed, it is possible to downconvert the GPS frequencies L1, L2 and L5 and the Galileo signals simultaneously with a sampling frequency of 55.51, 77.33 or 99.23 MHz. It is evident that subsampling receivers, in theory, do not deliver subpar performance as compared to super-heterodyne receivers. However, a major obstacle is that such architectures require good bandpass filtering before the digitization to prevent noise and interference aliasing. The proposed RF filter can be used as a component in such architectures to reduce the Noise Figure of the system and to suppress unwanted interference.



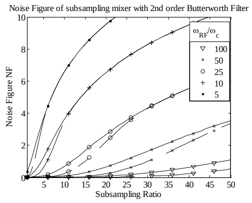
Subsampling architecture with Low-Noise Ampliifier, Q-enhanced resonator filter, A/D converter



Noise Figure (NF) of subsampling mixer with first order bandpass filter



Frequency plan of subsampling receiver

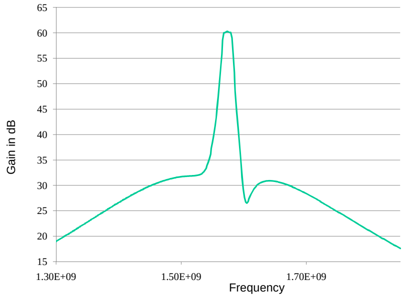


Noise Figure (NF) of subsampling mixer with second order bandpass filter

## Application 2: Replacement of off-chip SAW filter

The on-chip RF bandpass filter architecture proposed in this poster can be used to replace the off-chip SAW filter or to relax the requirements on the SAW-filter. The magnitude response of the on-chip RF bandpass filter is shown in the picture.

The bandwidth of the filter is approximately 15 - 20 MHz and the attenuation can be around 30 dB. It is possible to achieve even higher attenuation through tuning. The gain of the filter is roughly 30 dB. The noise figure of the filter can be greater than 15 dB. Therefore, it should be placed after a LNA with sufficient gain.



Magnitude response of RF bandpass filter and LNA with 30 dB gain

## Conclusion

A fully integrated BiCMOS RF filter suitable for GNSS and GPS receiver front-ends was presented. The filter can be employed in an integrated direct RF or integrated bandpass sampling architecture as well as be part of a traditional heterodyning architecture. It provides excellent interference suppression and can also be used to relax the requirements on the off-chip SAW filter.

## References

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