Low-noise tunable filter design by means of active components

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A low-noise tunable filter with high dynamic range and minimum power consumption is presented and addressed with circuit details. It is based on an active solution simulating an inductive behaviour that allows improving the filter quality factor without affecting the noise performance. The low-order bandpass filter is realised with minimum number of components and it is suitable to be integrated in integrated circuit or used in hybrid transceiver and modern reconfigurable radio systems. A prototype board with discrete components has been fabricated and tested with good results.

Introduction: The increased interest in RF communications has resulted in a considerable effort to provide components and complete radio systems on integrated circuits (ICs), especially in portable wireless systems that are expected to play a major role in providing access to future communications networks and information services. For instance, the digital radio approach is currently one of the most attractive [1]. In this architecture, analogue blocks are used to perform filtering and amplification before the analogue/digital conversion, being the following signal processing performed digitally at baseband. In this way, most of the benefits of the fully digital radio are preserved, while the principal drawback is that the use of high-performance analogue components potentially limits both the flexibility and energy efficiency of this design [2–4]. Generally, in order to minimise these limitations, the analogue front-end is designed to be as simple as possible and analogue components are used to perform only two essential functions: out-of-band interference filtering and low-noise signal amplification.

Even if most RF building blocks have been successfully implemented in ICs processes, nevertheless filters remain critical components and this is due both to the large occupied area of the inductors and to the degradation of performance in terms of noise and selectivity. Filters using active inductors [5–7] have received considerable interest to provide useful alternatives of their passive counterparts in many applications, but they are difficult to implement in commercial applications and often they suffer of low-power handling, potential instability phenomena or high-noise figure.

In this Letter, the design and characterisation of an innovative active solution to implement a low-noise bandpass filter is presented and based on a low-noise active inductor. The filter, designed as a discrete element board in a low-order configuration, is tunable in the ultra-high-frequency band and shows a centre frequency ranging from 810 to 850 MHz with Q in excess of 70 and an insertion loss of 1 dB. The measured 1 dB compression point is at −2 dBm with a minimum noise figure of 2.1 dB at 830 MHz, for a resulting 80 dB dynamic range.

Circuit design: The basic building block of the proposed filter is the low-noise active inductor, whose general scheme is shown in Fig. 1. This simplified model includes an inverting gain stage and a properly dimensioned compensation network in feedback connection. Analysing the phase relation between the input voltage and current, an inductive behaviour in a small bandwidth can be obtained, if the circuit is accurately defined. An exhaustive mathematical investigation of a generic active inductor have already been provided in [8] in the case of non-low-noise circuits and can be here reconsidered since the analysis is straightforward. Different solutions can be adopted both for the amplification stage and the feedback network that replaces the non-inverting gain stage in a classical gyrator-C capacitance. The proposed active inductor appears particularly suitable to be used in bandpass filtering circuits since it presents a series resistance value that is negligible only in the band of interest and where it shows an inductive behaviour, while it has shown greater losses elsewhere, enhancing the off-band rejection [9, 10]. Therefore, an equivalent inductive behaviour with a very high-quality factor can be obtained in respect of a traditional passive solution.

The main novelty introduced in this Letter concerns the possibility to use low-noise solutions in the design of the proposed active inductor that allows obtaining bandpass filters of reduced noise figure, improving dynamics and without affecting power handling and quality factor. The proposed design, taking advantages from the already developed theory in designing low-noise systems and coupling it with the proposed inductor-replacement solution, minimises the filter noise figure by reducing the added noise of the active inductor with a design of its amplification stage oriented towards a low-noise amplifier [11].

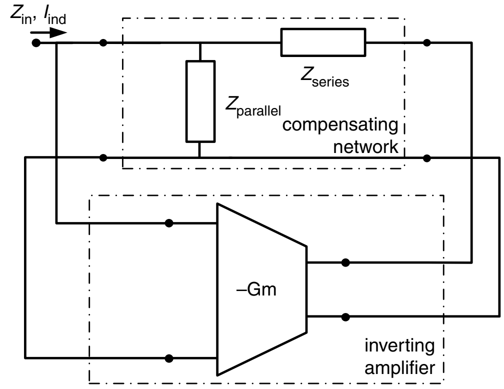

Fig. 1 *Simplified block scheme of active inductor*

Different solutions have been presented in the literature for noise cancellation and many design strategies are currently used for low-noise amplifiers, depending on the project constraints. In this Letter, the inductive degeneration common source topology with capacitive feedback has been chosen, since it combines very low-power consumption, which is mandatory in any modern communication system, with a non-neglecting gain. This solution has been applied for the implementation of the '-Gm' block depicted in Fig. 1 and shows a good compromise between power consumption, compression point, noise figure and signal gain. The complete schematic is shown in the solid line rectangle of Fig. 2. It is implemented with the bipolar transistor BFR92A, provided by NXP semiconductors in emitter-degenerated configuration and biased through the resistances R_b and R_c. The power dissipation is about 6 mW with a 3 V power supply voltage. The two C_b are DC block capacitances, whereas C_1 is the feedback component.

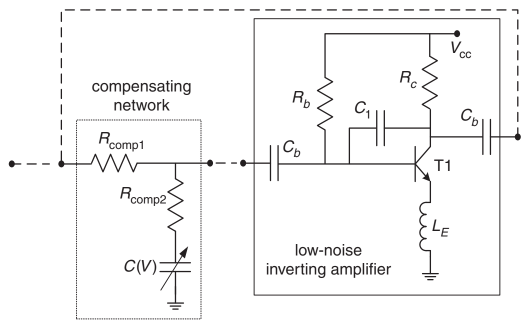

Fig. 2 *Electrical scheme of low-noise active inductor*

The LNA has been first separately designed in open-loop configuration and then optimised in the closed-loop configuration together with the delay network, see Fig. 2. In the dotted line area, the electrical scheme of the compensating network is also presented and it is composed of the resistances R_{comp1} and R_{comp2} coupled with a tuning diode $C(V)$, that is, the BBY58 provided by Infineon Technologies. The varactor allows the tunability from 810 to 850 MHz of the low-noise active inductor, without affecting its series resistance at the operational frequency that is negligible and slightly varying the noise performances. In Fig. 3, the complex simulated input impedance of the low-noise active inductor is shown for different tuning states.

From Fig. 3, it is important to note that the proposed circuit shows an inductive behaviour in a wide-frequency range, whereas it acts as an ideal inductor only in a small bandwidth that is the same considered for the filter passband. Cleary, the quality factor of this equivalent component is considerable, while the associated noise contribution is limited due to the design strategy. In addition, a correct choice of the active device in the design of the low-noise active inductor, together with a suitable choice of the bias point, is mandatory to ensure the further requirements of linearity.

The active solution already discussed has been used in the design of a low-order bandpass filter, whose schematic is presented in Fig. 4*a*.

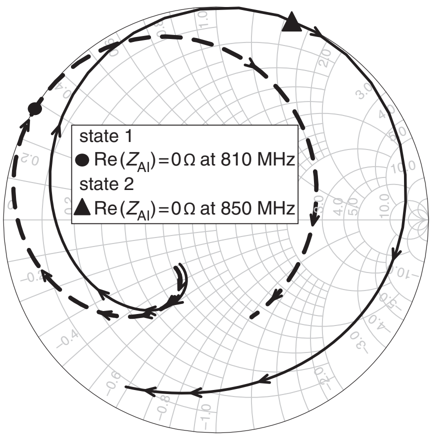

Fig. 3 *Input impedance of proposed low-noise active inductor for two considered tuning states*

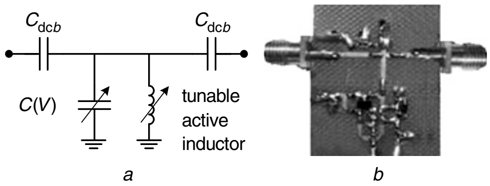

Fig. 4 *Low-noise active inductor-based bandpass filter*

a Schematic of bandpass filter
b Prototype board

There are two decoupling capacitances C_{dcb} and a shunt variable capacitance $C(V)$. This additional tuning element is necessary in order to preserve the shape factor of the tunable filter in the full bandwidth, since when acting on the control voltage of the equivalent inductor, obviously, both the 3 dB bandwidth and its insertion loss changes; therefore, an additional opposing tuning diode (the same BBY58 from Infineon) allows recovering the overall performance. Fig. 4*b* shows the fabricated prototype board implemented over a Taconic TLX8 substrate.

Fig. 5 shows the measured filters $S11$ and $S21$ parameters at the end of the useful bandwidth. The achieved 3 dB bandwidth varies approximately from 11 to 13 MHz with an insertion loss of ∼1 dB, whereas the measured filter noise figure, for the best performance achieved at 830 MHz, is 2.1 dB. In this case, the measured $P_{1\ dB}$ is −2 dBm that allows obtaining a dynamic range of ∼80 dB.

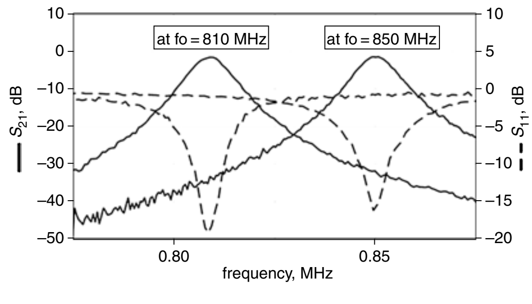

Fig. 5 *Measured S-parameter response for two filter tuning states*

Table 1: Filter parameters summary and comparison between simulated and measured results at 830 MHz centre frequency

Filter parameter at 830 MHz	Simulated	Measured
IL	0.9 dB	1 dB
$P_{1\ dB}$	0 dBm	−2 dBm
$S11$	−14 dB	−15 dB
NF	1.8 dB	2.1 dB
3 dB bandwidth	11 MHz	12 MHz

In the remaining part of the tunable frequency range there is a degradation in the filter noise figure (NF) up to 2.5 dB. In Table 1, a summary and comparison between simulated and measured results is given at the middle of the tuning band. These results make the proposed architecture suitable to be used in many RFs and microwave receivers.

Conclusions: We have presented a low-noise bandpass filter design based on a tunable low-noise active inductor. The proposed active filter, implemented with discrete components, shows good noise property and tunability characteristics, beyond an 80 dB dynamic range. Measurements have confirmed its suitability to be used, both as discrete and IC solution, in many RF/microwave radio practical applications, whereas agile filters with low-power consumption and low noise are required.

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