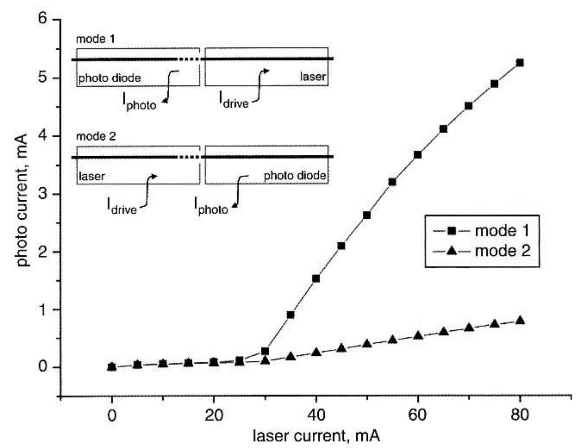

Fig. 4 *Photocurrent for two different modes of operation*

Responsivity of detector can be increased sixfold by placing integrated reflector inside detector

Conclusion: A single growth integrated reflector based on a sequence of slots etched in a ridge waveguide is introduced. It allows the monolithic integration of a detector with a laser. Different modes of operation are possible. The concept could be part of a technology platform for low-cost photonic integrated circuits.

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Miniature high selectivity filters using grounded spiral resonators

B. Jokanovic, V. Crnojevic-Bengin and O. Boric-Lubecke

A novel miniature high selectivity filter designed using a metamaterial resonator based on four grounded spirals (ForeS) is presented. This enables extreme size reduction together with high out-of-band rejection and low insertion loss. A fabricated third-order filter has overall dimensions of $\lambda_g/4$ by $\lambda_g/15$, a 3 dB bandwidth of 3.7% at 1.63 GHz, insertion loss of −3 dB, attenuation greater than 75 dB in the lower stopband and greater than 40 dB up to 2.6 times the centre frequency.

Introduction: The development of super compact bandpass filters with high selectivity, compatible with PCB and MMIC technology, is of great importance for the miniaturisation and integration of wireless communication front-ends. High selectivity can be achieved by increasing the number of resonators at the expense of higher insertion loss and larger size, or by using additional cross-coupling between nonadjacent resonators to realise quasi-elliptic characteristics [1, 2].

This Letter shows that super-compact high selectivity filters can be designed using only three resonators and without cross-coupling, thanks to the novel ForeS resonator, the overall size of which is only $\lambda_g/16$ by $\lambda_g/16$. This resonator exhibits considerably greater Q-factor in respect to the grounded S-spiral resonator [3], which is an important feature in the design of high selectivity filters. The proposed filter is designed as an IF filter for microwave links, where the most important requirements are small size and high out-of-band attenuation, especially at lower frequencies.

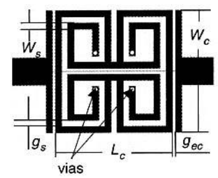

Fig. 1 *Layout of ForeS-noX resonator with relevant dimensions*

$L_c = 9$ mm, $W_c = 9$ mm, $W_s = 0.4$ mm, $g_s = 0.1$ mm, $g_{ec} = 0.1$ mm

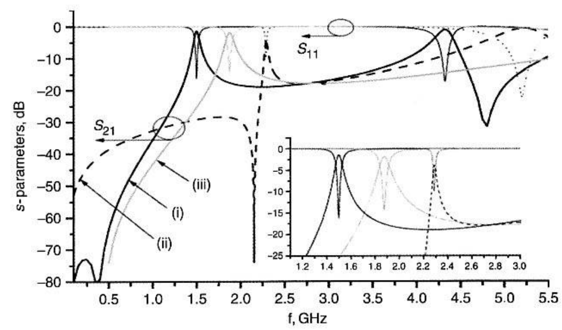

Fig. 2 *Simulated s-parameters for ForeS-noX resonator, OS-ForeS-noX and basic ForeS*

(i) ForeS-noX
(ii) OS-ForeS-noX
(iii) basic ForeS

ForeS resonators: These resonators consist of four grounded spirals end-coupled to the microstrip line. Such structures exhibit low insertion loss and large design flexibility: small changes of their inner dimensions result in a resonant frequency tuning range of 67%. At the same time, the second harmonic is positioned at more than four times the first resonant frequency [4].

Fig. 1 shows the layout of the novel ForeS resonator with the removed central cross (noX) denoted ForeS-noX. Owing to its specific shape, ForeS-noX exhibits lower resonant frequency (1.498 GHz) and lower insertion loss (−1.46 dB) than the basic ForeS (1.876 GHz and −1.86 dB, respectively). At the same time, radiation losses are reduced and Q-factor is increased. Reducing the spiral line width from 0.4 to 0.2 mm results in a ForeS-noX size of only $\lambda_g/27$ by $\lambda_g/27$, with an extremely high unloaded Q-factor of 113.77, while insertion loss increases only for approximately 1 dB. Figs. 2 and 3 compare simulated s-parameters and losses for ForeS-noX, ForeS-noX with open spirals (OS-ForeS-noX) and the basic ForeS with the same dimensions. All resonators are designed on Rogers 5880 substrate with $\varepsilon_r = 2.17$, $tg\delta = 0.0009$ and $h = 1.575$ mm. ForeS-noX exhibits 20% lower resonant frequency than the basic ForeS, at the cost of the second harmonic being shifted from 4.1 to 2.9 times the first-resonance. OS-ForeS-noX is included for comparison to show the effect of grounding the spirals: adding vias lowers the resonant frequency from 2.29 to 1.498 GHz and considerably reduces the insertion loss (from −3.89 to −1.46 dB), owing to reduced radiation losses.

Filter design: Two bandpass filters of the third order have been designed by using novel ForeS-noX resonators with spiral line widths $W_S = 0.4$ mm and $W_S = 0.3$ mm, respectively. To obtain the maximally flat transmission characteristics, the distances between adjacent resonators have been optimised, as well as the lengths of the input spirals. The optimised distances are $d = 2.2$ mm for the filter with spiral line width $W_S = 0.3$ mm, and $d = 1.9$ mm in the case $W_S = 0.4$ mm. The spiral length has been shortened by unwinding the spiral for $N = 2.25$ turns from the centre. Simulated characteristics are compared in Table 1. It can be seen that using a wider spiral line results in increased passband and reduced Q-factor, while the second spurious response appears at about three times the first resonant frequency. Both filters exhibit a very steep roll-off from passband to stopband frequencies, especially at the lower edge of the passband.

Table 1: Simulated and measured filter characteristics

	$W_S = 0.3$ mm simulated	$W_S = 0.4$ mm simulated	$W_S = 0.4$ mm measured
f_{R1}, GHz	1.308	1.638	1.628
s^1_{21}, dB	−2.88	−2.66	−3
s^1_{11}, dB	−19.3	−22.5	−24.3
B_{1dB}, MHz	26	35.5	39.5
B_{1dB}, %	1.81	2.17	2.4
B_{3dB}, MHz	37.4	53.9	60
B_{3dB}, %	2.86	3.29	3.68
Q_L	34.97	30.39	27.13
Q_0	72.14	66.35	53.4

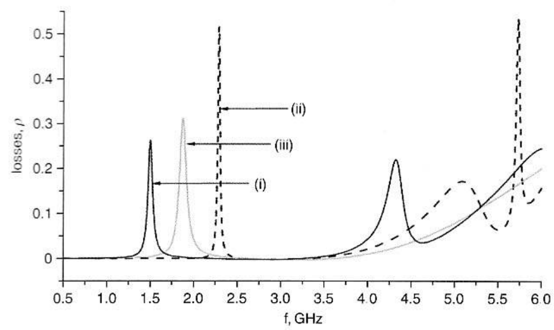

Fig. 3 *Losses $\rho = 1 - |s_{11}|^2 - |s_{12}|^2$ for ForeS-noX, OS-ForeS-noX and basic ForeS*

(i) ForeS-noX
(ii) OS-ForeS-noX
(iii) basic ForeS

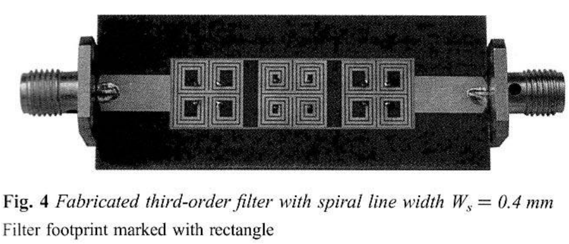

Fig. 4 *Fabricated third-order filter with spiral line width $W_s = 0.4$ mm*

Filter footprint marked with rectangle

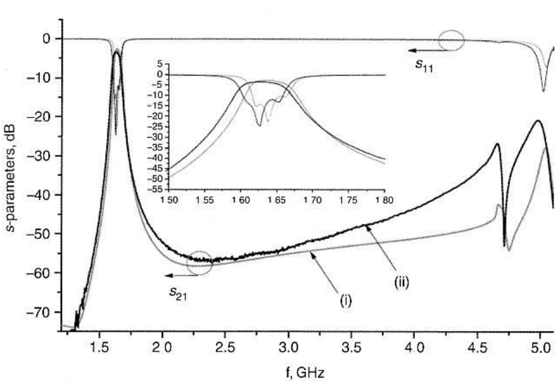

Fig. 5 *Simulated and measured responses of fabricated filter*

(i) simulated
(ii) measured

The fabricated filter with spiral line width $W_S = 0.4$ mm is shown in Fig. 4. The rectangle denotes the area occupied by the resonators with overall dimensions of 31.8 × 9.0 mm, i.e. $\lambda_g/4$ by $\lambda_g/15$ where λ_g is the guided wavelength. To the best of our knowledge this is the smallest filter of this kind so far reported in the literature. The measured filter response is shown in Fig. 5 and summarised in Table 1. Very good agreement with simulations is observed: the centre frequency of the filter is shifted only for 0.06%. The proposed filter exhibits very good out of-band characteristics: attenuation is greater than 75 dB in the lower stopband and greater than 40 dB in the upper stopband up to 4.2 GHz. The second harmonic, positioned at 2.86/3.06 times the centre frequency is suppressed for more than 26 dB/20 dB. Owing to the specific ForeS-noX design, the centre frequency of the filter can be easily tuned in the range 1–2 GHz without infuencing the overall filter dimensions, i.e. using the resonators with a combination of the spirals with different line widths [5].

Conclusion: The novel ForeS-noX resonator allows the design of extremely compact high selectivity bandpass filters. Its low insertion loss, increased Q-factor and reduced radiation losses arise from the application of grounded spirals in a specific geometric arrangement. To the best of our knowledge, the presented filter is the smallest design published so far, while its characteristics are comparable with other state-of-the-art filters of this type. Simple design and fabrication, very good in-band and out-of-band performances, robustness in serial production, even when a very simple photolithography is used, make this filter a promising candidate for wireless communication systems.

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Travelling-wave whispering gallery resonance sensor in millimetre-wave range

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A high sensitivity sensor with a simple structure is presented for analysis of (bio)chemicals in liquid or solution form. The proposed technique is based on the travelling-wave whispering gallery resonance perturbation method in the millimetre-wave range. The resonance modes are launched inside a dielectric disk through coupling into a dielectric image waveguide. The top surface of the disk is used as the sensing area where the resonance mode interacts with the sample. Theoretical analysis and experimental results for the proposed sensor are discussed.