7.6-8.6GHZ TUNABLE ACTIVE MMIC FILTER FOR AGILE ON-CHIP X-BAND RADAR RECEIVER FRONT-ENDS

Robert Malmqvist, Carl Samuelsson, Tony Nilsson, Isabel Ferrer, and Andreas Gustafsson

Swedish Defence Research Agency, Box 1165, SE-581 11 Linköping, Sweden
rma@foi.se, carsam@foi.se, tonnil@foi.se, isabel@foi.se and andreasg@foi.se

SUMMARY

In this paper, we evaluate a new design of a previously presented (second order) tunable active X-band MMIC filter. By using a two-stage low noise amplifier in each filter section a higher filter gain and selectivity as well as a lower filter noise figure can be achieved at the expense of a smaller filter tuning range. The filter is tunable to eight different center frequencies between 7.6-8.6GHz. Typical measured data for all eight tuning states show a maximum gain that varies between 13-26dB, a 4-5dB noise figure and a spurious-free dynamic range of 58-67dB. The presented filter could potentially be utilized as an important building block to realize agile compact on-chip receiver front-ends for future adaptive X-band radar array antennas, for example.

INTRODUCTION

A low vulnerability to jamming signals due to electronic warfare or electromagnetic interference, for example, is of prime importance in modern radar systems. One way to achieve this is to use a frequency hopping radar where the transmitter and the receiver jump in a pseudo-random like way between different selected frequencies. To further reduce the vulnerability to jamming signals adaptive methods and digital beamforming can be adopted [1]. In future adaptive array antennas the number of transmit/receive (T/R) modules required is anticipated to be as high as several hundreds or more. To be able to realize such multi-channel radar systems in a cost-effective way size and cost of each T/R-module should be minimized. As a consequence of this, increased interest has been focused on the possibility of using tunable narrow-band active monolithic microwave integrated circuit (MMIC) filters to reduce the vulnerable bandwidth of frequency hopping radar receivers [2]. Compared with using a fixed frequency bandpass filter, a tunable filter may reduce the number of down-converting stages required in an agile receiver by allowing a greater down-conversion step to be made. Rejection of interfering signals that, for example, may occur at the receiver image frequency ($f_{image}=f_{RF}\pm 2f_{IF}$ where f_{RF} and f_{IF} denote the radar frequency and the intermediate frequency of the receiver, respectively) should be high enough to minimize the effect of jamming. In this paper, we focus on active filters that may be used in receiver front-ends of adaptive X-band (8-12GHz) antennas. Typical requirements for such filters can be found in [3] (see Table 1). Below, we evaluate a re-design of a tunable X-band MMIC filter originally presented in [4]. Compared with results obtained in [4], an improved performance in terms of higher gain and selectivity as well as lower noise figure is achieved.

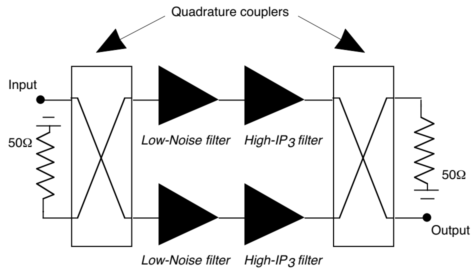
Center frequency gain (G)	> 10dB
Noise figure (NF)	< 5 dB
Input third order intercept point (IIP_3)	≥ 0 dBm
Spurious-free dynamic range (SFDR)	≥ 113 $dB/Hz^{2/3}$ (≥ 64dB for a noise bandwidth B= 20MHz)

Table 1: Typical requirements for active filters if used in receivers of adaptive X-band radar antennas.

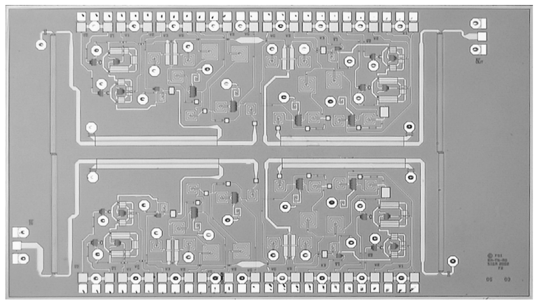
A 7.6-8.6GHZ TUNABLE ACTIVE X-BAND MMIC FILTER

Recursive active MMIC filters have been shown to be promising for narrow-band and low-noise applications since high-Q filters of this type can be designed with high gain in combination with a noise figure approaching that of the low-noise amplifier (LNA) used in the filters [5]. A frequency tunable recursive X-band MMIC filter with close to adequate noise and large signal performance

(NF=6dB and IIP_3≈0dBm) and a tuning range in the order of 20% (7.9-9.7GHz) was presented in [4]. Measured values of maximum filter gain and out-of-band rejection were, however, found to be 7-9dB and 3-5dB lower than expected, respectively. In this paper, we investigate if it is possible to improve performance by re-designing the active filter described in [4]. The filter is based on the topology depicted in Fig. 1a where two (second order) filters are placed between two quadrature couplers in a classic balanced configuration. This topology enables a relatively good filter input and output impedance matching to be achieved without significantly degrading the over-all filter noise figure. Each second order filter consists of two cascaded recursive active filters where the first filter is designed with a low value of NF (*Low-Noise filter*) and the second filter is designed with a high value of IIP_3 (*High-IP$_3$ filter*). Frequency tuning is implemented using the concept of self-switched (three-bit) time shifters that enables (eight) discrete center frequency (f_c) tuning states (i.e. 000-111) [4]. It was found in [4] that the large discrepancies between measured and simulated values of filter gain and out-of-band rejection could to a large extent be explained by a lower amplifier gain (compared with simulations) for the single-stage LNA used in each filter section of the fabricated filter in [4]. As a consequence of this, we propose that a cascaded two-stage LNA could be used in each filter section since such an LNA more easily can provide the gain values that are needed to achieve a higher filter gain and selectivity. Figure 1b shows a photo of the re-designed filter where two-stage LNA's are used in each filter section. The filter is fabricated in a 0.2μm GaAs PHEMT MMIC process from *OMMIC*.



a)

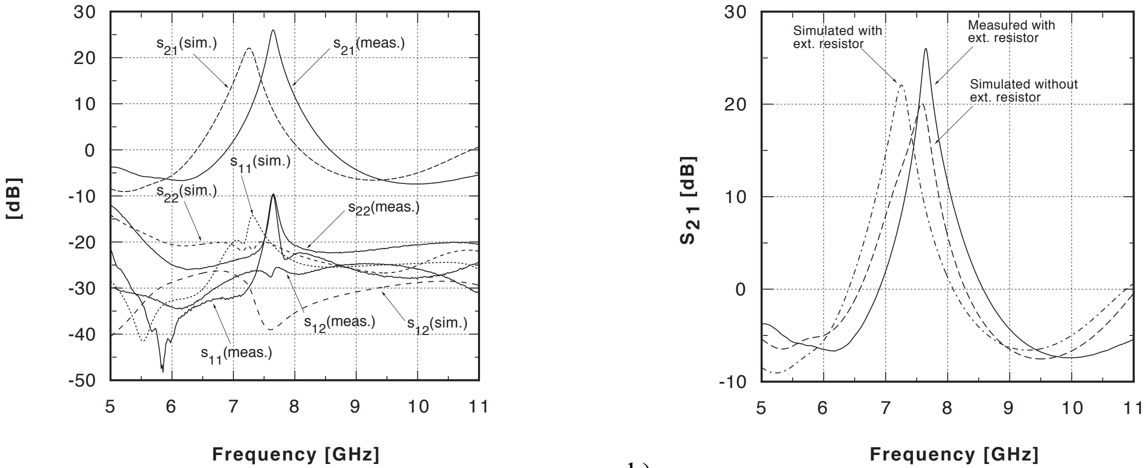


b)

Fig. 1. A balanced active filter a) schematic topology b) chip photo (circuit area: 3.4x5.5mm^2).

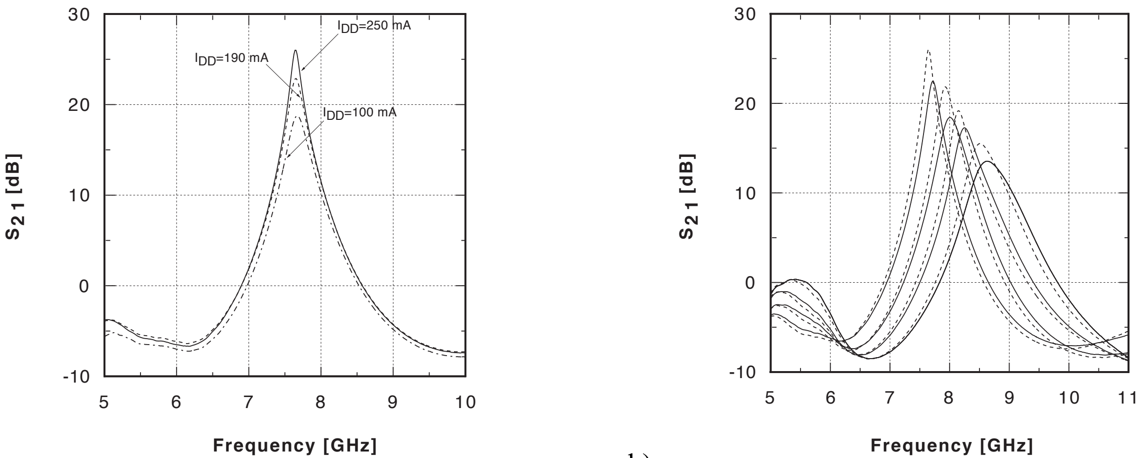
RESULTS

Next, experimental data of the re-designed filter is presented together with simulated results. In an attempt to compensate for a layout error (a missing gate bias resistor in each of the two *High-IP3 filter* sections) two off-chip resistors have been bonded to the filter chip. Figure 2a shows measured and simulated s-parameters when the filter is tuned to achieve maximum transmission gain (s_{21}) at the lowest of the eight possible center frequency tuning states (i.e. state 000). The total DC current I_{DD} drawn from a drain bias of 3V equals in this case 250mA and f_c.= 7.64GHz. According to simulations, however, maximum filter gain is obtained when I_{DD}=68mA. A comparison between measured and simulated values of s_{21} (both with and without using external resistors, respectively) is shown in Fig. 2b. As can be seen, the discrepancy between the measured and the simulated value of f_c is larger when external resistors are accounted for during simulation (compared with when they are not accounted for). The simulated filter gain is, on the other hand, somewhat higher in this case. Figure 3a shows measured s_{21} at state 000 for different values of I_{DD} (100mA, 190mA and 250mA, respectively). Measured values of s_{21} equal in this case 18.8dB, 22.9dB and 26.0dB, respectively. A relative 3dB bandwidth of 1.7% (corresponding to a filter Q-factor of close to 60) is obtained when I_{DD}=250mA. Measured s_{21} at all eight possible tuning states (i.e. 000-111) when I_{DD}=250mA is shown in Fig. 3b. The filter is tunable between 7.64-8.63GHz corresponding to a relative tuning range of 13%. Measured and simulated results at all eight tuning states (i.e. 000-111) are summarized in Table 2. Measured values of maximum filter gain and out-of-band rejection (720MHz and 2GHz below f_c) are found to be some dB's above what is expected according to simulations, respectively. For all eight tuning states, measured values of NF and IIP_3 are typically 1dB higher, respectively, than corresponding simulated results. Compared with results reported in [4], up to an order of magnitude higher gain and selectivity are obtained, respectively. Noise figure is in the same way improved by up to 1.5dB. The relative center frequency tuning range is somewhat lower for the filter evaluated in this paper (13%, compared with 23% for the filter in [4]). To achieve a larger tuning range the individual bits of the three-bit time shifter used in each filter section could be re-designed so that each bit presents a larger relative time shift. In summary, a comparison with the typical requirements given in Table I implies the over-all filter noise and large signal performance achieved is close to what could be considered adequate for the receivers of future adaptive X-band radar antennas.



a) b)

Fig. 2. Measured and simulated small signal data at state 000 a) s-parameters b) transmission gain s_{21}.



a) b)

Fig. 3. Measured s_{21} a) at state 000 for different values of I_{DD} b) at all eight center frequency tuning states (i.e. 000-111) when I_{DD}=250mA.

Filter results	**Out-of-band rejection [dB]** (f_c-2f_{IF})	**Gain [dB]** (f_c)	**NF [dB]** (f_c)	**IIP3 [dBm]** (f_c)	**SFDR* [dB]** (f_c) *B=20MHz
Measured	12-25 (f_c-720MHz) 22-32 (f_c-2GHz)	13-26	4.4-5.2	-8 to +5	58-67
Simulated† † (with ext. res.)	9-20 (f_c-720MHz) 21-31 (f_c-2GHz)	13-22	3.5-4.2	-9 to +3	58-67

Table 2: Summary of results.

USING THE TUNABLE ACTIVE FILTER IN AGILE ON-CHIP X-BAND FRONT-ENDS

If a tunable active MMIC filter is combined with a MMIC image rejection mixer, an on-chip receiver front-end that combines the attractive feature of small size at low cost with a good ability to reject unwanted signals over the agile bandwidth may potentially be realized. In order to minimize the effect of jammimg, image rejection in a radar receiver should be in the same order as the required *SFDR* value (i.e. around 60dB when B=20MHz) [4]. An X-band MMIC image rejection mixer that may help to ease the requirement on filter out-of-band rejection has recently been presented (see [2] and [6]). This mixer has been designed in two versions with an IF of 1GHz and 360MHz respectively. Measured results for these two mixer circuits show that it is possible to obtain 40-50dB of image rejection when using these mixers. Thus, if a mixer of that kind is combined with a tunable bandpass filter, the requirement on filter out-of-band rejection at f_{image} can be reduced to 10-20dB. The tunable filter evaluated in this paper can achieve an out-of-band rejection of 22-32dB at 2GHz below f_c. This corresponds to an equally high image rejection when an IF of 1GHz is assumed. It means that the filter out-of-band rejection achieved in this case could be considered high enough for the application in mind. In fact, we have implemented a single-chip X-band front-end by cascading the re-designed active filter and a re-designed version of the 1GHz-IF mixer described in [6]. According to measured front-end results (see [7]) it can achieve at least 50-85dB of image rejection and up to 13dB of conversion gain together with a 6.4dB minimum value of NF and 60-65dB of SFDR over the 7.6-8.6GHz agile bandwidth, respectively. In the receivers of a digital beamforming antenna AD-converters with 10-14 bits are normally required [2]. The relatively high IF of 1GHz for the front-end in [7] implies a second down-converting stage will be needed, since an IF of that order is too high for today's standard ADC's when such a high number of bits are required. It is believed that an IF in the order of a couple of hundreds of MHz or more could in a near future (or may already) be considered low enough for 10-14 bits bandpass-sampling ADC's. The maximum out-of-band rejection that can be achieved for the filter evaluated in this paper when we assume an IF of 360MHz varies between 12-25dB over the agile bandwidth (see Table II). This amount of filter image rejection could be sufficiently high if we assume the filter is combined with the 360MHz-IF mixer presented in [2]. The filter could thus in such case potentially also be utilized to realize an on-chip *single-stage* low-noise down-converter with close to 60dB of image rejection and spurious-free dynamic range, respectively.

CONCLUSION

A new design of a previously presented tunable active X-band MMIC filter has been evaluated. Compared with the original design, this filter obtains up to an order of magnitude higher gain and selectivity as well as up to 1.5dB lower noise figure at the expense of a smaller tuning range. The filter could be utilized to realize agile on-chip X-band low-noise front-ends with 60dB of image rejection and spurious-free dynamic range, respectively. The use of such front-ends may potentially result in a significant reduction of receiver size and complexity in adaptive X-band antennas, for example.

ACKNOWLEDGEMENTS

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