RF MEMS BASED IMPEDANCE MATCHING NETWORKS FOR TUNABLE MULTI-BAND MICROWAVE LOW NOISE AMPLIFIERS

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Abstract–*In this paper, we present different types of reconfigurable RF MEMS based matching networks intended for frequency-agile (multi-band) LNAs. Measured results of 2-bits matching networks show a centre frequency tuning range of 2-3 GHz (10-13%) around 20 GHz and 1.5-2.0 dB of minimum losses. Simulated tunable LNA results based on measured data of the RF MEMS matching networks show the possibilities of achieving similar high gain, good matching and low NF over the whole tuning range. The results demonstrate the potential of using RF MEMS switches for the realization of tunable LNAs at microwave and millimetre-wave frequencies.*

1. INTRODUCTION

Today, there is an increasing interest in making RF systems self-adjusting or "cognitive" [1]. Such a unique ability is expected to lead to very efficient RF systems with reduced size, weight, power and cost. Frequency-agile front-end architectures realised using RF Micro Electro Mechanical Systems (MEMS) is an enabling technology proposed to achieve those highly attractive benefits [1-2]. Reconfigurable MEMS matching networks could be utilized to implement tunable (multi-band) RF components such as LNAs, PAs and filters etc [3-6] that can be commercially very attractive since such devices could be useful for different frequency bands and applications. For example, today's wireless RF systems for point-to-point communication can operate at many different frequencies (sub-bands) within the 5 to 40 GHz range. A use of multi-band components that can be tuned over a wider frequency range could then be a way to reduce the over-all component count, system complexity and cost. To the best of our knowledge, the tunable LNAs using MEMS matching networks that have been reported so far aim at frequencies up to 10 GHz (see e.g. [5-6]). In this paper, we will investigate possibilities of implementing such LNAs also for frequencies and applications at 20 GHz and above.

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2. TUNABLE LNA ARCHITECTURE

Figure 1 shows a proposed tunable LNA architecture based on reconfigurable input and output impedance matching networks realized using variable switched RF MEMS capacitors. Two-bits matching networks are implemented using two shunt capacitive MEMS switches in parallel with fixed value Metal-Insulator-Metal (MIM) capacitors [6]. The impedance matching and LNA centre frequency tuning range (Δf_c) is controlled by the MEMS capacitance ratio (i.e. C_{up}/C_{down}).

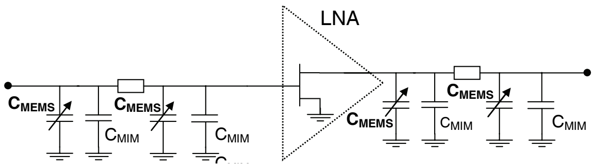


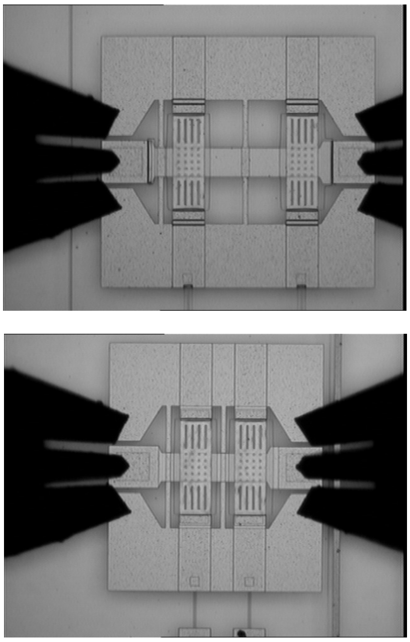
Fig. 1. Tunable LNA architecture using RF MEMS based reconfigurable impedance matching networks.

3. RF MEMS MATCHING NETWORKS FOR TUNABLE LNAs

Different types of reconfigurable impedance matching networks have been implemented on fused silica (quartz) substrates using a capacitive RF MEMS switch process at VTT. Below, we will present the experimental results of single-ended and differential types of RF MEMS matching networks intended for tunable LNAs.

3.1. Single-Ended Matching Networks for a Tunable GaAs LNA

Figure 2 a and b show two single-ended matching networks (denoted here as type I and type II, respectively) that have been fabricated using the VTT RF MEMS process. The 2-bits MEMS matching networks (that are intended for a tunable multi-band GaAs MMIC LNA) have been implemented as co-planar wave guide transmission lines with a variable capacitive loading obtained using the RF MEMS switches.

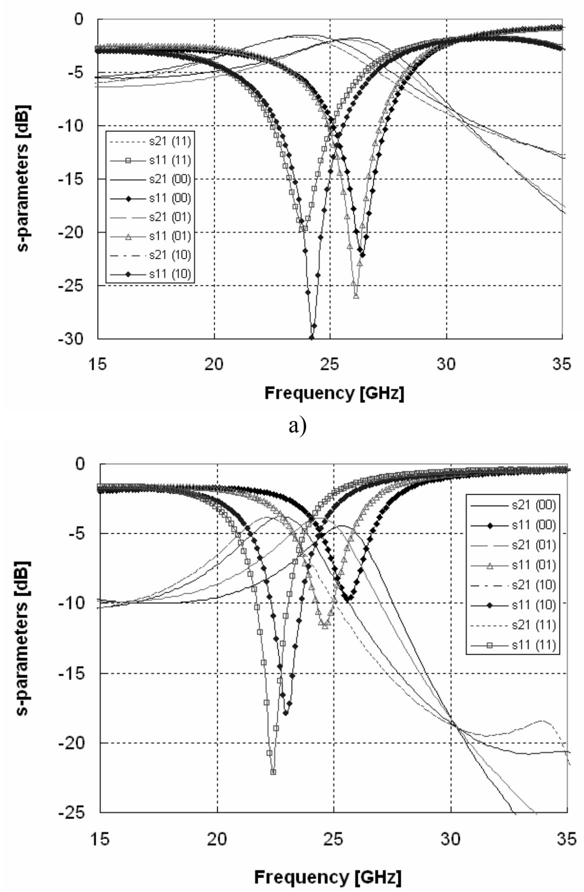


a) b)

Fig. 2. Chip photos of two 2-bits RF MEMS matching networks: a) type I and b) type II (area is 1mm^2).

Measured s-parameters of two 2-bits RF MEMS matching networks (type I and II) are shown in Fig. 3 a and b, respectively. Figure 3 a shows measured s_{21} (transmission loss) and s_{11} (input return loss) of a type I matching network at different switch combinations: 00 (both switches up), 11 (both switches down) and 01/10 (one switch up and one switch down). An actuation voltage of 50 V was used in this case in order to actuate the RF MEMS switches into the down-state position. As can be seen, applying this voltage to the MEMS switches made it possible to tune s_{11} over a certain bandwidth (f_{res}=23.9-26.4 GHz). The resonance frequency tuning range (Δf_{res}) achieved was 2.5 GHz (10%) and with $s_{11} \leq$ -15 dB within four different (1 GHz wide) frequency bands (from 23.3-24.4 GHz, 23.4-25.0 GHz, 25.5-26.6 GHz and 25.8-26.9 GHz, respectively). The measured minimum transmission losses within these four sub-bands are between 1.5-2.0 dB.

Figure 3 b shows the measured results obtained for a type II RF MEMS matching network. This particular design was made using a much shorter transmission line in between the two MEMS switches. The tuning range achieved in this case was found to be slightly larger 22.4-25.6 GHz (3.2 GHz or 13%) but on the same time the measured transmission losses were also higher (minimum s_{21} value around -4 dB).

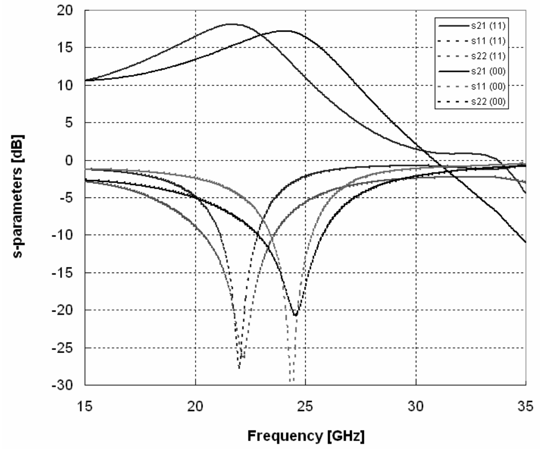


a)

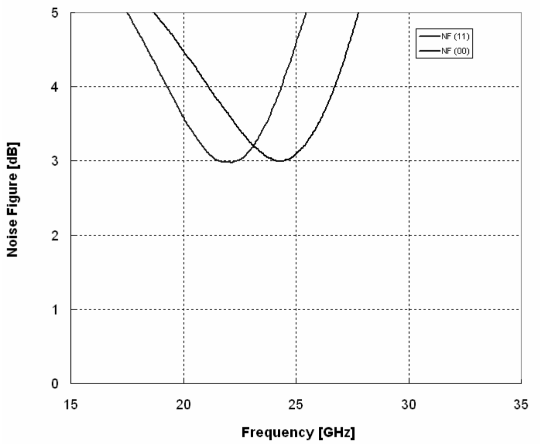
b)

Fig. 3. Measured s_{21} and s_{11} of two types of 2-bits RF MEMS matching networks at different switch combinations: a) type I and b) type II, respectively.

Figure 4 a and b show simulated s-parameters and NF of a tunable (multi-band) LNA using the measured data of two RF MEMS matching networks (type I) when all the switches are in up-state (00) and in down-state (11) position, respectively. The LNA is based on the GaAs mHEMT technology from the OMMIC foundry. We have used the foundry provided models for simulation of the active part (two transistor stages including biasing network). The tunable GaAs LNA results show that it can be possible to achieve similar high gain (above 15 dB), adequate impedance matching and low NF (3 dB) at different frequency-bands (10% tuning range). The results obtained using the measured data of the type II matching network show a LNA tuning range of 15% (NF=5 dB). These results show the potential of using RF MEMS switches for the realization of frequency-agile LNAs at microwave and millimeter-wave frequencies.



a)



b)

Fig. 4. Simulated results of a tunable GaAs MMIC LNA based on measured data of two RF MEMS input/output matching networks (type I) when all switches are in up-state (00) and in down-state (11), respectively: a) s-parameters b) noise figure.

3.2. Differential Matching Networks for a Tunable SiGe LNA

Figure 5 shows two differential MEMS matching networks made using the VTT process (circuit area is 6 mm^2) and that are intended for frequency-agile input and output matching of a differential 24 GHz SiGe LNA fabricated by the Atmel foundry (see Fig. 6). The combined tunable LNA (not shown here) was non-functioning (s21 < -40 dB) probably due to using too long bond wires. Wire-bonding (instead of flip-chip bonding) was needed in this case to connect the different circuits together as the pitch distance for the RF pads are different for the LNA and the matching networks used here.

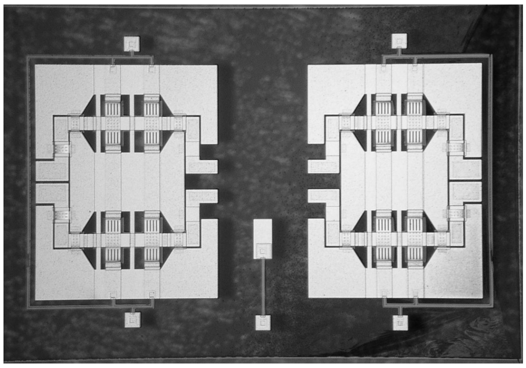


Fig. 5. Chip photo of two differential RF MEMS input and output matching networks (VTT process).

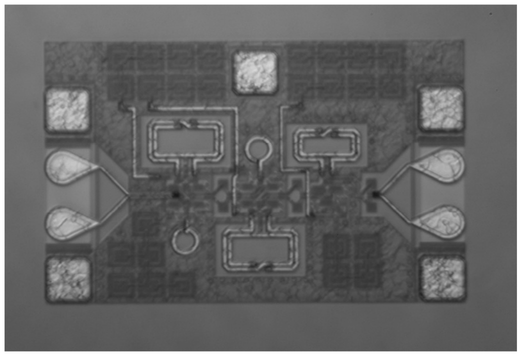


Fig. 6. Chip photo of a differential 24 GHz SiGe LNA (circuit area is 0.5 mm^2).

Figure 7 shows measured s_{22} of a differential 2-bits output matching network (VTT process). The results that have been obtained through 1-port measurements show an s_{22} tuning range of 2.4 GHz or 12% (f_{res}=19.1-21.5 GHz). The output impedance matching is better than -25 dB and -30 dB within the two different sub-bands.

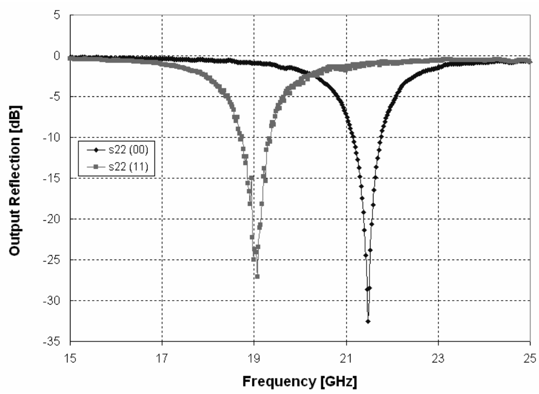


Fig. 7. Measured s_{22} of a differential 2-bits RF MEMS output matching network (VTT process) when all the switches are in the up-state (00) or in the down-state position (11), respectively.

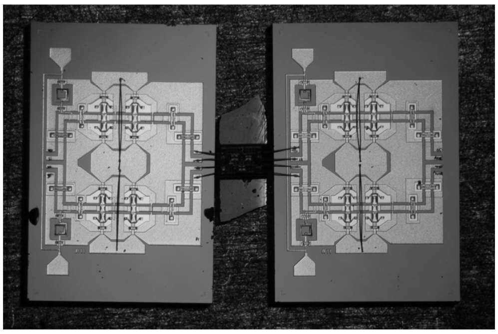


Fig. 8. Chip photo of a differential 24 GHz SiGe LNA combined with RF MEMS matching networks (total area is equal to 9 mm^2).

Figure 8 shows two 2-bits differential input/output matching networks that have been fabricated using a capacitive RF MEMS process at Fraunhofer ISIT. The two matching networks have been connected using bond wires to a 24 GHz SiGe LNA chip as also is shown in Fig. 8. The SiGe LNA was measured with a maximum gain of 17 dB at 23 GHz. The gain of the tunable SiGe LNA (with ISIT RF MEMS matching networks) was found to be greatly impaired ($s_{21} \leq -4$ dB) which also in this case most likely is a result of too large undesired parasitics of the connecting bond wires. Figure 9 shows the measured s_{11} results of the tunable SiGe LNA with ISIT RF MEMS matching networks when all switches are in up-state (00) and in down-state (11) position, respectively. The s_{11} tuning range is 3.9 GHz (20%) between 17.3-21.2 GHz. It is believed that better performance in terms of higher tunable LNA gain (due to reduced losses and improved matching) may be achieved by using flip-chip bonding resulting in lower interconnect parasitics compared with the relatively long bond wires we have used here.

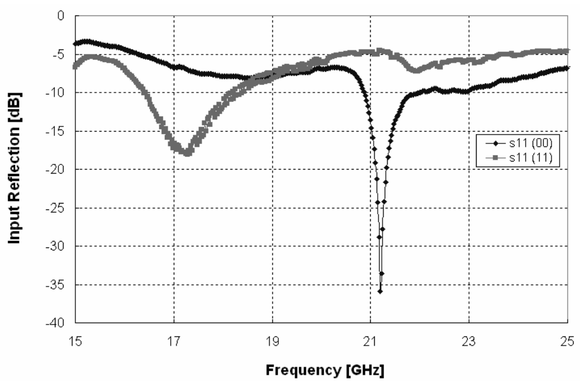


Fig. 9. Measured s_{11} of a tunable SiGe LNA with RF MEMS matching networks when all switches are in up-state (00) and in down-state (11), respectively.

4. CONCLUSIONS

We have presented different types of reconfigurable RF MEMS based matching networks intended for the realization of various frequency-agile (multi-band) LNAs. A tunable LNA architecture topology has been proposed based on adaptive input and output matching networks that are implemented using variable switched RF MEMS capacitors. The experimental data obtained for single-ended and differential types of MEMS matching networks show promising results in terms of relatively wide frequency tuning ranges (2-3 GHz around 20 GHz) and low RF losses. The validated MEMS matching networks have further been used for designing tunable LNAs with potentially high gain, adequate impedance matching and low noise figure at different frequency bands (at least 10-20% tuning range seems possible given the RF MEMS capacitance ratios of 5-15 achieved here).

The type of demonstrated tunable LNA RF MEMS based matching networks are considered as key building blocks for the realization of highly integrated, frequency-agile multi-band receiver front-end components at microwave and millimeter-wave frequencies.

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