Frequency-Adjustable PA Design Exploiting Reconfigurable Matching Networks

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***Abstract*—This project presents a Monolithic Microwave Integrated Circuit (MMIC) reconfigurable Power Amplifier (PA) in 0.25 µm GaN technology, working in C and Ku band. The reconfigurability is achieved by using a GaN HEMT as a switch inside the Output Matching Network (OMN). The OMN makes the reconfigurable PA work optimally at 3.4-4.2 GHz or 11.7-12.2 GHz depending on the state of the switch. This reconfigurable design is then compared with a dual-band PA and two single-band PAs based on the same transistor, working in the same frequency bands. The comparison shows the potential of reconfigurability but also its effect on performance.**

***Index Terms*—monolithic microwave integrated circuit (MMIC), power amplifier (PA), switch, reconfigurable PA, GaN.**

I. INTRODUCTION

With the ever-increasing demand of wireless data transmission, several new methods are being analyzed to optimize and upgrade RF front-ends, to achieve better performance with the minimum added cost possible, both in area and power consumption. A new emerging technique is based on frequency-adjustable power amplifiers (PAs), where the innovation comes from introducing switches in the matching networks (MNs) of the PA, to change their frequency response. A suitable technology for the design of such a device delivering high power at high frequency is Gallium Nitride (GaN), with which different reconfigurable solutions have also been developed, as in [1], achieving more than a watt of power at 2 and 12 GHz respectively.

In this project, a dual-band single-stage reconfigurable PA is designed in 0.25 µm GaN HEMT technology, covering two separate bandwidths centered at 3.8 and 12 GHz, thanks to a switchable element in its OMN. To evaluate the performance of this device, three other designs have been implemented: a dual-band switch-less PA and two single-band PAs. The dual-band PA comparison is needed to study if the switched OMN can provide some advantages with respect to the common non-reconfigurable solution, while the single-band PAs are used as examples to show the maximum achievable performance with the implemented technology.

II. AMPLIFIERS DESIGN

A. Reconfigurable PA Design

The schematic of the reconfigurable PA is shown in Fig. 1. It consists of a single stage PA with a fixed dual-band IMN and a reconfigurable OMN, both composed of lumped elements. The OMN contains a switchable shorted stub, controlled via a transistor with the same type and size as for the RF amplifier. All the amplifiers are implemented in microstrip technology in the 0.25 µm GaN HEMT process of the Ferdinand-Braun-Institut (FBH). The power cell is implemented using a HEMT, which has a size of 4x125 µm and it is biased with VDS = 28V and VGS = -2.8V. The best size for the switch was found to be the same as the amplifier transistor, to obtain the best trade-off between R_{ON} and R_{OFF}. A large-signal extended Chalmers (Angelov) model was used for all simulations [2], [3] to characterize the transistor used. Large-signal harmonic balance simulations were conducted in Keysight Advanced Design System (ADS) to identify the optimum matching and design the amplifier.

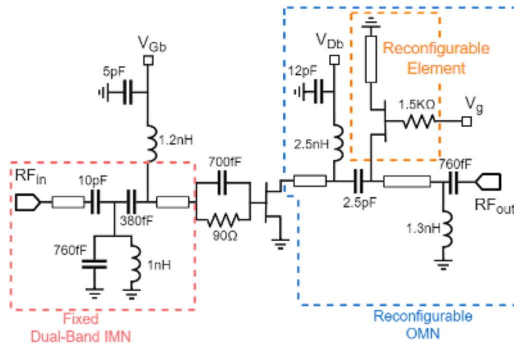

Fig. 1. Schematic of the MMIC Frequency-Adjustable PA.

B. Additional PAs Designs

The second topology considered in this evaluation is a classic dual-band PA, which design consists of a multi-pole input and output MN to match both frequency bands simultaneously. Given that the IMN for the frequency-adjustable PA already covered both bands, the same IMN was considered also for the dual-band PA. Instead, the OMN was modified by removing the switching cell and placing fixed components in its place.

To complete the comparison, two single-band PAs were designed, which represent the best achievable solutions with this technology in each band with the least occupied area. Both designs are composed of fixed MNs, making them much smaller than the multi-band designs. The layout of the four amplifiers is presented in Fig. 2.

III. SIMULATED RESULTS

All the devices were thoroughly simulated both under small signal and large signal conditions. For the frequency-adjustable

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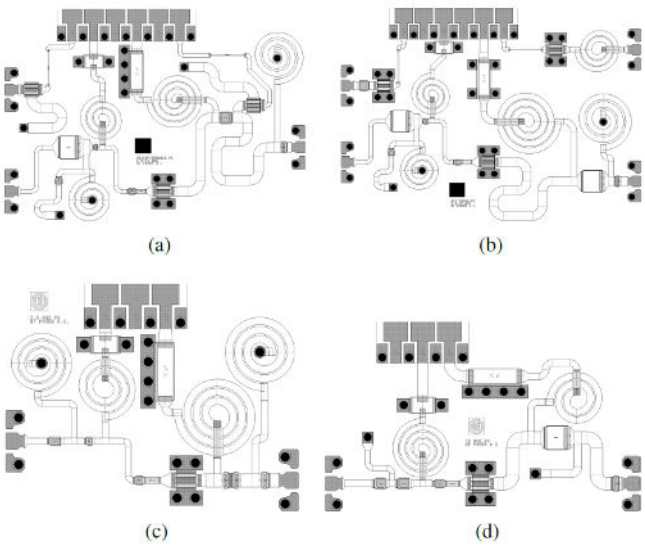

Fig. 2. frequency-adjustable (a), dual-band (b), 3.8 GHz (c) and 12 GHz (d) MMIC PA layouts.

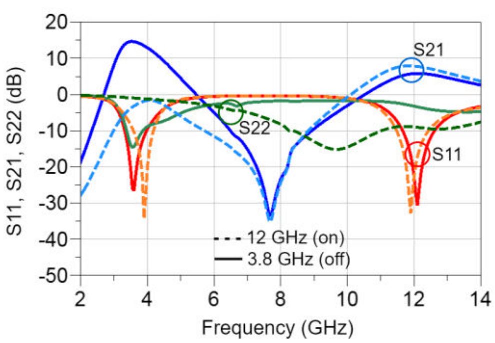

Fig. 3. S-parameter simulations of the reconfigurable PA.

PA, the results are shown in Fig. 3 and Fig. 4. The PA reaches an output power of more than 31.4 dBm in the lower band and 30 dBm in the upper one, with a PAE above 29% and 19%. For the small-signal analysis, a gain greater than 13.5 dB and 7.5 dB respectively was achieved.

Table I shows a summary of all the simulated results obtained from the designed PAs. As expected, the single band PAs achieve better results while being much smaller in size, since they are perfectly matched in just a single band while using less components, minimizing the losses. Noteworthy is that the dual-band PA performs better than the reconfigurable one, due to the quite high on-resistance and low off-resistance of the switch transistor. Even with an equivalent matching for the two dual-band solutions, the efficiency and power are partially reduced for the reconfigurable design.

How well the results compare to measurements of the proposed designs remains to be evaluated when the chips have been fabricated.

IV. Conclusion

In this project, the feasibility of a frequency-adjustable MMIC PA in 0.25 µm GaN technology working in C (3.4-4.2 GHz) and Ku (11.7-12.2 GHz) band has been investigated. In addition, a dual-band and two single-band MMIC PAs in the same technology have been designed for comparison purposes.

This device proves that the desired reconfigurability is achievable in the specified bands. The main drawback found in this investigation concerns the quite high on-resistance of the transistor switch, which reduces the performance of the PA both in power and efficiency compared to a standard dual-band solution for these frequency bands. On this matter, further research is being conducted on how to improve the response of the transistor as a switch to obtain a more compact and efficient reconfigurable cell.

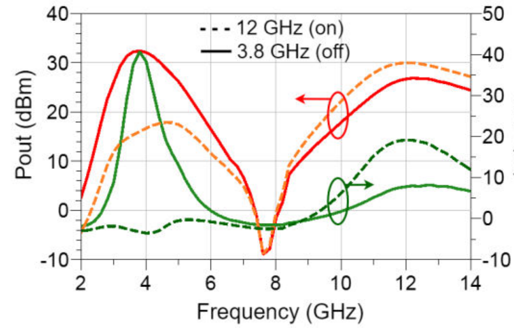

Fig. 4. Large signal simulations of the reconfigurable PA.

TABLE I. Comparison between the designed PAs

PA type	Pout (dBm)	Gain (dB)	PAE (%)	Size (mm^2)
Reconfig.	31.4-32.4 /29.8-30	11.5-14/ 7.6-7.8	29-40.6/ 18.8-19.2	2x2.8
Dual band	31.9-32.8 /30.5-31	12.5-15.4 /9-9.1	35.7-46.6 /23.1-27	2.15x3
3.8 GHz	32.1-32.5	13-13.8	43.3-46.4	1.5x1.9
12 GHz	31.1-31.5	10.2-10.7	32.7-33.5	1.4x2.3

V. Impact statement and future plans

The MTT-S scholarship helped me pursuing this prolonged and challenging project, which helped me in developing skills and interests in the microwave world. Right after graduating from my Master Degree in Electronics, I've started pursuing a Ph.D. program at the Ferdinand Braun Institut, continuing the work on PAs and in the microwave world.

References

[1] L. Kang, W. Chen and A. Wu, "A Reconfigurable S-/X-Band GaN MMIC Power Amplifier," in *IEEE Microwave and Wireless Components Letters*, vol. 32, no. 6, pp. 547-550, June 2022, doi: 10.1109/LMWC.2022.3141230.

[2] I. Angelov, H. Zirath and N. Rorsman, "A new empirical nonlinear model for HEMT-devices," *1992 IEEE MTT-S Microwave Symposium Digest*, Albuquerque, NM, USA, 1992, pp. 1583-1586 vol.3, doi: 10.1109/MWSYM.1992.188320.

[3] Luo P, Schnieder F, Bengtsson O, et al. A streamlined drain-lag model for GaN HEMTs based on pulsed S-parameter measurements. International Journal of Microwave and Wireless Technologies. 2019;11(2):121-129. doi:10.1017/S1759078719000060