Design Method for Arbitrary Concurrent Tri-Band Doherty Amplifiers and Development of a Prototype for LTE, UMTS and WiMAX Applications

Ferdinando Costanzo, *Student Member, IEEE*, Rocco Giofrè, *Member, IEEE* and Luca Piazzon

***Abstract*—This paper presents the design of a concurrent tri-band Doherty Power Amplifier (DPA) for 1.84 GHz, 2.14 GHz and 2.65 GHz frequency bands. The frequency response around each operating band is maximally flattened adopting a new design strategy. The DPA is based on hybrid technology using two 8 W GaN HEMT as active devices. The results show a peak of drain efficiency higher than 60% in each operating band and over 45% at the corresponding 6 dB output power back-off (OBO). Finally, more than 200 MHz of bandwidth is achieved around each operating frequency**.

***Index Terms*—Doherty power amplifier, tri-band, wideband.**

I. INTRODUCTION

The signals involved in modern communication systems are characterized by large amplitude variations, which results in high peak-to-average power ratios (PAPRs). In this contest, the Doherty Power Amplifier (DPA) is a recognized solution to achieve high level of average efficiency while maintaining acceptable linearity performance. On the other side, nowadays communication standards are spread in different carrier frequencies. Therefore, in order to minimize production and maintenance costs, research efforts aiming to realize DPAs with ultra-wideband/multiband behaviors are of great interest.

Focusing on the multiband DPAs, many solutions of dual- and tri-band [1] prototypes were presented. However, to date, the proposed methods are mainly focused on the optimization of the output combiner, so they show an extremely narrow bandwidth around each carrier frequency. Then, to give a possible solution at this issue, this report describes a new design approach of the input matching network (IMN) which allows a maximally flat frequency response of the DPAs. The proposed design method is validated through the design of a new concurrent tri-band DPA.

II. NEW DESIGN STRATEGY OF IMN FOR DPAS

The developed method to design the IMN is based on the approach proposed in [2], which provides analytical equations to implement wideband input/output matching networks knowing the active device parasitic. However, the approach in [2] does not take into account the variation of the device's input impedance caused by the stabilization network. To avoid such a limitation, the analytical procedure proposed in [2] has been inverted. The idea is to define, for a desired input return loss, normalize impedance (Z_T) and fractional bandwidth (usually selected by the designer), the contour on the Smith Chart in which the input impedance of the active device has to be maintained through the stability network. Subsequently, keeping the input impedance (Z_{StM}) of the stabilized device (stabilization network + active device) within the selected contour at constant return loss, the design of the IMN can be easily performed by applying the closed form system equations. This method was applied to design the IMN of the main device in the realized prototype as graphically depicted in Fig. 1.

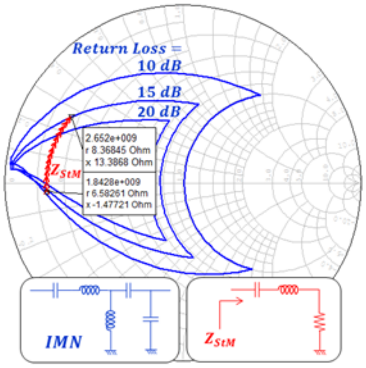

Fig. 1: Blue contours refer to a 3° order IMN with a constant input return loss of 20dB, 15dB and 10 dB in the 1.84-2.66 GHz frequency range and for a Z_T=30Ω. Instead, the red curve represents Z_{StM}.

The stabilization network has been represented as a series connected RLC circuit including the *Cgs* and *Rg* parasitic of the active device (Cree CGH60008D). The IMN has been assumed to be a third order network. Accounting for these conditions and the theory in [2], the contours at 20dB, 15dB and 10dB constant input return loss have been derived. The registered behaviors are reported in Fig. 1 with blue lines. After that, the stabilization network has been designed in order to fulfill the unconditional stability at all frequencies and to keep Z_{StM} within the same contour in the 1.84-2.66 GHz frequency range. A similar approach has been applied for the Auxiliary amplifier. Following this design approach an extremely flat frequency response of the input passive networks of the DPA and, thus, of the output current ratio (I_A/I_M) has been achieved.

III. DESIGN OF THE TRI-BAND DPA

The scheme of the designed tri-band DPA is reported in Fig. 2. It employs two Cree CGH60008D as Main and Auxiliary devices. The DPA design parameters have been determined by adopting the theory in [3]. The inferred values for the output impedances of the Main at the break and saturation are $R_{M@B}$=99.2 Ω and $R_{M@S}$=46 Ω, respectively while the optimum value of the common node impedance is R_L=17.6 Ω.

This work was supported by the MTT-S Scholarship program. The authors are with the Department of Electronic Engineering, University of Rome Tor Vergata, 00133 Rome, Italy (e-mail: giofr@ing.uniroma2.it).

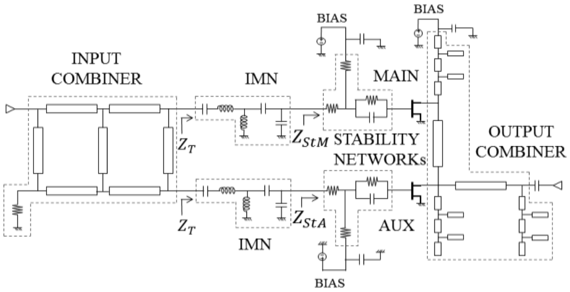

Fig. 2: Block diagram of the implemented tri-band DPA.

In order to meet these impedance requirements at the three operating frequencies (1.84 GHz, 2.14 GHz and 2.65 GHz), an output combiner, which implements an impedance inverter network (IIN) and an input transformer network (ITN), has been implemented by using two quasi-optimal tri-band quarter-wave transmission lines as described in [4]. This has also been designed to neutralize the output capacitance C_{ds} of both devices.

Wideband IMNs, covering the whole 1.84-2.66 GHz frequency range, have been designed applying the procedure described in the previous section. Then, the input power splitter (IPS) and the phase compensation network (PCN) have been implemented by means of a two-section branch-line [5].

The gate bias voltages of the Main and the Auxiliary devices are V_{gM}=-3V and V_{gA}=-5V, respectively while the drain bias voltage was fixed to V_{DD}=28V.

IV. RESULTS

Fig. 3 shows the DPA performance in terms of gain and drain efficiency versus output power at each carrier frequency. As can be noted, the typical Doherty behavior is always obtained achieving similar levels of efficiency and gain.

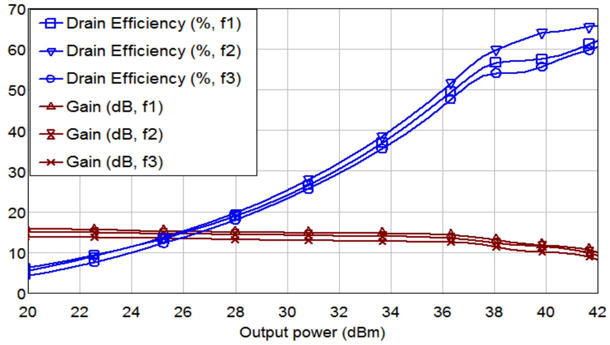

Fig. 3: Performance at f_1=1.84 GHz, f_2=2.14 GHz and f_3=2.65 GHz.

Fig. 4 reports the output power and drain efficiency throughout the frequency range from 1.6 GHz to 2.8 GHz and for an input power of Pin=24dBm and Pin=31dBm. As can be noted, the designed DPA has more than 200 MHz of bandwidth around each of the three carrier frequencies. Moreover, these performances are verified at both break and saturation conditions, confirming that the DPA behavior is maintained for a broad frequency range around the center frequencies. Fig. 5 shows the picture of the realized tri-band DPA. Passive networks have been designed on Taconic TLY-5A substrate (dielectric constant 2.17, height of 787 μm).

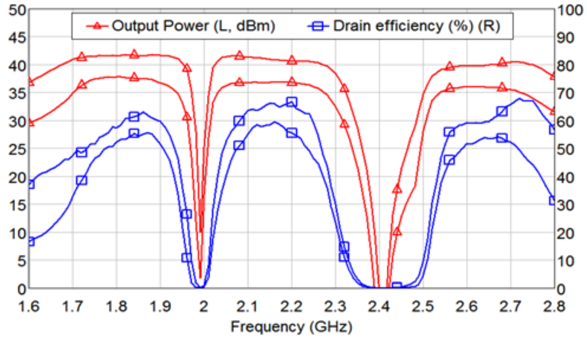

Fig. 4: Performance vs. frequency at Pin=24dBm and Pin=31dBm.

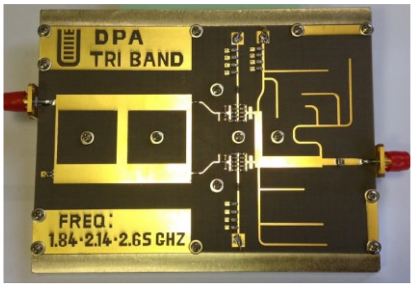

Fig. 5: photo of the realized tri-band DPA.

V. CONCLUSION

In this paper, the design of a concurrent tri-band DPA at 1.84 GHz, 2.14 GHz and 2.65 GHz frequency band has been described. The design is based on a novel design solution that allows to obtain a maximally flat output power response around each center frequency. The results have shown more than 60% and 45% of peak and 6dB back-off efficiencies at all operating frequencies. Moreover, more than 200 MHz of bandwidth is achieved around each operating band. The experimental results is in progress and it will be reported in a future paper.

ACKNOWLEDGEMENTS AND FUTURE PLANS

I would like to thank MTT-S for this award because it increased my interest about microwave engineering and it gave me a practical and moral support during my thesis work. Regarding my future plan, I would like to find a job as microwave designer.

REFERENCES

[1] X. A. Nghiem, J. Guan, T. Hone, and R. Negra, "Design of Concurrent Multiband Doherty Power Amplifiers for Wireless Applications," *IEEE Trans. Microwave Theory & Tech.*, vol. 61, no. 12, pp. 4559-4568, December 2013.

[2] Dale E. Dawson, "Closed-Form Solutions for the Design of Optimum Matching Networks," *IEEE Trans. Microwave Theory & Tech.*, vol. 57, no. 1, January 2009.

[3] P. Colantonio, F. Giannini, R. Giofrè, and L. Piazzon, "Increasing Doherty Amplifier Average Efficiency Exploiting Device Knee Voltage Behavior," *IEEE Trans. Microwave Theory & Tech.*, vol. 59, no. 9, pp. 2295-2305, September 2011.

[4] L. Piazzon, P. Saad, P. Colantonio, F. Giannini, K. Andersson, and C. Fager, "Design Method for Quasi-Optimal Multiband Branch-Line Couplers," *Inter. Jour. of RF & Microwave CAE*, January 2013.

[5] S. Kumar, C. Tannous, and Tom Danshin, "A Multisection Broadband Impedance Transforming Branch-Line Hybrid," *IEEE Trans. Microwave Theory & Tech.*, vol. 43, no. 11, November 1995.