Ultra Wideband, High Efficiency RF Power Amplifier based on GaN HEMTs

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Abstract— **This paper presents a new ultra wideband, high efficiency RF power amplifier based on a GaN HEMT transistor This amplifier provides more than 50W of output power from 20MHz to 1400MHz (almost two decades) and exhibits a drain efficiency of up to 50%. The gain of the power stage of the amplifier is G_P = 17dB in saturation conditions and reaches 22dB in small signal operation, gain flatness is ±1dB all over its frequency band. The topology of the amplifier is a balanced Class-AB one and its input and load networks are made of coaxial transmission line transformers loaded with ferrite cores that provide both impedance transformation and balancing functions.**

I. INTRODUCTION.

RF power amplifiers with the capability of covering several frequency bands could be used in civil and military communications systems that require integrating several services with reduced number of components and size. These kinds of amplifiers also have applications for instrumentation purposes.

There are three main parameters that have to be considered for designing this type of amplifier: broadband operation, good linearity and medium level of power efficiency. The class AB push-pull [1] provides good linearity with an acceptable efficiency at maximum output power [2,3]. Using two transistors with a phase shift of 180º gives the additional advantage of canceling the even harmonics in the output RF signal

II. DESIGN AND SIMULATION

The selected device for this design is the CREE HEMT GaN transistor CGH40090PP. This device consist of two identical unmatched transistors placed in the same package (Fig. 1), which makes it ideal for a push-pull amplifier design because the two transistors present the same characteristics since they were manufactured with the same process. This transistor can work from DC to 2.5GHz with a saturated output power of 100W, 28V of drain voltage supply and a drain efficiency of 55%.

As initial goal for the design, the amplifier should provide a minimum output power of 50W from 50MHz to 2GHz. For broadband operation, the input and output matching networks have been implemented using transmission line transformers. A feedback network was used to reduce the gain at lower frequencies in order to have a flat gain and flat output power over the overall frequency range. Figure 2 shows the schematic used for the design.

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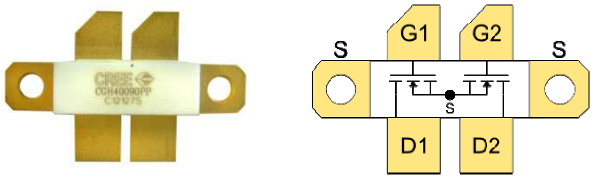


(a) (b)

Fig. 1. Picture (a) and scheme of transistor (b) selected for the amplifier design.

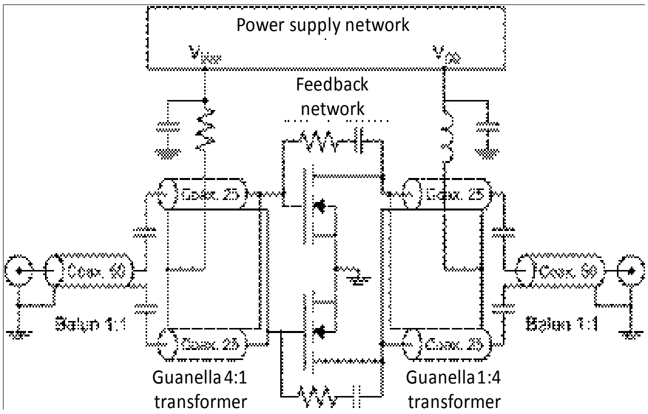
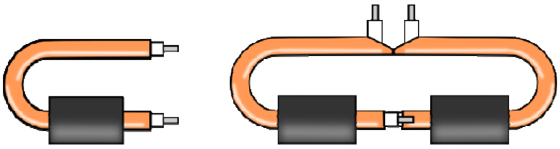


Fig. 2. Schematic of broadband amplifier.

The use of transmission line transformers is a key in this amplifier design [4,5] and the same type and topology of transformer has been used at input and output networks. The transformer has two sections. The first section is a 50Ω coaxial 1:1 balun (Fig 3a) and the second one is a 25Ω coaxial cable Guanella transformer (Fig 3b) that converts 50Ω to 12.5Ω. With this transformer network each transistor is seeing 6.25Ω at its drain (final impedance reduction of 8:1) with a phase shift of 180º from one to the other. To cover the low frequency range (below 100MHz) a ferrites of 61 material from Fair-rite have been inserted

Another advantage of this kind of transformer is that it simplifies the biasing network because the intermediate point (Fig2) of Guanella transformer can be used for that purpose. This point allows the insertion of DC to the two transistor gates and drains with no RF return due to cancelation of two RF signal with a 180 phase shift.



(a) (b)

Fig. 3. Coaxial line transformer sections. Balun 1:1 (a) y Guanella (b).

Figure 4 shows the 3 port S parameters measurement of the designed transformer with a 4 port Agilent PNA-X N5242A. The results show that the transformer can work from few MHz to above 1GHz. The return losses (<-20dB) and coupling (losses of 1dB) are pretty good in all frequency range.
The S parameters measured for the transformer and the AWR model of the transistor were used to simulate the amplifier performances. To get a flat gain an output power a drain to gate feedback network was needed for each transistor. This RC network additionally increases the amplifier stability, it was implemented with a 110Ω and a 10nF ATC capacitor.
Figure 5 shows the simulation results of output power, gain and power efficiency for Vd=28V and Id=2A.

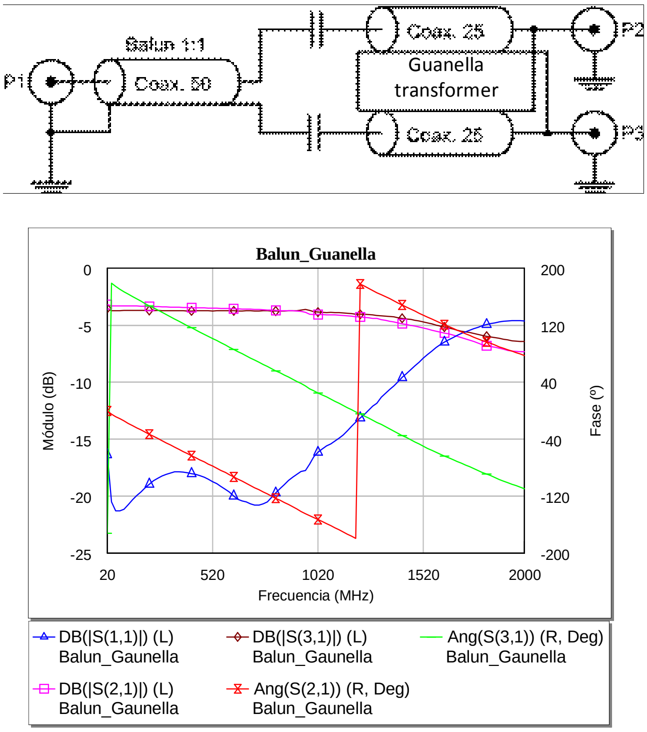


Figure. 4 Coaxial transformer and. s3p measured

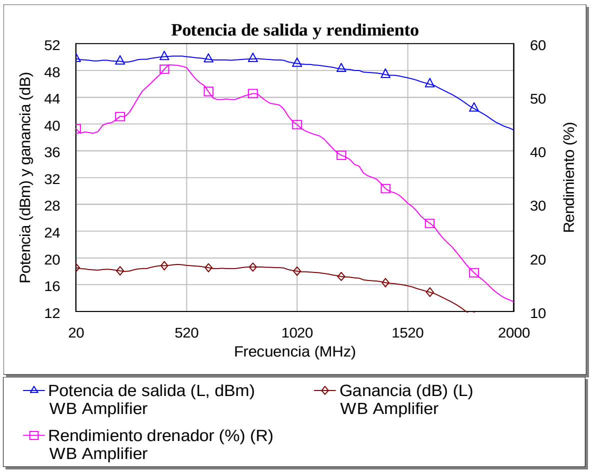


Figure. 5. Simulation of output power and efficiency for the broadband amplifier

Figure 6 shows simulation results of output power and efficiency versus input power at two different frequencies

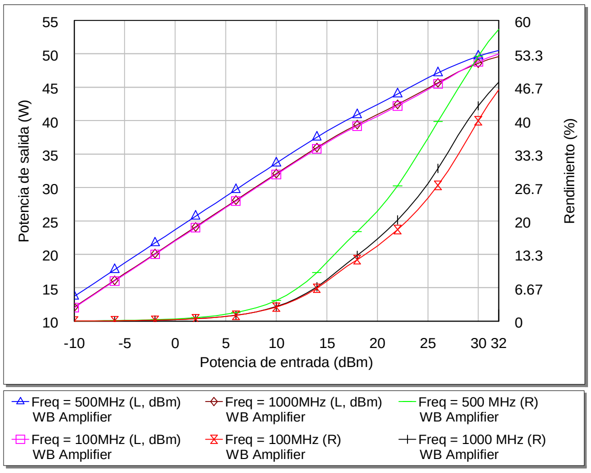


Figure. 6. Simulated output power and efficiency versus Pin.

The stability of the amplifier was also verified by AWR simulation. Figure 7 shows that the amplifier is unconditionally stable in all the frequency range, with a stability measurement (B1)>0 and a stability factor (K)>1

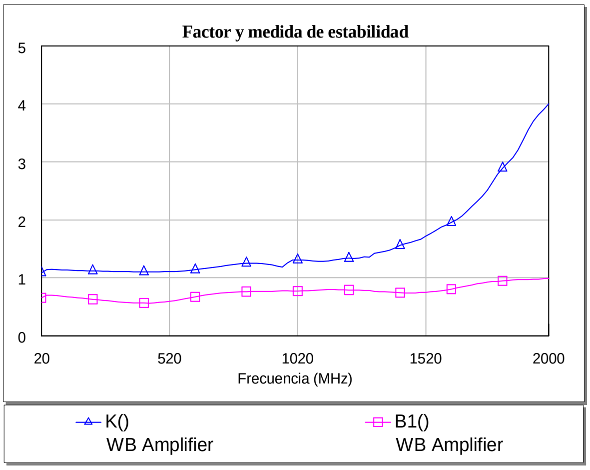


Figure. 7. Simulated stability measurement (B1) and Rollet stability factor (K)

III. EXPERIMENTAL RESULTS

Figure 8 shows the implemented amplifier, it can be seen that the transformer configuration used at the input and output matching networks are identical with the only difference that at the input port a flexible coaxial cable is used instead of semi rigid cable used at the output. The NXP circuit proposal [6] was used for biasing the transistors. This circuit generates the negative voltage for the gate and provides the gate-drain voltage sequencing necessary in this kind of transistors

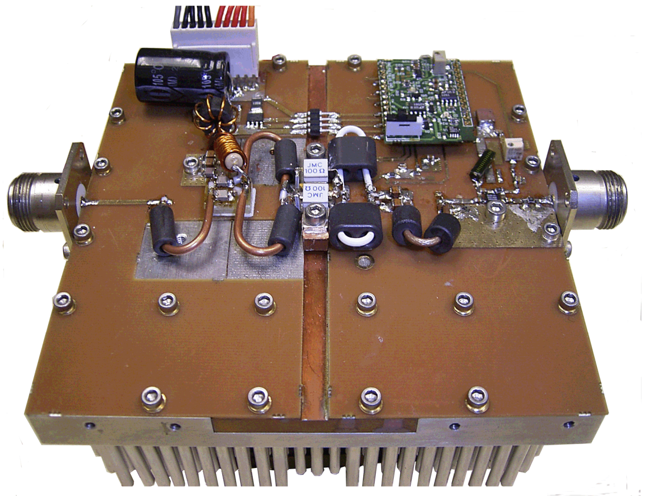


Figure. 8. Implemented broadband amplifier.

Figure 9 shows the measured saturated output power and the drain efficiency. Figure 10 shows the curves of output power versus input power for different frequencies. The measurements was performed with a Vd=28V and a Id=2A

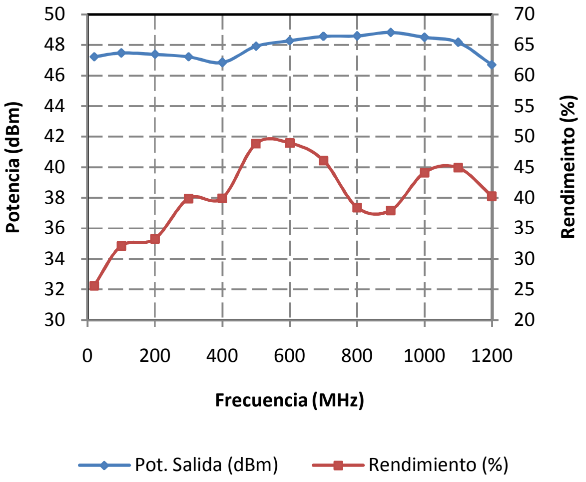


Figure. 9. Measured of saturated output power and efficiency from 20MHz to 1.2GHz .

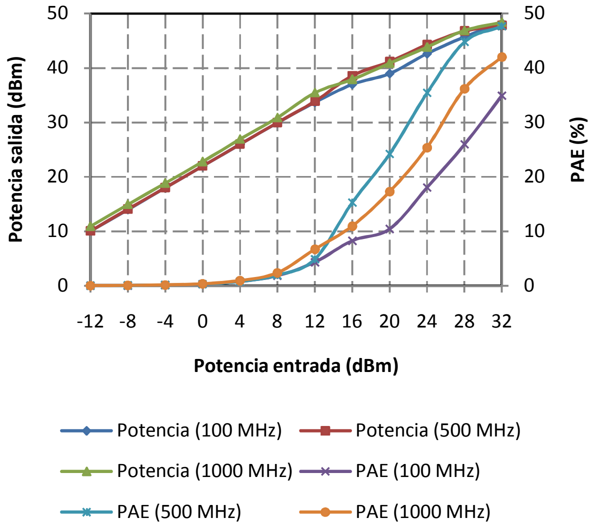


Fig. 10. Output power and PAE (Power Added Efficiency) versus Pin for different frequencies.

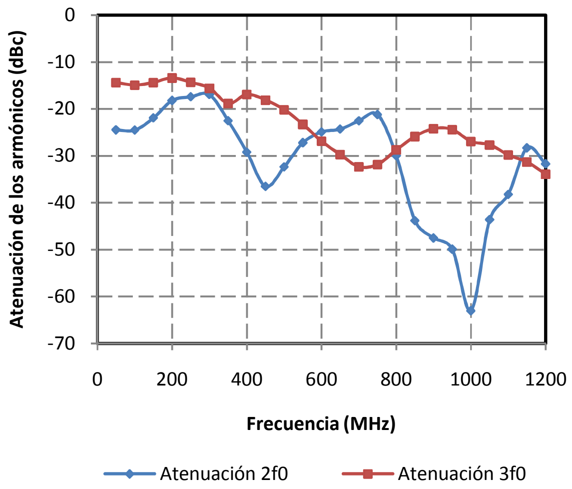
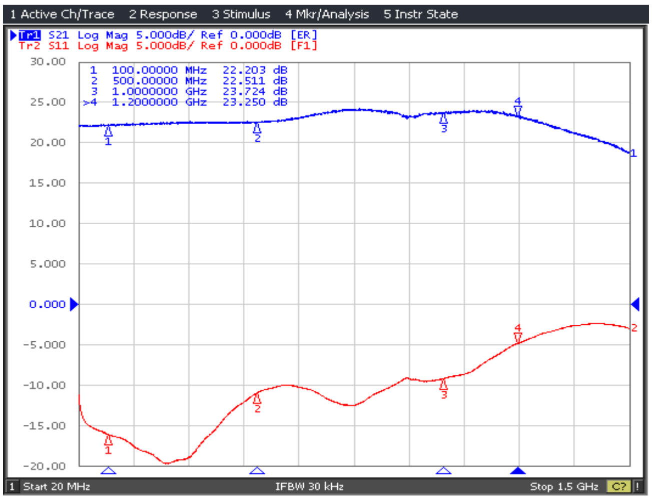


Fig. 11. Harmonic attenuation for 2fo and 3fo for 25W of Pout.



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Tr1 S21 Log Mag 5.000dB/ Ref 0.000dB [ER]
Tr2 S11 Log Mag 5.000dB/ Ref 0.000dB [F1]
 1   100.00000 MHz   22.203 dB
 2   500.00000 MHz   22.511 dB
 3   1.0000000 GHz   23.724 dB
>4   1.2000000 GHz   23.250 dB
1  Start 20 MHz          IFBW 30 kHz          Stop 1.5 GHz
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Fig. 12. Small signal gain and input return losses.

The harmonic attenuation has been measured for $2f_o$ and $3f_o$ and as it can be seen in Figure 11 with the push-pull configuration the $2f_o$ harmonic attenuation is higher than $3f_o$ in almost all the frequency range. Figure 12 shows the measured small signal gain and return losses

IV. CONCLUSIONS

A 50W broadband GaN amplifier had been designed and implemented. The amplifier can works from 20MHz to 1.2GHz with a small signal gain of 22dB and a saturated gain of 17dB. The gain ripple is ± 1dB and the efficiency at the best case is 50%. The transformer used for the design of input and output matching networks is the element that limits the maximum operating frequency of the amplifier due to the ferrites that it had to be used to cover the low frequency range.

REFERENCES

[1] Cripps, S. C., “RF Power Amplifiers for Wireless Communications,” 2nd Edition, Artech House Publishers, 2006.

[2] Krishnamurthy K., Driver, T.; Vetury, R.; Martin, J., “100 W GaN HEMT Power Amplifier Module with > 60% Efficiency over 100-1000 MHz Bandwidth,” in *2010 IEEE MTT-S Int. Microw. Symp. Dig.*, pp. 940 - 943, June 2010.

[3] Smith R., Lees, J. ; Tasker, P. J. ; Benedikt, J. ; Cripps, S. C. , “A 40W push-pull power amplifier for high efficiency, decade bandwidth applications at microwave frequencies,” in *2012 IEEE MTT-S Int. Microw. Symp. Dig.*, pp. 1 - 3, June 2012.

[4] Sevick, J., “Transmission Line Transformers”, Noble Publishing Corp., 4th Edition 2001.

[5] Smith R., Lees, J.; Tasker, P.J.; Benedikt, J.; Cripps, S.C.,“A Design Methodology for the Realization of Multi-Decade Baluns at Microwave Frequencies”, in *IEEE MTT-S Int. Microw. Symp. Dig., 2011*, June 2011.

[6] NXP semiconductor, “Bias module for 50 V GaN demonstration boards,” AN11130 application note, December 2011.