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Improving Harmonic Characteristics of Class F Power Amplifier with Filter-Matching Network

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Abstract - The new topology for high power and excellent harmonic response power amplifier is presented in this paper. GaN HEMT class F power amplifier is designed and simulated at 2.4 GHz for high power output and excellent harmonic response. Microstrip low-pass filter is deployed as output matching network is integrated into power amplifier. Filter orders are varied and responses are compared with output matching network. For 5th order Chebyshev Filter (0.5 dB ripple) and 26 dBm input power, the class F amplifier provides output power around 41.2 dBm. It significantly reduces power present in second and third harmonics of signal.

Keywords – class F power amplifier, Chebyshev filter, filter-matching network

1 INTRODUCTION

Superheterodyne receiver architecture consists of bandpass filter attached at the output of power amplifier to filter out unwanted frequency components. Also, several classes of amplifiers used to improve the power output or efficiency of power amplifier. Peter Wright *et al.* in [3], Kenle Chen *et al.* in [8] and Tian He in [9] study some of the amplifier classes and their efficiencies. In these conventional architectures, power amplifier output is matched to 50 Ω and bandpass filter designed at 50 Ω is attached to it. But when output matching network is directly replaced by filter, the filter can be directly designed for output impedance value of transistor to improve its performance. Kenle Chen in [1] and [2] verify this fact. In this work, output matching network of power amplifier is replaced by low pass filter to obtain good harmonic performance and high power output. Second and third harmonics are considerably reduced. The paper is organized as follows; Section 2 consists of selection of device. Section 3 briefs about selection of filter type for this new topology. Comparison of power amplifier performance when order of filter is varied is studied in Section 4. It is then followed by conclusion.

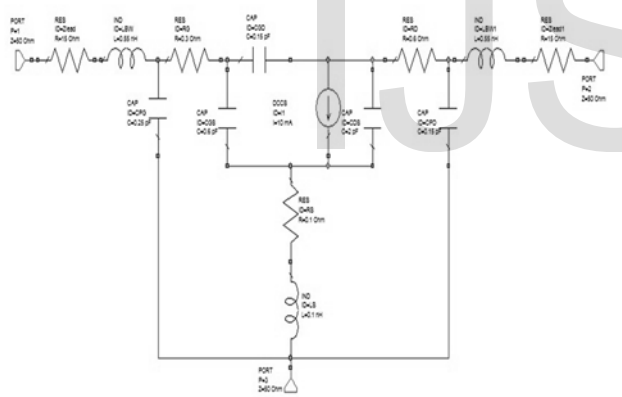

Fig. 1. Large signal package model of CGH40010F constructed from datasheet.

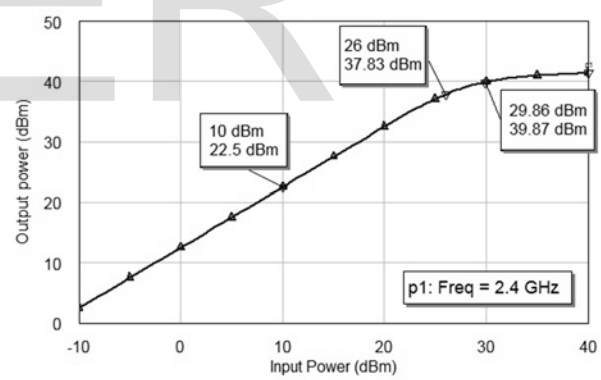

Fig. 2. Linear region of amplifier is defined by 1-dB compression point after which 1 dB compression is observed, it comes around 29.86 dBm.

2 Selection of device

Cree Inc.'s CGH40010F used as the amplifying device which is basically 10W, GaN HEMT. Large signal model for simulation purpose is provided by Cree Inc. This model includes package parasitics, allow harmonic terminations to be considered and two-tone or three-tone measurements [4]. Such a model also includes junction temperatures to be included in the simulations thereby making simulation results more realistic. All the simulations in this work are

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carried out in AWR Microwave Office 2009. Large signal model has been built up for load pull simulations as given in [1], [4], [5], [6], is depicted in Fig. 1.

The linear region of the device exists up to 29.86 dB of the input power which is obtained by plotting 1-dB compression point as in Fig. 2. For linear operation of device, input drive power is selected as 26 dBm at 2.4 GHz. Also, power added efficiency (PAE), output power and small signal gain are plotted for comparing the amplifier performance as in Fig. 3. Load pull and source pull simulations are carried out to determine optimum load and source impedances for maximum power delivery at output at 2.4 GHz and 26 dBm input power level.

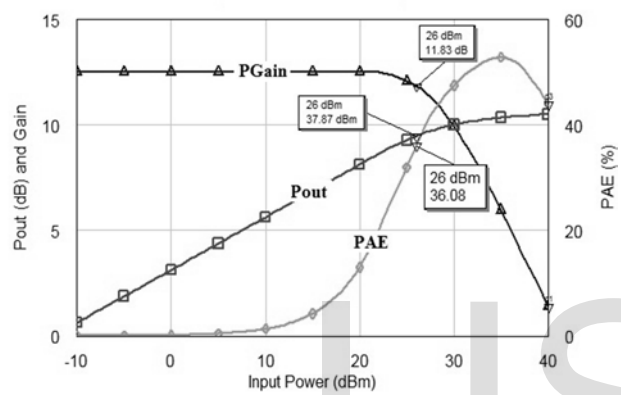

Fig. 3. Power-added-efficiency (PAE), power gain and output power power of the device for 26dBm input level at 2.4 GHz.

3 Selection of filter type

Matching network for power amplifier has been designed with Smith Chart approach to match the device load impedance to 50 Ω. This conventional approach can be

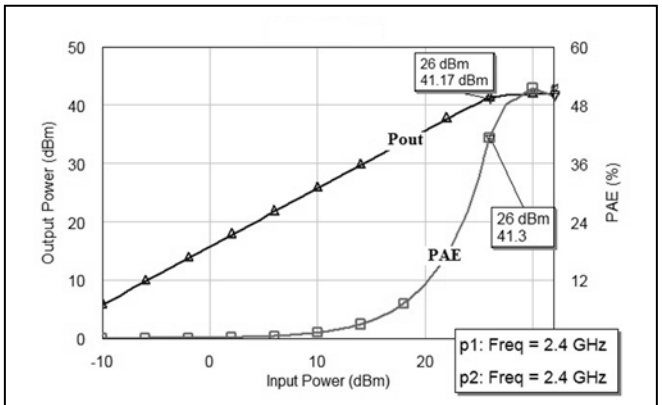

Fig. 4. PAE and Pout of the class F power amplifier with Chebyshev 5th order lowpass filter as its output matching network

further modified by adding harmonic tuning circuit to

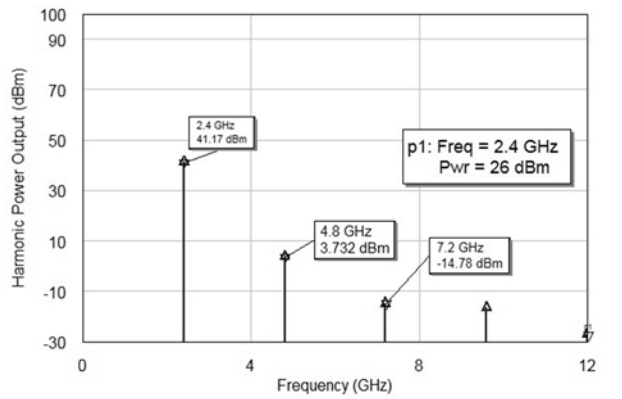

Fig. 5. Harmonic response of class F power amplifier with 5th order Chebyshev lowpass filter as output matching network

improve its harmonic response. The harmonic tuning circuit is designed as proposed by J. Kim in [7]. As previously mentioned, in this work, output matching circuit is replaced by filter to improve harmonic response. For this, the filter type need to be carefully selected. Use of high pass flters and band stop filters may lead to spurious response [10]. The filters of interest here are lowpass and band pass filters. But as mentioned by G. Matthei in [11] and has been verified in this work, conventional microstrip filters cannot provide optimum performance parameters beacause restrctions on out-of-band performances. Hence, these filters need to further optimized.

It has been found that tuning even number of microstrip elements in the filters lead to suppression of second harmonic at the expense of some power in third harmonic. Third harmonic in this case can be suppressed by

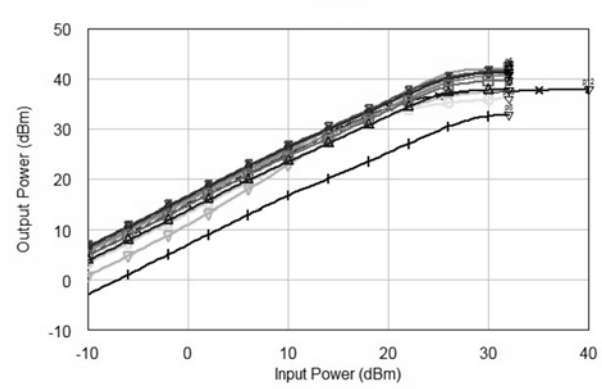

Fig. 6. Combined output power graphs of all power amplifiers listed in Table I

designing narrowband filter. Also, as studied by Matthei

and also verified during the design of filters for intended amplifier, higher order filters lead to enhanced bandwidth and steeper stopband attenuation. To conclude this work, when the optimum amplifier configuration is selected, these factors were also taken into consideration. Two types of filter design approaches considered here are maximally flat and equi-ripple (0.5 dB ripple). Matching network is consecutively replaced with 1. Maximally flat lowpass filter section, 2. Maximally flat bandpass filter section, 3. Chebyshev lowpass filter section and finally, 4. Chebyshev bandpass filter section. For lowpass filter sections, it has been observed that power present in second and third harmonics drastically varies when filter orders are increased while for bandpass filter section the power level are almost same.

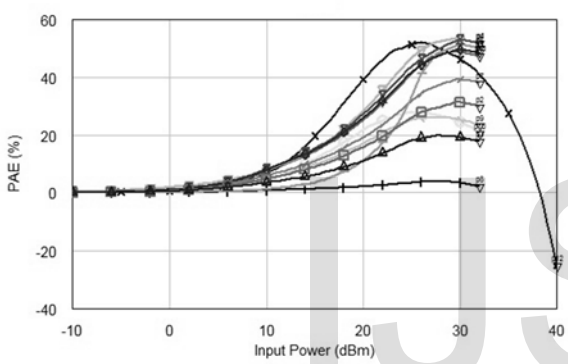

Fig. 7. Combined PAE plots of all amplifiers listed in Table I. PAE values are listed in Table I for power amplifier configurations

4 Power amplifier performance with filter-matching networks

Table I summarises the comparison of power amplifier performance parameters with varying filter orders for lowpass and bandpass sections and a power amplifier with output matching network. It is to be noted from the table that the filters whose response dosen't vary significantly after optimization expalined above, are not inlcuded in table. Finally selected power amplifier with optimum harmonic response, best possible PAE and high output power is the one whose output matching network is replaced by 5th order Chebyshev lowpass filter section.

Conclusion

From the simulation work carried above it can be concluded that replacing output matching network of the power amplifier improves harmonic response of the amplifier. Also, careful optimization of filter section may lead imprived PAE and output power. Other findings in this work include tuning even numbered microstrip elements leads to secong harmonic suppression. But while doing so, power in the third harmonic increases. Third harmonic then can be suppressed by selecting proper filter bandwidth.

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TABLE I
Power Amplifier Designs with Filter Matching Networks

Approach	PAE (%)	Pout (dBm)	1st Harmo. Power (dBm)	2nd Harmo. Power (dBm)	3rd Harmo. Power (dBm)
Output Matching Network	47.92	39.98	39.83	25.19	-1.528
Max. lowpass 3rd order	52	36.77	36.76	5.077	5.471
Max. lowpass 3rd order optimized	44.4	40.03	40.03	-0.03758	1.114
Max. bandpass 3rd order	27.72	35.19	35.19	-14.8	-2.337
Max. bandpass 3rd order optimized	25.73	36.43	36.43	-27.46	5.425
Chebyshev lowpass 3rd order	44.21	39.97	39.97	2.81	-1.81
Chebyshev lowpass 3rd order optimized	46.33	40.3	40.29	10.99	-0.1269
Chebyshev lowpass 5th order	41.24	40.93	40.93	7.698	-13.43
Chebyshev lowpass 8th order	3.667	30.47	30.47	-28	-12.47
Chebyshev lowpass 8th order optimized	34.36	39.33	39.33	-7.167	-9.251
Chebyshev bandpass 3rd order	18.97	37.2	37.19	4.101	-5.281
Chebyshev bandpass 3rd order optimized	27.86	38.55	38.55	1.069	-7.537