

Application of Load-pull in Power Amplifier Design

Xiaoguang Li^a, Xuchan Bai^{*a}, Qiang Yuan^b, Songan Zhang^c

^aDepartment of Electrical Engineering and Automation, Luoyang Institute of Science and Technology, Luoyang, 471023, P.R.China

^bLuoyang Urban Planning and Architecture Design Research Institute Company Limited, Luoyang, 471023, P.R.China

^cEnvironmental Protection and Energy Saving Department of SCIVIC Engineering Corporation, Luoyang, 471023, P.R.China

lyglxg@163.com

Aiming at parasitic effect physical design of the power amplifier, according to the load-pull result of input and output impedance by the conjugate match, a wideband high efficiency method of power amplifier was proposed basing on the momentum technology and load-pull method in this paper after using the ADS software. To realize high efficiency, matching circuit is applied to the amplifier to reduce the chip size, which are changed into corresponding momentum components and re-used in schematic design with well improvement design accuracy are designed by the conjugate match method basing on the analysis of unconditional stability, as well as to realize the optimum impedances over a wide bandwidth for high efficiency at each stage. The simulation results showed that the new method could get the optimal output within three iterations, which verified that the new method is a practical and efficient in power amplifier design.

1. Introduction

The Power amplifier (PA) module has been widely used in radar, navigation, electronic countermeasures, satellite communications equipment system, which is the key (Kim and Konstantinou, 2011) to modern wireless communication equipment. High efficiency, high output power, high linearity and high gain power amplifier can be widely used in the digital transmitter, in the field of mobile communication base station and military technology (Song, 2015) has reported the development of 3G and 4G technology requirements of RF microwave power amplifier has a better performance, in order to meet the practical application on the bandwidth, efficiency, and output power and linearity requirements. Ge Qin (2014) pointed out that L-band as a common frequency band in the world; Liao H Y and Pan MW (2010) have proved many systems are working on this spectrum. Therefore, the components and modules on the band have a very wide range of applications (Megherbi and Benramache, 2014).

PA is one of the key components of transmitting front-ends for modern wireless communication systems, electronic countermeasure and radar, and so on. It plays a very important role in transmitter system. RF amplifier is the main energy-consuming module in communication system. Fagotti R (2014) has reported that the efficiency of RF power amplifier not only affects the energy-consuming and stability of the whole communication systems, but also affects the usable time of the battery and dissipating heat of device. Some high efficiency amplifiers, such as power amplifier using non-linear component, envelope tracking power amplifier and multistage Doherty power amplifier, are adopted in foreign and domestic researches. However, these methods increase level of design complexity and device cost. The research to realize high efficiency power amplifier by simple circuits structures, has received more and more attention from researchers.

Usually, the amplifiers are nonlinear devices, especially in high efficiency power amplifier. The linear technology has to be used for improving the non-linearity of power amplifiers (Wang, 2015). Many traditional linearization techniques, such as predistortion and feed forward, should be adopted. (Shen, 2015) has reported these methods require the use of external control circuits and signal processing, resulting in an increased circuits complexity and cost. Under ensuring high efficiency, the power amplifier with considerably high linearity has become attractive difficult problem.

At present, RF power amplifier is developing toward minimization and integration; however, it will affect the performance and the cost of communication systems. Besides, the structure is limited (Hassan and Larson, 2012) greatly in practical application. The miniaturization of power amplifier with high performance is researched. The proposed power amplifier has wide applied value in communication domain.

Other than the prevalent models based design methodology, here with the help of load-pull system, the output power, gain and other characteristic parameters of LDMOS power transistors are measured. Based on the absolute stability analysis, conjugate matching procedure is applied to design the output matching network. Besides, full wave based MOMENTUM algorithm is taken, which is capable of producing accurate electromagnetic models and considering the coupling and parasitic effects at the same time, and therefore MOMENTUM components with more accurate matching network can be achieved to promote the accuracy of electric circuit designs.

2. Momentum analysis

Under the condition of high frequency, physical design plays an important role in the circuit performance. The parasitic effects in practical circuit integration determine the success of the design. However, only upon reaching a certain circuit design specifications, general design method was analyzed parasitic effect. As a result, designers focus on the parasitic effect on the circuit design and physical separation. This kind of logic design and physical design phase separation approach requires the designers to spend more energy in between map and map to find the actual conditions meet the design specifications of the ultimate goal.

In order to break through the bottleneck in the design of a cutting-edge design tool is necessary. Momentum is a three dimensional plane in ADS (Advanced Design System) electromagnetic simulator, using Momentum can calculate micro strip line, strip line, coplanar waveguide electromagnetic properties, such as antenna radiation characteristics, and the parasitic, coupling effect of circuit boards. Momentum calculation methods for the method of moments can produce accurate EM model in the simulation, and considering the coupling and the parasitic effects, the simulation results for the S parameter or produce far zone radiation field and surface current distribution pattern. There are two kinds of Momentum simulation model: Microwave Mode and RF Mode. Microwave Mode called Momentum, it collects by full-wave algorithm, the calculation results more accurate, and can calculate the radiation field; RF Mode call Momentum RF, it uses quasi static algorithm is more efficient, is generally used in frequency is not too high and there is no need to consider the occasion of radiation effect. Momentum has a lot of very powerful and practical function.

The principle diagram of the map element and element association simulation broke the principle diagram of the map element and element between bottlenecks. In circuit simulation, to introduce the physical significance of layout element to simulate the design; Will join the rest of the circuit design layout element circuit simulation, or will join the core chip encapsulation parameters design association (Core Chip Design) do simulation, this can be some physical effects of landscape element, such as linear coupling between into consideration. In addition, the effect of PCB layout element can use Mo2mentum simulation results or the actual.

Momentum can open space, and contains two side or four side wall structure, which makes (Moon and Jee, 2012) the wall of the intercepting, current mirror, and the effects of closed cavity can be taken into account, it is very important for practical circuit design. We will use the ideal principle diagram and the above this Momentum method to design a power amplifier module.

3. Analysis and design

In order to minimize the energy loss in the transmission signal, input and output signal cables with 50 the characteristic impedance of micro strip transmission line and level before and after the match. Matching circuit through the ADS simulation software implementation, the traction load method is adopted to find the best load impedance of power amplifier module.

In this design, a RF power amplifier is design for 925 to 960MHz base station applications, with linear gain of 20dB, P_{3dB} output power of 180w, and P_{3dB} efficiency greater than 60%. At the same time, linearity under WCDMA modulation is measured, which shows the output ACPR is less than -36dBc when the input peak-to-average ratio is 7.5dB and the output power is 20w.

3.1 Load-pull method

In order to make the power solid state devices work under the best condition, and give full play to their potential, to measure the load of traction characteristics are required. By measuring the contour may obtain has important reference value to the power impedance circle diagram, so as to provide reference for the design of high power microwave circuit. There is a lot of research work in this field both at home and abroad.

The so-called traction load, its principle is inspired in large signal level, to test the output power amplifier by continuous load change, draw on Smith chart wait gain and power curve (Tuffy and Guan, 2012). So you can by selecting the appropriate output impedance to design accurately. Traction load method is to be able to accurately find out the best load impedance value, is used to simulate the large signal amplifier features, such as the output power, gain, additional power efficiency, as well as the IMD3 and IP3.

Adopts load drawing method, considering power output and efficiency to get the best load impedance value as shown in Figure1, $Z_L = 6.507 + j5.79\Omega$, the same method, the best source impedance values $Z_S = 1.89 - j5.599\Omega$, Z_L and Z_S is used in the design of matching network.

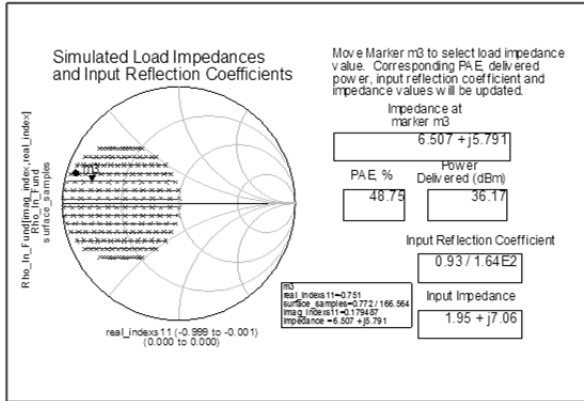


Figure 1: Optimal load impedance obtained by load-pull method

3.2 The design of the matching circuit

Amplifier design is a critical part of the matching circuit design. The input matching circuit is mainly in order to achieve the wide bandwidth and larger power gain; Output matching circuit is to achieve high efficiency and large power output. To consider when designing circuit matching network of the circuit simple, frequency band width, the kind of the circuit and regulatory. Comprehensive the above aspects, this paper use the micro strip line and the mixed discrete component matching network. Micro strip line is at present relatively popular in the planar transmission lines; it can use Gerber to processing, and easily with other passive and active microwave device integration. Micro strip line is at present relatively popular in the planar transmission lines; it can use Gerber to processing, and easily with other passive and active microwave device integration. Under the condition of the material, the characteristic impedance depends on the width of the micro strip line. According to the Eq (1) can calculate the width of the micro strip line:

$$M = \sqrt{\epsilon_{eff}} [1.393 + w/h + 0.667 \ln(w/h + 1.444)] \tag{1}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} (1 + 12 \frac{w}{h}) \tag{2}$$

$$Z_f = \sqrt{\frac{\mu_0}{\epsilon_0}} = 376.8\Omega \quad Z_0 = \frac{Z_f}{M} \tag{3}$$

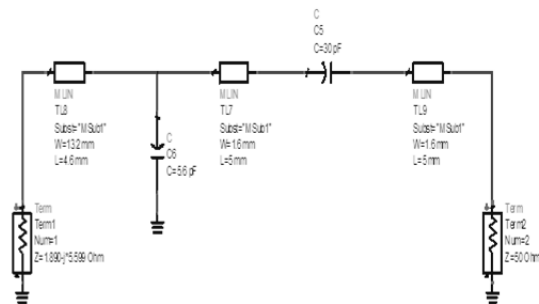


Figure 2: Input matching network

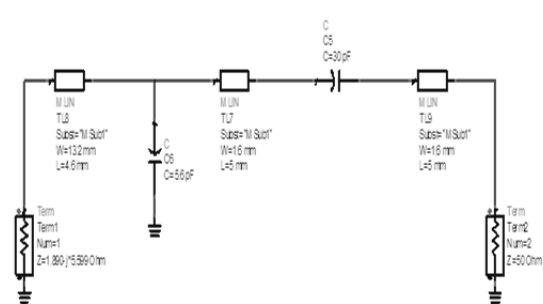


Figure 3: Output matching network

Where, h is medium thickness, Module selects the free scale MW6S004NT1 chip. Considering from module in miniaturization and high performance, using the discrete component and micro strip mixed way of matching, dielectric substrate using ROGERS corporation RO4350B, the relative dielectric constant of 3.48. The whole matching process on Smith chart, and the matching of the circle to the bandwidth of the design need to make full use of Q, finally get the input and output matching network, as is shown in Figure2 and Figure3.

3.3 Stability design

Before determining the best input after output impedance matching, we need the power amplifier stability analysis and design. Stability of the amplifier, the amplifier design is a very important factor; it generally depends on opposite ends of S-parameters and conditions of the transistor. PA stability can be determined based on a stable factor, calculated as follows:

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\sigma|^2 \quad (4)$$

$$B_2 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\sigma|^2 \quad (5)$$

$$K = \frac{B_2}{2 \times |S_{12} \times S_{21}|} \quad (6)$$

The formula needs to meet $B_1 > 0$, $K > 1$ Amplifier is absolutely stable. If the result of instability in the input or output port negative resistance when it may oscillate, you need to use the input or output end in series or in parallel or negative feedback method of the transistor stable. The design of the power amplifier stability curve MRF18030, Obviously, the design frequency range is absolutely stable. Stability factor must be greater than 1; the stability factor must be greater than zero.

3.4 The design of PA Momentum

Circuit schematic diagram of the simulation was conducted under the condition of ideal completely, and the actual circuit board production, often there is a difference and theory, it is need to consider the effect of factors such as interference, coupling. To map need to be further simulation. ADS map by Momentum method for electromagnetic simulation, the simulation results in the schematic diagram are more accurate.

Agilent Momentum is leading plane three-dimensional electromagnetic simulator, can be used in the passive circuit modeling and analysis. Can emulate any geometric structure design (including multilayer structure), and using frequency domain method of moments technology, the precise simulation of complex electromagnetic effect (including the coupling and parasitic). Accurate electromagnetic simulation can support RF/MMIC RF module, RF/high-speed circuit board, Sip and antenna designers improve the design performance, and ensure that the products can reach technical indicators. Momentum is a combination of static electromagnetic full-wave solver, used for RF passive components, high frequency interconnection and parasitic modeling. Its efficient grid, adaptive frequency sampling and thread NlogN solver, can shorten the simulation time and simulation of complex electromagnetic effects, including skin effect, substrate effect, thick metal and dielectric effect. The matching network is transformed into Momentum components in the circuit design, the combination of bias circuit to get a PA module circuit as shown in Figure 4.

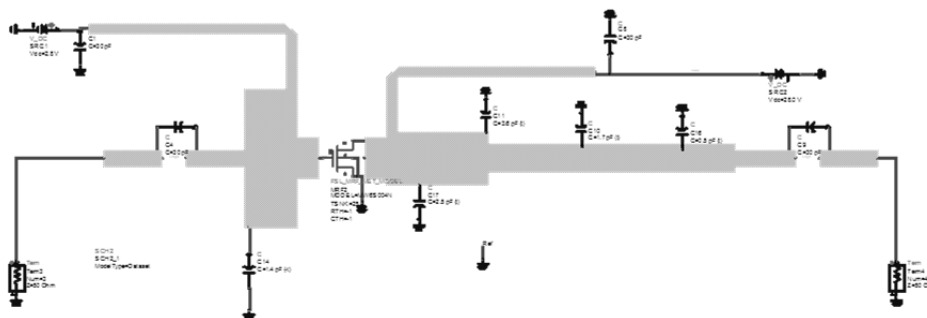


Figure 4: The design of PA Momentum

Mono harmonic balance method to the simulation of circuit set the drain voltage to 28V, grid voltage of 2.8V. Working frequency of 1.95GHz, scanning power of 0~25dBm. The simulation results are shown in Figure 5 can be seen from the Figure, the output power of the circuit is 1dB compression point approximately 36dBm, about 20dB gain, power added efficiency by about 40%, meet the design requirements.

Dual harmonic balance of circuit simulation, the result is shown in Figure6, when the output power is 36dBm the IMD3 approximately 30 dBc, which has a good performance.

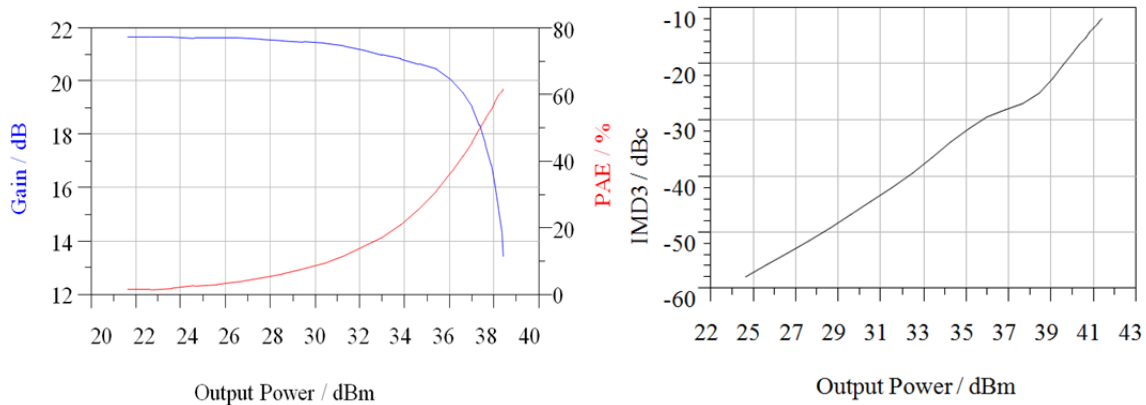


Figure 5: Relationship curve of gain, PAE and output power Figure 6 Relationship curve of IMD3 and output

4. Experimental results and analysis

In power amplifier design, the load-pull test error introduced into the system, the circuit board processing error, plus LDMOS power transistor manufacturers produced each transistor there will be differences, could cause actual results and simulation difference can be significant. Therefore, in order to make the performance of the microwave power amplifier to achieve the desired performance, it must be repeated debugger designed microwave power amplifier. Amplifier debugging mainly by adjusting the quiescent point, input and output matching circuit to reach to meet all the indicators in the working band, these indicators include output power, gain, and efficiency and so on.

During commissioning, you must first be familiar with the operation of a variety of microwave equipment to prevent damage to test equipment during use; second, we must understand the protection method to prevent microwave radiation injury to persons.

According to the momentum simulation circuit module for processing, after repeated testing, after debugging test instrument using vector network analyzer Agilent new PNA-XN5242A, get the gain curve is shown in Figure 7, you can see the small signal gain of 19.7dB at center frequency 1.95GHz, well agreement with the simulation curve. Figure 8 for module IM3 curve, the curve is shown in the 1.9GHz to 1.95GHz frequency band range, IM3 under-31dB, which has a good linearity.

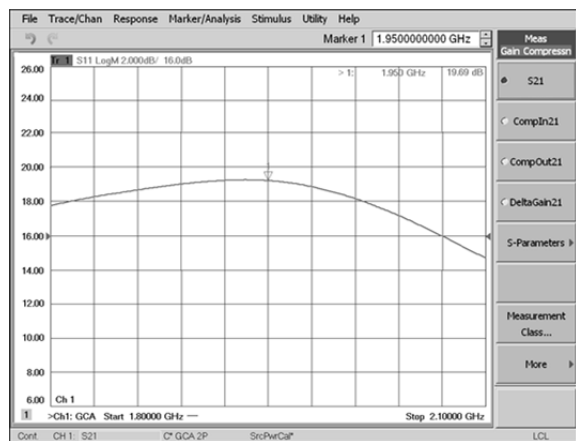


Figure 7: Gain curve of the PA

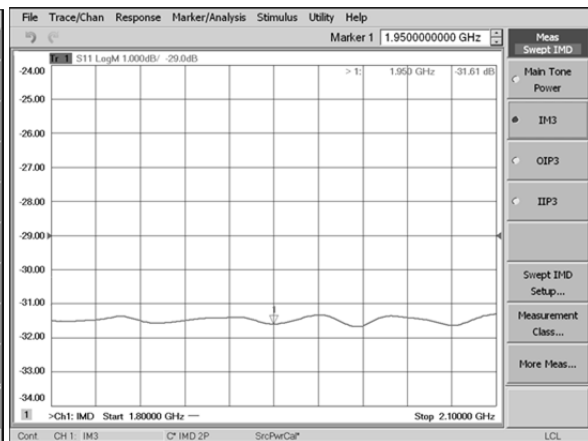


Figure 8: IM3 curve of the PA

Table1 compares the performances between this work, class-F(Liao and Chen, 2009), and IBM SiGe BiCMOS technology(Song J, Wang Z and Peng Y,2008), conventional class-E(Mury et., 2011) and SiGe HBT(Mury and Vincent, 2011). The measured efficiency and harmonics suppression are excellent among the summarized reports.

Table 1: Performance comparison with previously published works

Parameter	class-F	SiGe BiCMOS technology	conventional class-E	SiGe HBT	This work
f (GHz)	3	2.3	2.5	2.3	1.9
V_{DD} (V)	7	3.1	1.7	3.3	5.8
P_{1dB} (dBm)	25.3	21	19.6	27.5	32
PAE (%)	21.8	55	23.1	46	56
Gain (dB)	20.7	9.7	14.9	31	34
Class	AB	E	F	-	F
2nd/3rdHar (dBc)	-45/-52	-50/-46	-32/-33	-44/-49	-53/-60

5. Conclusions

In this paper, we have designed a wide band high efficiency power amplifier based on Momentum method. Momentum method makes the design of the PA from the simple circuit level rose to the physical level, the result more accurate. Throughout the design process, the momentum method using Smith chart for input and output impedance of conjugate matching, make full use of Q round to design the bandwidth, high performance PA module, The real test of load-pull system can reach 0.5Ω impedance point. The load-pull impedance value of the maximum power point of the transistor and the point of maximum efficiency, optimal use of traction out of the input and output impedance point, carried ADS simulation design, LDMOS power transistor matched to 50Ω . Test results show that the module 1dB output power for about 36dBm, PAE at close to 39%, the gain of the center frequency 1.85GHz, 20dB, at 1.6GHz~2.0GHz frequency band range gain in more than 15dB, IM3 under -31dB, which shows that this design could be a good driver amplifier for use in measurement systems and instrumentation applications. Test results and simulation results to verify the validity of the design.

References

- Fagotti R., Cidronali A., Manes G., 2011, Concurrent Hex-Band GaN Power Amplifier for Wireless Communication Systems, IEEE Microwave and Wireless Components Letters, 21, 89-94. Doi: 10.1109/LMWC.2010.2098859
- Ge Q., Tao H.Q., Yu X.M., 2014, a 1.8-3GHz-band high efficiency GaAs pHEMT power amplifier MMIC, Journal of Semiconductors, 36, 1-4.
- Hassan M., Larson L.E., Leung V.W., 2012, A combined series-parallel hybrid envelope amplifier for envelope tracking mobile terminal RF power amplifier applications, IEEE J Solid-State Circuits. 47, 1185-1198. Doi: 10.1109/JSSC.2012.2184639
- Kim J., Konstantinou K., 2011, Digital predistortion of wideband signals based on power amplifier model with memory, Electronics letters, 23, 1417-1418. Doi: 10.1049/el:20010940
- Liao H.Y., Chen J.H., Chiou H.K., 2009, Harmonic control network for 2.6 GHz CMOS class-F power amplifier, IEEE International Symposium on Circuits and Systems, 29, 1321-1326.
- Liao H Y, Pan MW, Chiou H K, 2010, Fully-integrated CMOS class-E power amplifier using broadband and low-loss 1:4 transmission line transformer, Electron Lett, 22, 1490-1498.
- Megherbi A.C., Benramache S., Guettaf A., 2014, Backgating effect in GaAs Fets with a channel-semi-insulating substrate boundary, Journal of Semiconductors, 35, 034004-06.
- Moon J., Jee S., Kim J., 2012, Behaviors of class-F and class-F-1 amplifiers, IEEE Trans Microw Theory Tech, 60, 1937-1943.
- Mury T., Vincent F., Peter G., 2011, Power-combining class-E amplifier with finite choke, IEEE Trans Circuits Syst, 58, 451-456.
- Raghavan A., Deukhyoun H., 2002, a 2.4GHz high efficiency SiGe HBT power amplifier with high-Q LTCC harmonic suppression filter, IEEE MTT-S International Microwave Symposium Digest, 2, 1019-1025.
- Shen Z.J., Wang R.G., Sun G.C., 2015, SVPWM algorithm in Using variable-frequency air conditioner control system, Chemical Engineering Transactions, 46, 343-348. DOI: 10.3303/CET1546058
- Song Q.X., 2015, Research on Steel pipe tracing system, Chemical Engineering Transactions, 46, 133-138.
- Song J., Wang Z., Peng Y., 2008, A 2GHz power amplifier realized in IBM SiGe BiCMOS technology 5P Ae, Journal of Semiconductors, 29, 2101-2105.
- Tuffy N., Guan L., 2012, A simplified broadband design methodology for linearized high-efficiency continuous class-F power amplifiers, Microwave Theory and Techniques, 6, 1952-1963.
- Wang E.N., Chen L., 2015, A novel normal cloud-based model for distributed transmission and aggregation of the information, Chemical Engineering Transactions, 46, 127-132. DOI: 10.3303/CET1546022