A design of L-band second harmonic power amplifier

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Abstract. In the recent years of rapid development of communication technology, the transmission power and efficiency of RF signals are required for much higher level. As a key part of the transmitter, the performance of the power amplifier is considered a crucial part of the overall performance of the system. Compared with the traditional power amplifier, better performance can be achieved by the second harmonic power amplifier in the large signal state, and higher efficiency can also be obtained. A design of an L-band second harmonic power amplifier is proposed in the article. CREE’s gallium nitride transistor is selected for simulation through ADS software, and a drain efficiency of more than 70% can be achieved in the final test.

Keywords: Second harmonic, Power amplifier, Efficiency.

1. Introduction
With the continuous upgrading of mobile electronic products, for a battery with a limited capacity, a higher overall efficiency is equivalent to an increase in the use time of the product. Power amplifier (PA, hereinafter referred to as power amplifier) is generally considered as a key component of energy consumption indicators in the transceiver system. Under the condition of ensuring linearity and output power up to standard, research on improving the efficiency of power amplifiers is developed as the main attention of major manufacturers.

Changing the bias point and reducing the conduction angle are adopted for traditional power amplifier to improve the efficiency of the power amplifier, while the output power and gain of the power amplifier are reduced in general [1]. Due to the presence of non-linear components in the design of the power amplifier, it will be affected by the various harmonics. If it can be used to adjust the drain voltage and current waveform of the power amplifier, reducing the power consumption caused by the overlap of the two, the power amplifier efficiency can be significantly improved. At the same time, the output power of the power amplifier is also increased to a certain extent under the guaranteed gain [1]-[3].

The drain voltage and current of the power amplifier are shaped by second harmonic tuning power amplifier through the second harmonic [4]. In the case of large signal operation, a square wave state of the drain current waveform is shown to reduce power consumption. In general, it is a harmonic power amplifier design with a significantly improved overall performance [5] [6].

2. Design Theory of Second Harmonic Tuned Power Amplifier
For the design of harmonic power amplifier, similar with traditional power amplifier, various indicators are chosen for a trade-off as well. The design bias of traditional power amplifiers is more obvious. Higher efficiency can be obtained when working at a class C bias point [7], and higher gains can be
obtained when working at a class A bias point [8]; relatively, greater design freedom could be got by harmonic power amplifiers. Besides, the design can be combined with the advantages of bias point and harmonic tuning to a certain extent.

In view of the attenuation of harmonics, only considering the influence of the third harmonic in the circuit, the voltage at the drain can be expressed as:

$$v_{DS}(t) = V_{DD} - V_1 \cdot [\cos(\omega t) + k_2 \cdot \cos(2\omega t) + k_3 \cdot \cos(3\omega t)]$$

(1)

Among them $k_n = \frac{V_n}{V_1}$ is the normalization processing based on the fundamental frequency voltage amplitude, $V_{DD}$ is the drain power supply voltage value, and $V_n$ is the harmonic voltage amplitude value of each order. The non-harmonic tuning condition is usually used as a measurement standard and is called a Tuned Load Power Amplifier (TLPA). The $k_3$ value in the design of the second harmonic power amplifier (2HTPA) is zero, and the drain waveform of the power amplifier is mainly adjusted by the value of. The expression of its drain voltage is written as follows:

$$V_{DS,N} = \cos(\omega t) - k_2 \cdot \cos(2\omega t)$$

(2)

Derivation of the parameters in the second harmonic power amplifier is written as follows:

$$\frac{\partial v_{DS,N}(\theta, k_3)}{\partial \theta} = \sin(\theta) + 2k_2 \cdot \sin(\theta) = 0$$

(3)

Considering that the solution of the equation needs to be practical, it can be known that $k_2 \in \left[ k_2 \leq -\frac{1}{4} \right] \cup \left[ k_2 \geq \frac{1}{4} \right]$ the differential equation has a solution at that time and should satisfy $\delta(k_2) > 1$, this time $k_2 < 0$, so it can be obtained:

$$\delta_2(k_2) = \begin{cases} 
-\frac{1}{k_2 + \frac{1}{8k_2}} & k_2 \leq -\frac{1}{4} \\
\frac{1}{1 + k_2} & -\frac{1}{4} \leq k_2 \leq 0 
\end{cases}$$

(4)

The maximum $\delta_2$ value obtained from this is $\sqrt{2}$ at this time. As shown in theory, the drain efficiency and output power of the power amplifier under the second harmonic tuning are improved to a 42% theoretical growth compared with the non-harmonic tuning. At the time, the phase state of second harmonic is presented inverse phenomenon to the fundamental frequency signal.
3. Simulation design and testing

3.1. Simulation Design of Second Harmonic Power Amplifier

In the simulation, the CGH40010F transistor is selected as the core, the working center frequency is 1.5GHz, the bias point selection gate voltage is -3V, the drain voltage is 28V, it is in deep AB working mode, the maximum drain current is 1.5A, and the knee voltage is 7V. Compared with the case of no harmonic tuning, the fundamental impedance of the two and the harmonic control of the second harmonic power amplifier are shown in the Smith chart as follows:

![Figure 1. The 2HTPA impedance in Smith chart.](image)

Compared with the case of no harmonic tuning power amplifier, the fundamental frequency impedance point of the second harmonic power amplifier is also promoted to times. This is because that the fundamental frequency voltage amplitude is increased by the introduction of the second harmonic, and the fundamental frequency impedance needs to be adjusted synchronously to avoid excessive drain current. Through the traction design of the two, the comparison between the two in terms of output power and efficiency is shown as follows:
Through the comparison of simulation results, it can be included that compared to the case of no harmonic tuning, the second harmonic power amplifier basically has no loss of gain performance, and the output power and efficiency in the large signal working area have been significantly improved. Follow-up circuit input and output matching design, due to the low operating frequency, the performance of the power amplifier does not change much after verification by electromagnetic simulation. The final layout structure of the second harmonic power amplifier is shown as follows:

3.2. Power amplifier processing and testing
The power amplifier substrate material is RO4003C, the thickness is 0.508mm, and the via is metalized and grounded. Through processing and assembly, the final physical picture of the finished product is shown as follows:
Power up the above power amplifier test, where the gate voltage is -3V, the drain voltage is 28V, and the input power range is from 0dBm to 30dBm. The performance test results of the power amplifier are shown as follows:

![Graphs showing output power and drain efficiency](image)

(a) the Output Power  (b) the Drain efficiency

Through the test results, it can be found that the power amplifier can basically maintain a gain of 15dB in the linear region, and the linearity is better. The above two test results show that the saturated output power is about 42dBm, and the drain efficiency can reach more than 70% at this time. Compared with the 40dBm typical 60% drain efficiency value given in the official data manual, the performance improvement of the power amplifier is more obvious.

4. Conclusions
This article explains the basic theory of the second harmonic power amplifier. Through ADS software simulation design and subsequent processing tests, the saturated output power can be finally obtained above 42dBm, and the maximum drain efficiency is above 70% for typical bias point. Compared with the typical reference performance indicators provided by the die, the design presented in this article significantly improves the performance indicators in terms of output power and efficiency while ensuring the gain of the power amplifier. As a highly practical power amplifier performance optimization technology, the good operability and broad development prospects can be expected for harmonic tuning technology.

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