Optimized E-Class Power Amplifiers Widely Covering 4.5 GHz from 2.5 to 7.0 GHz

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Abstract

Based on TSMC 0.18 micron process, the fabricated CMOSFET devices, whose model is implemented in Agilent ADS, are used to design an E-Class power amplifier. This radio frequency amplifier is optimized to cover 2.4 to 7.1 GHz, in which two center working frequencies, 5.0 GHz and 6.0 GHz, are intentionally included. The resulting gain (S21) is always higher than 20dB, while the isolation addressed by S12 is shown to be as low as -35dB. S11 and S22, which are responsible for impedance matching, are tuned to be as low as possible. Therefore, the applicable frequency range is demonstrated to be as wide 4.5GHz from around 2.5GHz to around 7.0GHz. Also, the minimum noise figures (NFmin) are found to be less than 1.0 at the center working frequency 5.0GHz and 1.2 at 6.0GHz. Those promising results encouragingly promote this power amplifier with a low noise feature.

Keywords: Power amplifier, RFIC, Broad band, 5G network

1 Introduction

Modern technology unifying the cell phone in communication and the web greatly promotes and impacts current development, and is supposed and expected to be overwhelming in the future. The extremely integrated transistors, which are so-called acceptably low cost, and higher-speed devices with noticeable noise-immunity, are used to even make analog signals digitalized. Owing to the high level of repeatability and reliability based on the stable processing for manufacturing MOSFET devices, the design of radio frequency integrated circuit (RFIC) becomes efficiently generated on Advance Design System (ADS) with implemented TSMC 0.18 micron model.

Three important amplifiers, OPA (operational amplifier), LNA (low noise amplifier) [1-3] and PA (power amplifier), may be used in modern communication system. As the signal through the microphone forms on the transmitter site, an optional way is to integrate the signal using OPA and mixer to enhance the phase of the radio frequency (RF) carrier wave for frequency modulation, which takes the advantage of high noise immunity of RF carrier waves. Carriers with the signals carried gets power amplified on PA prior to the antenna. On the receiver site, carrier waves are received through antenna and predominantly low noise amplified for suppressing the noise for the whole subsequent components. The signal is to be popped up using phase lock loop (PLL) to RF capably differentiate the low noise amplified carrier wave.

Wide-band applications are so popular because of revolutionary communication algorithms not only combining analog to digital (AD) and digital to analog (DA) but also computer added wide band network development. Cellular phones with functions of network and associated or installed memory become smart enough to strengthen information share. Artificial Intelligent, such as convolution neural network (CNN, image sorting) and recurrent neural network (RNN, speech recognition), are impressively implemented in the communication system as the basic functions on the smart phone. Semi-conductor fabricated photo-detectors or photo-sensors are thus responsible for collecting data which are processed immediately by high speed micro-control unit (MCU). [4-8]

In the era of mobile broadband network, the subsequent and thus the upcoming fifth generation (5G technology) is ushered with higher speed, superior reliability, and ignorable lower latency. The telecommunication 5G makes possible enhanced mobile broadband, the massive internet of things, and even mission-critical communications. For example, navigation using 5G network helps achieve finding the best vehicle route by an efficient algorithm in multiple-objective optimization (MOO) problem. In addition, certain specific 5G technique, such as network slicing, is proposed to enable a single net to meet differential needs from multiple tenants. In the near future, 6G is supposed to be speeded up for user level [9-11].

In this paper, the mechanism for an E-class power amplifier is proposed and the optimization of the applicable band width has been done for the communication system. However, the newly developed technique might be provided as an encouraging option in radio frequency circuit area. An advisable E-class power amplifier with low noise figure in this study is promoted. Basically, the amplifier, centrally working at 5.0 GHz, 6.0 GHz or around, is tuned to fit impedance matching. The applicable band width is defined through S21 which is greater than 20dB, and is intentionally widened by varying capacitance and inductance of specific capacitors and inductors, respectively.

2 Circuit Design of Low Noise Power Amplifier

In E-Class PA circuit [2-3] as presented in Figure 1, C_V value is varied by fixing the inductance of L_O to change the

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central working frequencies at either 5.0GHz or 6.0GHz. DC voltage source (Vdd) attaches to Gate of M5 through L5 which shows no impedance because of Z_L=jωL_O and also prevents high frequency signals from escaping from the circuit. The signals are mainly amplified in the two sets, (M1, M2, M3) and (M4, M5), and the ranges of amplification are adjusted by tuning two equivalent filters with (C2, L2) and (C3, L3). S11 and S22, addressing the reflective signals and are expected to be as low as possible. Once S11 and S22 approach to zero, the voltage gain (S21) is supposed to go up high. The desired S21 is tuned up above 20 dB,

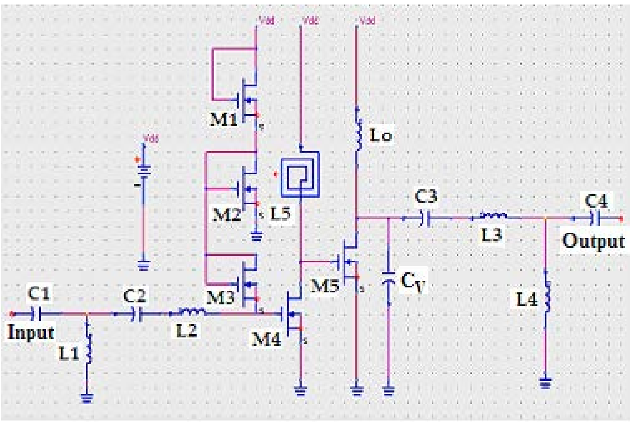


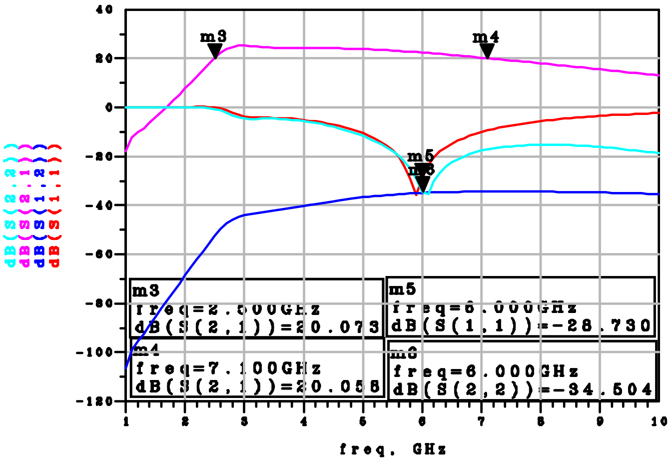
Figure 1. An extensively band-widened low noise E-class power amplifier

3 Results and Discussion

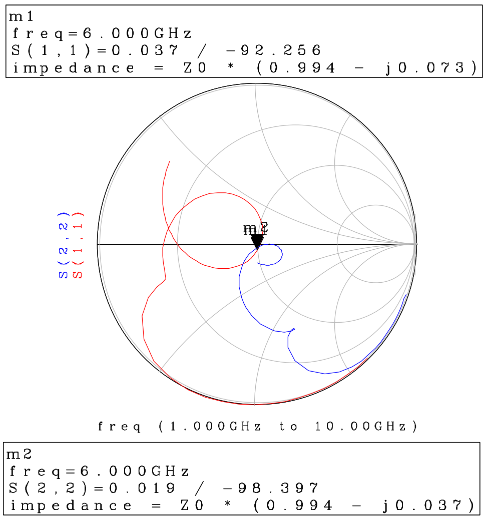
Wide band applications are noticeable because of the popularity of network, which have become significant throughout the globe. Radio frequency integrated circuits associated with the communication serve to be responsible for providing high-quality signals. As shown in Figure 2(a) and Figure 3(a), an amplifier capable of wide-band functioning and low noise figure is extensively applicable [6-8]. The tuning skill is due to Smith Chart, where S11 and S22 are observed and expected to be an close as to the center of the Chart. After careful calibrating, Figure 2(b) and Figure 3(b) demonstrate that both do approach to the origin, namely impedance matching. The linearity shown in Figure 2(c) at 6.0GHz and Figure 3(c) at 5GHz is convincing. In addition, the minimum noise figures found in Figure 2(d) at 6.0GHz and Figure 3(d) at 5GHz, somewhere between 0.9 and 1.2, are also encouraging. Therefore, the above promising performances thus provide significant features for future applications, which are thus qualified as an power amplifier with wide-band and low noise characteristics (WBLNPA).

For an amplifier, S21 over 20dB is often referred to, which is corresponding to the voltage gain over 10. Furthermore, many RFIC is specifically subjected to narrow band with higher Q, where Q is defined to be the ratio of the maximum imaginary consuming power to the maximum real consuming power. For wide band circuit associated with low Q, tuning difficulty comes from the impedance matching. Therefore, lower Q takes a lot more careful matching steps compared to higher Q.

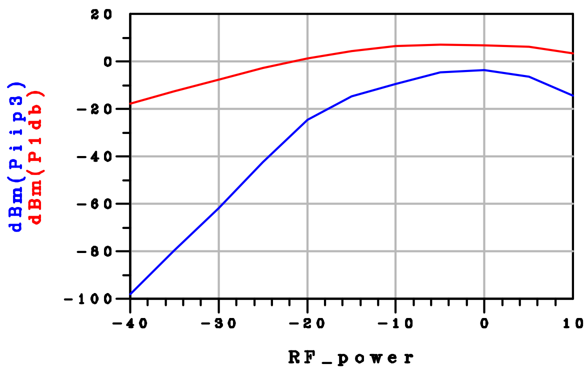
The procedures involve choosing either 6.0GHz or 5.0GHz to be the targeted working frequency. And at various C_V's, Figure 2(a) and Figure 3(a) with mark_3 and mark_4 pinning down the lowest frequency and the highest one, respectively, appear to be promisingly applicable over as wide as 4.5 GHz. At center working frequency at 6.0 GHz, the collected data is listed Table 1, and the maximum bandwidth in between 2.5 GHz and 7.1 GHz can be as wide as 4.6 GHz at C_V= 0.01pF. Besides, at center working frequency at 5.0 GHz, the collected data is listed Table 2, and the maximum bandwidth in between 2.55 GHz and 6.85 GHz can be as wide as 4.3 GHz at C_V= 0.04pF. Surprisingly, both Tables show that an amplifier with wider band applications prefer large impedance Z_C, which means almost open to ground. On the other hand, the two inductors (L_O and L5) built in the circuit as in Figure 1 make V_{dd} short to the gate and prevent signals at higher frequency from leakage, which may promote radio frequency designs.



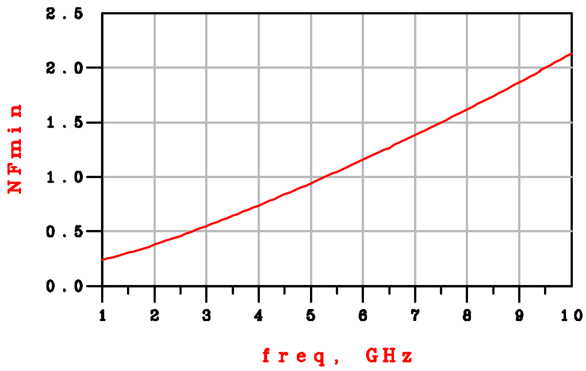
(a) S-matrix of an LNPA at 6.0 GHz



(b) S11 and S22

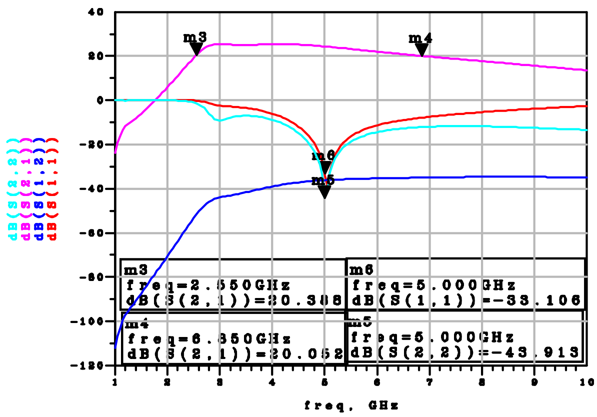


(c) 1dB compression point

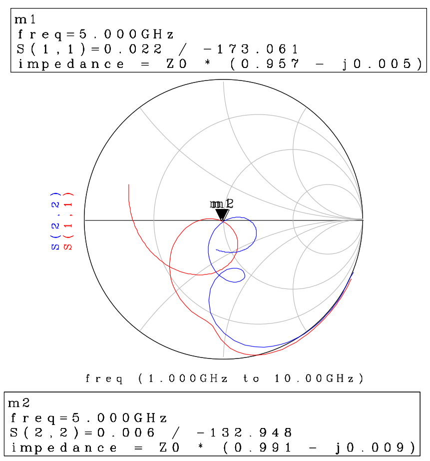


(d) NF_{min}

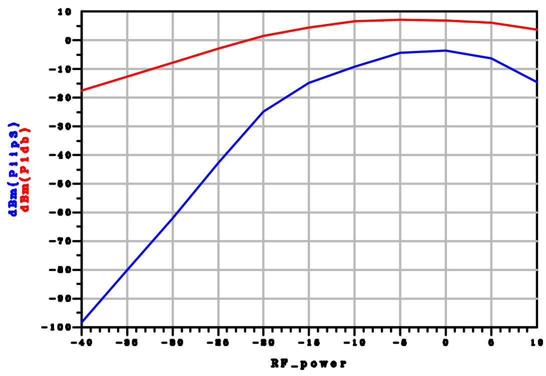
Figure 2. (a) S-matrix of an LNPA at 6.0 GHz (b) S11 and S22 (c.) 1dB compression point (d) NF_{min}



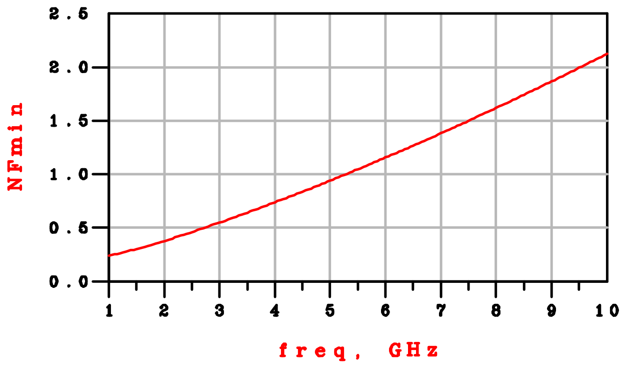
(a) S-matrix of an LNPA at 5.0 GHz



(b) S11 and S22



(c) 1dB compression point



(d) NF_{min}

Figure 3. (a) S-matrix of an LNPA at 5.0 GHz (b) S11 and S22 (c.) 1dB compression point (d) NF_{min}

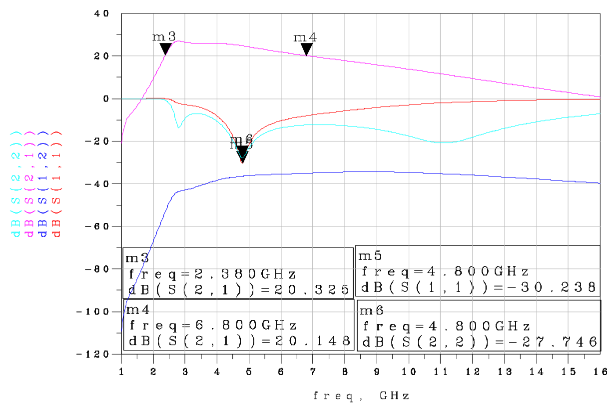


Figure 4. The applicable frequency band is shown to be extensively enlarged with modified lowest S11 and S22 at 4.8 GHz.

4 Conclusion

E-class power amplifier may be enhanced by adjusting the values of C_V at fixed L_O. However, to sustain the applications on RF signals, L_O is kept large as possible, and C_V is kept low as possible, as shown in Table 1 and Table 2. Also, the power added efficiencies are determined to be about 76.1%, which is encouraging. Moreover, to address the dynamic range and spurious dynamic rang, P1dB and iiP3 are determined to be 3 dBm and 12 dBm, respectively. If the frequency band is set to 4.0 GHz, noise figure is taken to be 1.0 dB in this study, and thus the minimum output power level is -54dBm, the dynamic range and the spurious dynamic range are then determined to be 57.0 dBm and 44.0 dB, respectively, which are really applicable and encouraging.

One interesting thing is that the bandwidth becomes much narrower as the C_V value is increased. From C_V=0.01pF to C_V=0.6pF, the bandwidth drops from 4.6 GHz to 2.28 GHz in Table 1, From C_V=0.01pF to C_V=0.6pF, the bandwidth drops from 4.6 GHz to 2.28 GHz in Table 1, while from C_V=0.04pF to C_V=4.04 pF, the bandwidth drops from 4.3 GHz to 0.2 GHz in Table 2. The explanation shall be provided in the near future.

Also, the bandwidth range is adjustable as one chooses the center working frequency to be 4.8 GHz. As shown in Figure 4, the applicable frequency band covers 2.4 GHz with the range from 2.36 GHz to 6.8 GHz.

Table 1. Band width by varying CV

6.0GHz as the center working frequency			
C_V (pF)	m1 (GHz)	m2 (GHz)	Band Width(Hz)
0.01pF	2.5	7.1	4.6GHz
0.1pF	2.6	7.1	4.5GHz
0.2pF	2.8	6.8	4.2GHz
0.3pF	2.9	6.9	4GHz
0.4pF	2.8	6.8	4GHz
0.5pF	3.1	6.7	3.6GHz
0.6pF	4.3	6.9	2.28GHz

Table 2. Band width by varying CV

5.0GHz as the center working frequency			
C_V (pF)	m1 (GHz)	m2 (GHz)	Band Width(Hz)
0.04pF	2.55	6.85	4.3GHz
0.14pF	4.1	5.6	4.0GHz
0.84pF	3.9	5.7	1.8GHz
1.54pF	4.6	5.3	0.7GHz
2.04pF	4.8	5.2	0.4GHz
3.04pF	4.9	5.1	0.2GHz
4.04pF	4.9	5.1	0.2GHz

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Biographies

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