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Design of Wide-band Power Amplifier Using Power Combining Technique for S-band Communication Applications

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Abstract

This paper presents design of S-band wide-band power amplifier using power combining technique. Class-A amplifier topology, and Avago Technologies's ATF-511P8 Gallium Arsenide (GaAs) high linearity E-pHEMT transistor are used in this design. Advanced design system software used to simulate the designed circuit. The simulation results show that the designed amplifier is stable over the bandwidth, where stability factor k > 1. It shows input return loss S_{11} less than -10dB, gain S_{21} higher than 10 dB, which approximately 15 dB over the bandwidth. Inter-modulation distortion less than -50 dBc, which considers as low inter-modulation distortion. The designed power amplifier can be used in satellite communications, wireless applications (WLAN, WiMAX), and other applications related to microwave engineering.

Keywords: Power Amplifier, wide-band, Inter-modulation distortion.

INTRODUCTION

The rapid growth of mobile telecommunication services has increased demand for low-cost, high-efficiency, and compact equipment. Generally, power amplifier (PA) is one of the most important subsystems for radio frequency (RF) transmitters. In addition, it is also a component which requires a lot of electrical power [1]. Power amplifiers are main blocks for constructing wireless communication systems. Also, radio frequency power amplifiers are one of challenging blocks in designing RF transceivers, this is due to non-linearity behavior of power Amplifiers that leads to inter-modulation distortion. From the transmitter point of view, the power amplifier (PA) is the most critical component since its performance strongly influence the overall system features in terms of bandwidth, output power, efficiency, and operating temperature. This makes wide-band PAs that cover many frequency bands while maintaining high efficiency an important research topic. Nowadays, Wireless network is a network system which used by all people around the world in many fields of the life and becomes one of the important demands. Wide-band power amplifier design becomes more important because; wider bandwidths are required to cover many microwave applications such as radar communication, WiMAX, satellite communications, military communication, and other related applications. Designing of wide-band power amplifier will cause a problem in generating more inter-modulation distortion products that make power amplifiers have losses. And therefore will influence on the efficiency of power amplifier. In other words, the higher the input signal power, the higher the output signal power produced and the more the inter-modulation distortion (IMD) product generated due to more frequency interferes with each other in the large frequency range. Reduce the input power will make the power amplifier to loss its identity as a device to make the signal strong to propagate in the medium [2].

RF power Amplifier circuits consist of several components: Transistor, DC biasing circuit to let the transistor work in its an active region, input and output matching networks to allow maximum power to transfer from input to output. Figure 1 shows the components of RF power amplifiers.

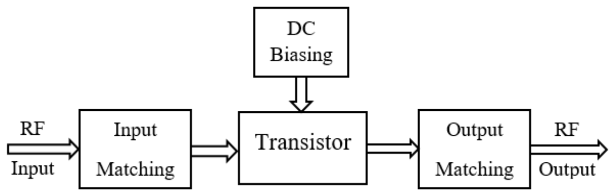

Figure 1: Components of RF Power Amplifier

High power, and wide-band power amplifier using gallium nitride-high electron mobility (GaN-HEMT) technology was proposed in [3], this work has achieving that 10W output power with approximately 15dB gain, and maximum power added efficiency (PAE) of 61%. However, this work suffers from a limited bandwidth which is 1.1GHz, and which does not meet the specifications of wide-band power amplifier. In [4], C-band microwave power amplifier design proposed by A.S.Alqadami and M. F. Jamlos for wireless applications , the design can achieve up to 2.14dB gain and covers from 5.6 GHz to 6 GHz frequency band. However, the covered bandwidth only 0.4 GHz which cannot be considered as wide-band. Recently, many researchers designed and developed power amplifier, but most of the designed power amplifiers have been suffered from limited bandwidth and high inter-modulation distortion which is consider as a measure for linearity of amplifier (between -20 and -30dBc) [5],[6],[7],[8]. In this paper, a wide-band RF power amplifier using power combining technique is designed for S-band. Where the frequency band (2 GHz to 4GHz) is divided into two bands which are 2 GHz to 3 GHz & 3 GHz to 4 GHz respectively. Then to combine two bands, power divider/combiner has been used in this design. Due to -3dB insertion loss of power divider/combiner which will reduce the gain of each stage, two cascaded transistors are implementing for each stage in order to avoid this problem. Band pass filter (BPF) is designed for two bands to be used for each band separately in order to allows only the desired frequency band to pass through amplifier, and this will reduces the inter-modulation distortion causes by new frequency components generated in a wide-band. Single-section quarter wave transformer matching network is designed to provide maximum power delivered to the load. The design meets the requirement of wide-band frequency band which covers from 2 GHz to 4 GHZ. Simulated results of the designed wide-band power amplifier are presented.

RESEARCH METHOD

A. Power Combining Technique

Power combining technique is one of the most design concepts used in designing of wide-band power Amplifier, due to its ability to achieve high output power and huge bandwidth rather than others. The concept of power combiner technique can be described as follows: two or more amplifiers arranged in parallel. Where their inputs connected to the output of power divider, and their output recombined by using power combiner [9]. Figure 2 shows power combining technique.

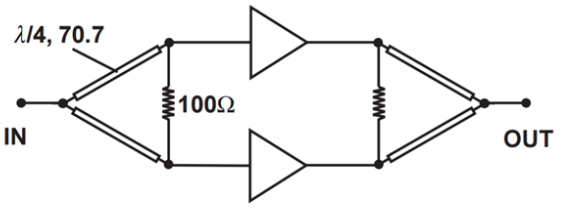

Figure 2: Two Stage Amplifier using Power Combining Technique [9]

B. Parallel Coupled Line BPF

The purpose of using band-pass filters at the input and output of amplifiers is to allow only the required bands to pass through the amplifier and will lead to remove unwanted frequency components generated in a wide band of the amplifier. Steps of designing parallel coupled line BPF are shown in equations below.

$$n \geq \frac{\cosh^{-1}\sqrt{\frac{10^{0.1L_{AS}}-1}{10^{0.1L_{Ar}}-1}}}{\cosh^{-1}\Omega_s} \qquad (1)$$

$$Ripple\ level, L_{Ar} = -10\log(1-10^{0.1L_R})\ dB \qquad (2)$$

$$Stopband\ attenuation, l_{As} > 40dB \qquad (3)$$

$$Ripple\ level, L_{Ar} = 0.1dB \qquad (4)$$

$$Return\ loss, L_R = \frac{\log\left(1-10^{\frac{-L_{Ar}}{10}}\right)}{0.1} = -16.42dB$$

Number of order, n= 3

$$g_0 = 1.0000$$

$$g_1 = 1.0316$$

$$g_2 = 1.1474$$

$$g_3 = 1.0316$$

$$g_4 = 1.0000$$

$$Z_{oJi,i+1} = \sqrt{\frac{\pi\ FBW}{2\ g_i\ g_{i+1}}}\ , \text{where } i = 0 \text{ and } n \qquad (5)$$

$$Z_{oJi,i+1} = \frac{\pi FBW}{2\sqrt{g_i g_{i+1}}}\ , \text{where } i = 1 \text{ to } n-1 \qquad (6)$$

$$FBW = \frac{w_2 - w_1}{w_0}$$

$$(Z_{oe})_{i,i+1} = \left[1 + Z_{oJ\ i,i+1} + \left(Z_{oJ\ i,i+1}\right)^2\right] \qquad (7)$$

$$(Z_{oo})_{i,i+1} = \left[1 - Z_{oJ\ i,i+1} + \left(Z_{oJ\ i,i+1}\right)^2\right] \qquad (8)$$

C. Design Procedure

In designing WPA, there are several steps needed to carry out:

- **Transistor selection**

The transistor that has been selected in this work is ATF-511P8 provided by Avago technologies. The device is ideal as a high linearity, low-noise, medium power amplifier. Its operating frequency range is from 50MHz to 6 GHz. This transistor is manufactured undergo Gallium Arsenide Enhancement Mode pHEMT process.

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- **Biasing network**

Biasing network uses to supply the transistor with optimum dc voltage, to give optimum performance of WPA. The topology of biasing network is voltage divider network.

- **Matching network**

The matching network uses to provide maximum power delivered to the load. Matching network is usually place between the transistor and the source (input matching), and between transistor and the load (output matching). Single section quarter wave transformer technique uses as a matching network, because it considers as a useful and practical circuit for impedance matching, furthermore its simple transmission line circuit [10].

D. Circuit Design and Simulation

According to designs in previous work, we can set the design specifications needed to be achieve in order to design wide-band power amplifier. The design specifications of WPA are shown in table 1 below.

Table 1: Design Specifications

Parameter	**Value**
Frequency range	2-4 GHz
Gain (S_{21})	>10 dB
Input return loss (S_{11})	<-10 dB
Intermodulation distortion (IMD3)	<-50 dBc

The designed circuit of wide-band power amplifier in ADS is shown in figure 3.

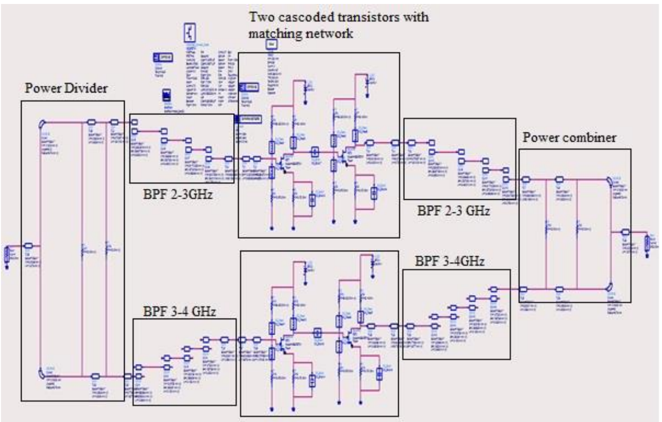

Figure 3: Full schematic diagram of WPA

SIMULATION RESULTS

The first parameter needed to be checked when we designing amplifier is stability. The amplifier must be stable over the range of the required frequency band. The Rollett factor K is used as a measure of stability and must be greater than one in order for an amplifier to be stable. The designed amplifier is stable, where k is greater than one over the whole bandwidth 2-4 GHz as shown in figure 4

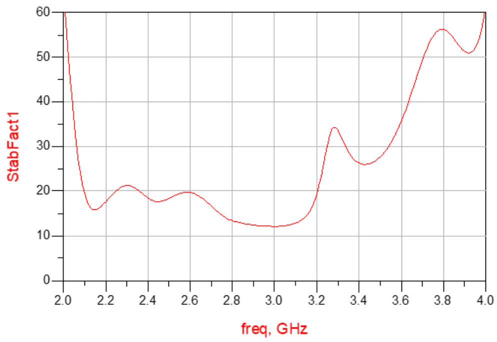

Figure 4: Stability of power amplifier

From figure 5, the designed amplifier can give 15 dB ±2dB within 2 GHz BW (2-4GHz) and considers as flat gain as well. And also the gain is higher than 10 dB which meet the specifications of WPA.

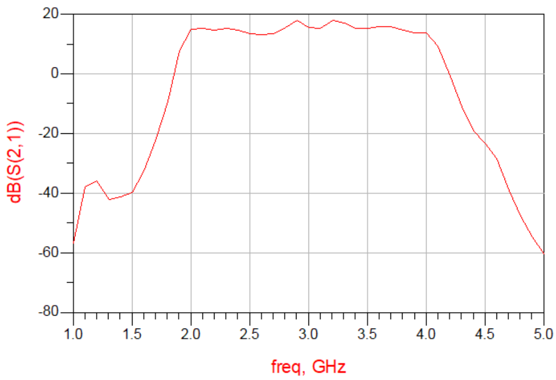

Figure 5: Gain (S_{21})

The simulated input return loss S_{11} was lower than -10 dB within the required frequency range 2-4 GHz, and which considers as the lowest input return loss. With -10 dB input return loss, the amplifier can give up to 90% of its output power. Furthermore, the simulated result of input return loss S_{11} meet the specification of WPA. Figure 6 shows the simulation of input return loss S_{11}.

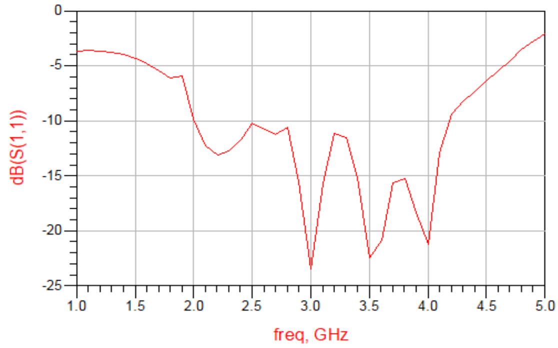

Figure 6: Input return loss S_{11}

Inter-modulation distortion (IMD3) is a parameter that determines the linearity of PA, and should be as low as possible. As the IMD3 decreases, the distortion decreases and the PA becomes more linear. From figure 7, the simulation result of IMD3 shows that with 10dBm input power, the IMD3 was -56.919dBc which shows low inter-modulation distortion which is less than -50dBc, and satisfies the specification of designed wide-band power amplifier as well.

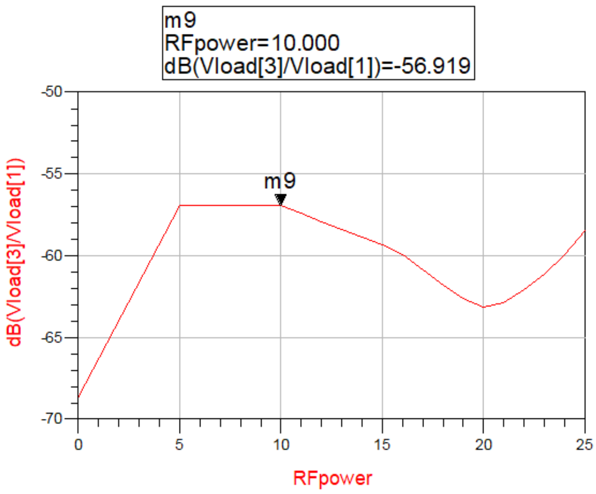

Figure 7: IMD3 vs RF power

CONCLUSION

Wide-band power amplifier for S-band has been designed and simulated successfully using advanced design system (ADS). The technique used in this design is power combiner. The results show that input return loss (S_{11}) less than -10 dB, gain S_{21} higher than 10dB, stability factor (K>1), and inter-modulation distortion (IMD3) less than -50dBc. The designed amplifier can be used in satellite communications, wireless applications (WLAN, WiMAX), and other applications in microwave engineering. Other matching techniques such as multi-section quarter wave transformer can be used in order to minimize the return loss and increase the gain.

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