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Wideband power amplifier based on Wilkinson power divider for s-band satellite communications

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ABSTRACT

This paper presents design and simulation of wideband power amplifier based on multi-section Wilkinson power divider. Class-A topology and ATF-511P8 transistor have been used. Advanced Design System (ADS) software used to simulate the designed power amplifier. The simulation results show an input return loss (S11)<-10dB, gain (S21)>10 dB over the entire bandwidth, and an output power around 28dBm at the Centre frequency of 3GHz. The designed amplifier is stable over the entire bandwidth (K>1). Inter-modulation distortion is -65.187dBc which is less than -50dBc. The designed amplifier can be used for the microwave applications which include weather radar, satellite communication, wireless networking, mobile, and TV.

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1. INTRODUCTION

Nowadays, Wireless network is a network system which used by all the people around the world in many fields of the life and becomes one of the important demands. And wherever there are wireless communications, there are transmitters, and wherever there are transmitters, there are RF power amplifiers [1-4]. Wideband power amplifier design becomes more important because; wider bandwidths are required to cover many wireless applications. Designing wideband power amplifier suffers from generating more intermodulation distortion products that influence the performance of power amplifier (PA). Intermodulation distortion products generate due to frequency components interfere with each other in the wide frequency range. To overcome this problem, two or more narrow bands power amplifiers are needed to design and then recombine using power divider/combiner as shown in Figure 1.

Power dividers are the devices that are used to divide the input power into many output powers or vice versa based on the required design. There are many types of power dividers such as T-junction power divider, directional couplers, and Wilkinson power divider. The simplest type of power dividers is T-junction. However, it suffers from low isolation between output ports. To solve the isolation problem, Wilkinson power divider (WPD) considers as a good choice. This is because of the shunt resistor inserted between output ports which provide high isolation. Figure 2 shows single section WPD.

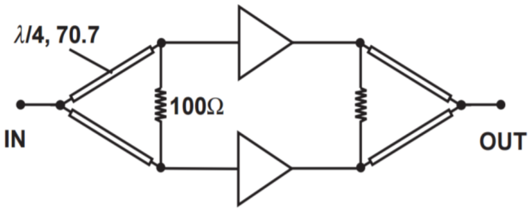

Figure 1. Two power amplifiers combining [1]

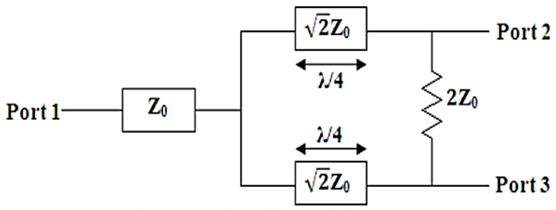

Figure 2. Single-section Wilkinson power divider [5]

However, the single section Wilkinson power divider only can achieve narrow bands. To broaden bandwidth, the multi-section approach can be used [5-11]. Several designs of wideband power amplifier have been proposed in [12-14]. However, the achieved return loss (S_{11}) does not meet the specifications which are required to be less than -10dB. In [12], high power wideband power amplifier designed using low-pass matching networks. However, the design suffers from limited bandwidth of 1.1GHz. In [13], C-band power amplifier design proposed for wireless applications. The design provides up to 12.4dB gain, but it suffers from limited bandwidth where covers from 5.6GHz to 6GHz (0.4GHz). Recently, many researchers have designed and developed power amplifiers, but most of the designed power amplifiers have been suffered from limited bandwidth, and high inter-modulation distortion which is considered a measure of linearity of the amplifier [14-25]. In [14], authors designed single stage wideband power amplifier with flat gain of 10-11.8 dB, and good input and output return loss. However, the proposed design has not shown any performance in the terms of linearity. Class-AB power amplifier is designed in [15] based on CMOS technology with aim to increase the efficiency in order to solve the problem of battery lifetime limitations in portable devices. The proposed design provides power added efficiency of 35 % with an output power of 30dBm. The work of [16] presented the design of low voltage class-AB power amplifier based on 0.18 µm CMOS technology. This design achieved power added efficiency of 26.73 % with low output power of 6.35 dBm. In [17], wideband power amplifier has been designed with the focus of maintaining gain flatness over the entire bandwidth 2-4 GHz. The proposed design maintains good gain flatness of 11.1-12.6 dB across the entire bandwidth, efficiency higher than 50 % and output power of 40 dBm. Wideband power amplifier design based on a new concept of scattering parameters is presented in [18]. This work shows the variation of the gain between 10 and 14 dB over the entire bandwidth, good input return loss (S_{11}) of -20dB, and output return loss (S_{22}) of less than -10 dB. In [19], cascode class AB power amplifier based on 0.18 µm CMOS process. Although this work used shunt peaking technique in order to obtain proper input and output return loss. However, the achievable return loss is -7 dB. In [20], high efficiency of 80 % is obtained from class-E power amplifier designed over 1.7-2.7 GHz using second harmonic tuning technique. In [21], high efficiency power amplifier based on AlGaN/GaN-HEMT technology is presented. The proposed design achieves efficiency of 34 % with high output power of 30 W. In [22], two stages power amplifier has been designed based on distributed matching network in order to obtain good impedance matching and high gain. Although the designed amplifier achieves an excellent gain of 20-28 dB. But it suffers from low output power of 12.45 dBm and limited bandwidth of 600 MHz. Parallel cascaded class A and B power amplifiers based on CMOS technology for increasing linearity and efficiency have been proposed in [23]. The proposed design exhibits saturated output power of 32.5 dBm with power added efficiency (PAE) of 37.9 %. In [24], class-AB 10W GaN HEMT power amplifier is designed based on load-pull technique. At 1.5 GHz, The proposed design achieves flat gain 15-17 dB over the entire bandwidth, efficiency of 36 % with 40 dBm output power at 1.5 GHz. On the other side, authors have not shown any linearity analysis. Recently, single stage power amplifier using T matching network is proposed in [25]. The proposed design provides high gain of 19.4 dB, good input and output return loss of -38 & -33.5 dB respectively. The proposed design suffers from low output power of 8 dBm.

In this work, wideband power amplifier based on discrete components and printed cicuit board using power combining technique for S-band is proposed. The wideband divided into two parallel narrow bands using WPD, and then recombined using power combiner at the output. Band pass filters (BPFs) are designed at the input and output of each narrow band amplifier to ensure passing only the desired frequency. Due to -3dB insertion loss generated from WPD which affects the gain of the amplifier, two cascaded transistors are implemented for each narrow amplifier to compensate for gain reduction. The proposed design meets the specifications of wideband power amplifier (WPA). The simulation results of the proposed design show good flat gain of higher than 10 dB over 2 to 4GHz, high output power of 27.8 dBm, and low third-order intermodulation distortion (IMD3) of -65 dBc.

2. DESIGN
2.1. Power amplifier design

In order to achieve wideband performance of PA, the desired wide frequency band is divided into two narrow bands. The proposed WPA was designed using ADS. In each of narrow bands design, there are sequence steps needed to follow:

a. Selection appropriate transistor:

WPA is designed using ATF-511P8 transistor provided by Avago Technologies. ATF-511P8 is a single voltage high linearity transistor and is operating in the wide frequency range from 50MHz to 6GHz.

b. Stability:

Transistor used in the design should be tested in terms of stability using s-parameter of the transistor. Stability of power amplifier can be defined as an amplifier's immunity to causing spurious oscillations. The amplifier must be stable over the range of the required frequency band. One of the methods used to determine the stability of PA is K-Δ test using (1) and (2). The condition of the amplifier to be stable is K>1 & Δ<1.

$$K = \frac{1-|S11|^2-|S22|^2+|\Delta|^2}{2|S12S21|} \quad (1)$$

$$\Delta = |S11S22 - S12S21| \quad (2)$$

Where: S_{11} is the reflection coefficient at port 1, S_{21} transmission coefficient from port 1 to port 2, S_{22} reflection coefficient at port 2, and S_{12} transmission coefficient from port 2 to port 1.

c. Biasing network:

For ATF-511P8 transistor used, the transistor should be biased at the point where VDS=4.5V, IDS=0.2A. Figure 3 shows the graph of IV characteristics of the transistor. The topology of biasing network used in WPA design is class-A voltage divider.

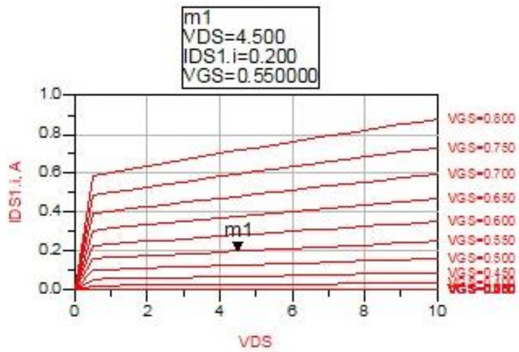

Figure 3. Graph of IV characteristics of transistor

d. Input and output matching:

The input and output matching technique that is used for the design of WPA is a single section quarter wave transformer. The reason for choosing this technique, it is considering as a useful and practical circuit for impedance matching. Furthermore, it's simple transmission line circuit [26].

2.2. Wilkinson power divider

Once completed design two narrow bands PAs. Multi-section Wilkinson Power Divider needed to design to combine the two narrow bands in order to achieve wideband power Amplifier. The (3) and (4) can be used to calculate characteristics impedances of WPD.

$$\ln\frac{Z_{n+1}}{Z_n} = 2^{-N} C_n^N \ln\frac{Z_L}{Z_o} \quad (3)$$

Where,

$$C_n^N = \frac{N}{(N-n)n} \quad (4)$$

Where, C_n^N is a binomial coefficient, N=No. of sections, n=0 to N-1, Z_L=50, and Z_0=100 Ω.

The calculated characteristics impedances of multi-section WPD design are shown in Table 1. The physical parameters (length and width) of microstrip line are presented in Table 2. Figure 4 shows the schematic diagram of multi-section WPD design in ADS.

Table 1. Characteristics impedances of multi-section WPD

No of section	Z_0	Z_1	Z_2
Two	50Ω	84Ω	59.4Ω

Table 2. Parameter values of microstrip line of multi-section WPD

Z_0 (Ω)	W(mm)	L(mm)
50Ω	3.30089	14.7276
84Ω	1.21923	15.333
59.4Ω	2.45948	14.9226

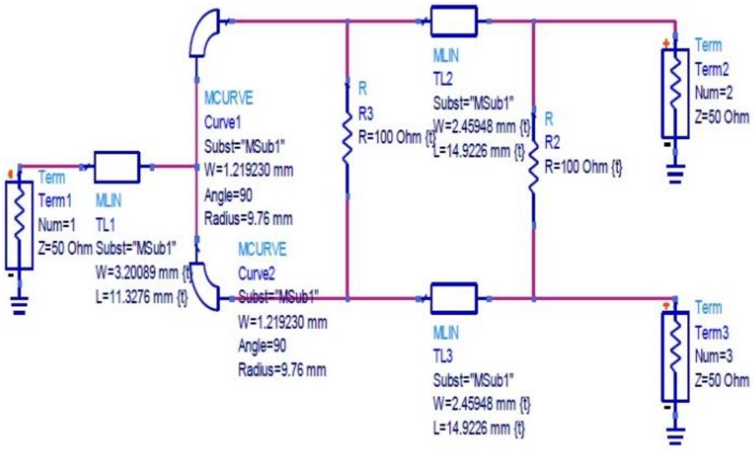

Figure 4. Schematic diagram of multi-section WDP

3. SIMULATION RESULTS

The design of WPA is constructed as in Figure 5 using ADS software. The design implemented as following: two parallel narrowband amplifiers (2 to 3 GHz & 3 to 4GHz respectively). Each of which integrated with bandpass filter at the input and output, to ensure passing only the required frequency band.

The first parameter needed to simulate is the stability. Over the entire frequency band, the stability factor must be greater than one in order to avoid the oscillation. From the simulation result shown in Figure 6, the WPA designed is stable over the frequency range 2-4GHz. From Figure 7, the designed amplifier can achieve gain up to 10dB over the frequency range 2-4GHz. Intermodulation distortion is a factor that determines the linearity of WPA and should be as low as possible. The WPA designed can achieve -65.187dBc at the input power of 10dBm as shown in Figure 8, and which considers as a low distortion. With applied 10dBm power at the input, the designed device can achieve around 28dBm output power at the Centre frequency of 3GHz as shown in Figure 9.

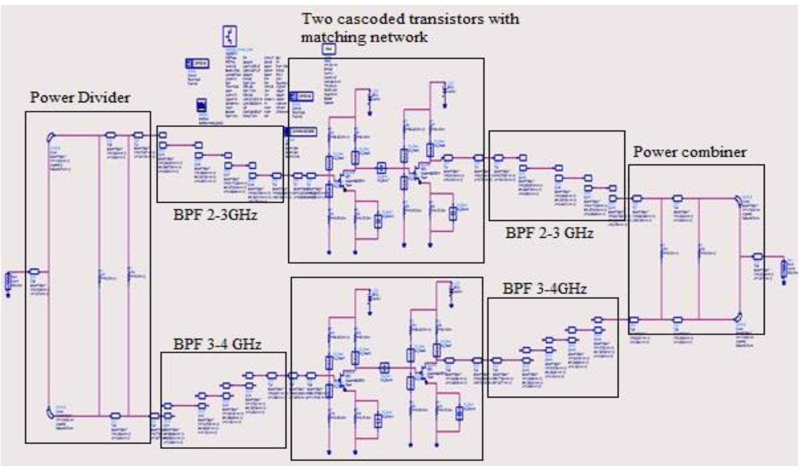

Figure 5. Simulation circuit of WPA

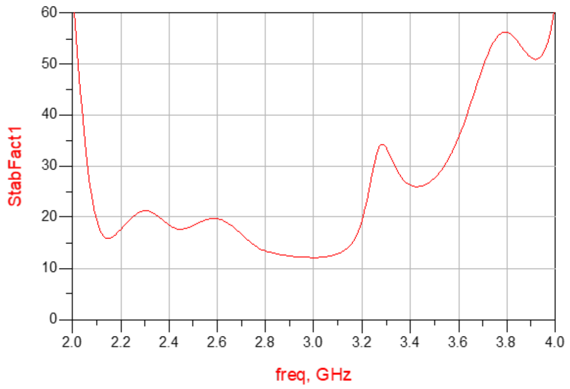

Figure 6. Stability of WPA

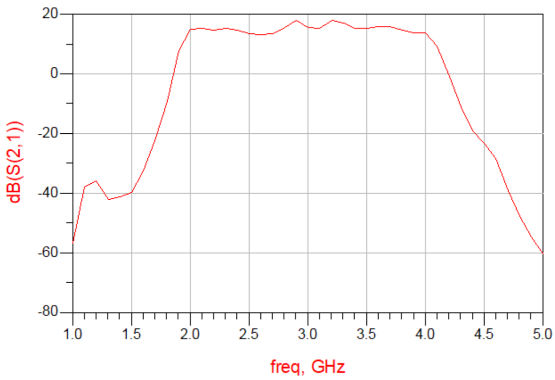

Figure 7. Gain of WPA

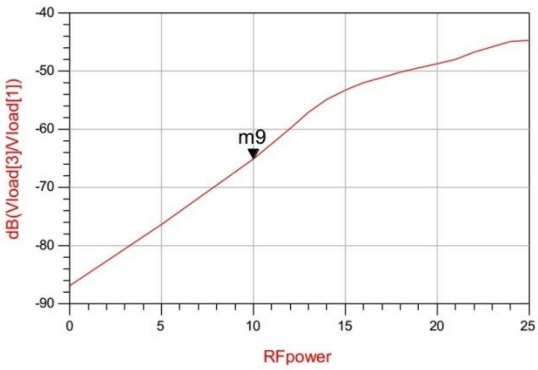

Figure 8. Intermodulation distortion of WPA

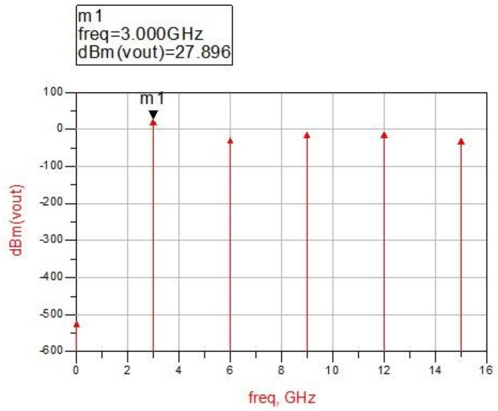

Figure 9. Output power vs frequency

4. CONCLUSION

In conclusion, WPA has been designed and simulated successfully. The designed frequency band in this work was 2 to 4 GHz (S-band). The designed WPA can be used in satellite communications, wireless applications (WLAN, WiMAX), and many other applications in microwave engineering. Two narrow band power amplifiers have been designed separately. Then, by using multi-section Wilkinson power divider the two narrow bands are combined in order to get the wideband. Class A amplifier has been used. ADS software has been used to simulate the designed circuit. The simulation results show an input return loss S11<-10dB, which satisfies the specifications of WPA. Furthermore, the designed amplifier is stable over the entire bandwidth from 2 to 4GHz. Where, the simulation results show K-factor higher than one over the entire bandwidth which satisfies the condition of stability (K>1). The simulated gain of the amplifier is flat and higher than 10 dB over the required bandwidth. For the main purpose of the power amplifier which is an amplification of signal power, the simulation results show an output power of around 28dBm with 10dBm applied at the input of WPA. Finally, in the aspect of linearity, the simulation results show low intermodulation distortion which is -65.187dBc at the Centre frequency 3 GHz. For the future work, it is recommended to use other matching technique such as multi-section quarter wave transformer in order to enhance the performance of WPA. For the fabrication process, it is recommended to use R04350 substrate provided by Roger boards to achieve good results. Also, R04350 has low losses comparing to FR-4.

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