A New Amplifier Power Combining Scheme with Optimum Efficiency under Variable Outputs

Cynthia Y. Hang, Yuanxun Wang, and Tatsuo Itoh

Electrical Engineering Department, University of California Los Angeles, Los Angeles, CA 90095

Abstract — **This paper presents a new power combining scheme, which has either one or four amplifiers on depending upon the levels of input signal. This approach realized by utilizing a unique combiner that is lossless and has constant gain under both scenarios. As a result, for the system where variable output power is required, this combining scheme can be used in an amplifier design with optimum efficiency. Measurement data show 15% power efficiency for the four-amplifier scenario and 28% for the single amplifier scenario at 13dBm input power. We also investigate the possibility of using this combiner in an envelope tracking amplifier.**

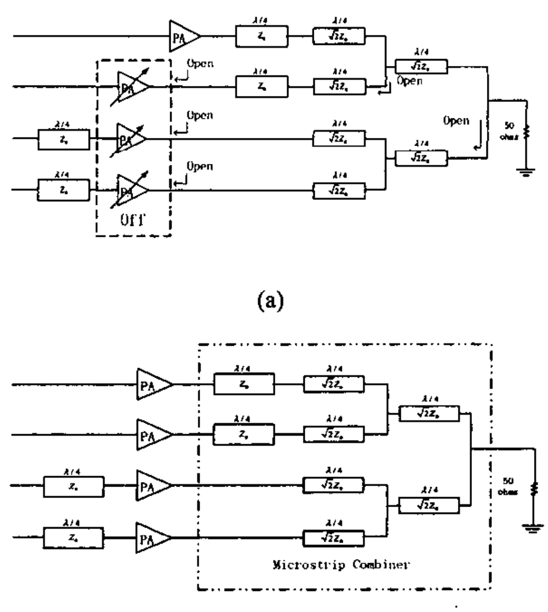
I. Introduction

Power amplifiers are the major power consumption building blocks in any transmitting system. To save the battery cell life time, it is important to design a power amplifier with higher efficiency, which usually occurs at the maximum output power level. However, in a modern communication system, due to the modulation format and requirement on power controlling, the amplitude of the output signal varies dynamically. Therefore, amplifiers in wireless communication systems only need full-power capability for a small fraction of time [1]. The output power fluctuation also occurs in phased array antenna systems, where power weighting for each antenna element is required. Because of this output power variation, the overall system efficiency is lower. Efficiency enhancement techniques, such as Doherty amplifier and switching networks, are often used to cope with this problem [2-4]. Unfortunately, it is difficult to maintaining a constant gain while implementing these schemes. The variation of gain can introduce signal distortion and cause linearity to suffer. In addition, if output switches are used, the power loss and nonlinearity associated with switching devices will increase, leading to lower linearity and efficiency.

In this paper, a new approach for handling variable output power is introduced. The essential idea is to combine the output power from an array of amplifiers while the number of amplifiers in use is selected according to the signal input power level. The technical challenge for such a system is to realize a lossless combiner network with impedance always matched at each different selection state. In the proposed approach, a four-amplifier array is used with a dual-state combiner. A single amplifier is in use when signal level is low. As the level increases, four amplifiers are turned on simultaneously. The power combiner is designed in such a way that constant gain can be maintained for different states over a wide range of output power. In addition, combining loss is minimized since switches are not used at the output.

In this paper, the combiner design topology is first introduced. The performance is verified by the measured S parameters. A power amplifier is then built for dual-state operation, followed by the measured output power and efficiency data for each state. Finally possible applications of such amplifier systems are discussed.

II. COMBINER DESIGN TOPOLOGY



(a)

(b)

Fig. 1 Schematic of the dual-state combiner under (a) lower state (low power) operation, and (b) higher state

Fig. 1 shows the design topology of the dual-state combiner, which operates under two modes depending upon the input signal level. This power combining network consists of a four-amplifier array and a 50-Ω matched microstrip combiner. When the signal level is low, the combiner is operated at its lower state. The combining scheme for this state of operation is shown in Fig. 1(a). In this state, only one amplifier is active, while all others are off. When an amplifier is turned off, its output impedance is nearly infinite (open circuit). The dual-state combiner is designed using this fact in such a way that the active amplifier is able to deliver power to the output 50-Ω load with minimum influence from the loading of the other three amplifiers. This is done using a number of quarter-wavelength transformers (see Fig. 1a). For higher signal level, the combiner can be switched to its higher state of power combining operation. This state is described in Fig. 1(b). In this case, four parallel amplifiers are evenly delivering maximum power to the 50-Ω load. Notice, 50-Ω quarter-wavelength transformer must be added at the input of the 3rd and 4th amplifiers so that the power can be added in phase at the output.

To verify the proposed power combining idea, a microstrip combiner as shown in Fig. 1 is fabricated and its insertion loss under the two operating states are measured. The circuit is fabricated using 25 mil duroid substrate with dielectric constant of 10.2. To test the microstrip combiner, a comparison of insertion loss for the two operation states is done. For the high state, when all four amplifiers are used, power is split into all four ports of the combiner using a 1 to 4 power splitter. To measure the insertion loss of the lower state where only one amplifier is active, power is fed through only the top most branch of the combiner, while the other three ports are terminated with open circuit loads, which simulate the loading of an amplifier which is turned off. .As shown in Fig. 2, the insertion is -0.439 dB for the four ports through case, while -0.805 dB is obtain for the case when three ports are ideally open. These two numbers are almost the same, which indicates that a fairly constant gain can be maintained over a wide range of input power if the dual-state combiner is used.

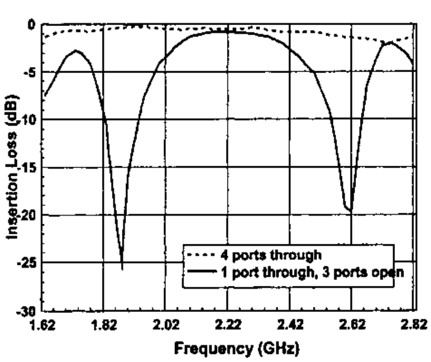


Fig. 2 Insertion loss of the microstrip combiner.

In a real scenario, power amplifiers are always connected with the microstrip combiner even at the lower state operation. Open circuit effect can be achieved by turning off the unused amplifiers to create infinite output impedance. The comparison between the case with off amplifier loading and the ideal open circuit loading is shown in Fig. 3. Insertion loss is -0.897 dB at 2.2 GHz, which is less than 0.1 dB lower than the case using the ideal open circuit.

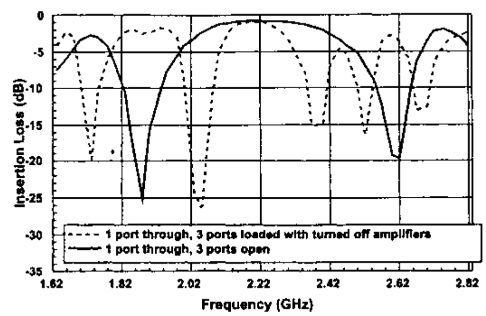


Fig. 3 The microstrip combiner insertion loss for lower state operation.

III. DESIGN AND PERFORMANCE OF POWER AMPLIFIERS

Upon testing the microstrip combiner, power amplifier performance under the dual state operation is also investigated. The device used is the MicroWave Technology MWT-8HP power GaAs FET. The large-signal model of this device and the Agilent's Advanced Design System (ADS) harmonic balanced simulator is used in the design. The amplifiers are all biased at 20% of Idss with 5 V drain voltage. When the lower state combining scheme is tested, three amplifiers are turned off by lowering the gate bias voltage to -4.5V.

Output power and PAE vs. the input power at the operating frequency of 2.2 GHz are shown in Fig. 4 and 5, respectively. When all four amplifiers are turned on, a comparison is drawn between the new combining scheme and the combining method using conventional Wilkinson combiners. When only one amplifier is on, the maximum PAE of 28% with the output power equal to 21.16 dBm is obtained at 13 dBm input level. When all four amplifiers are on, measured maximum PAE is about 34% at output power equal to 28.16 dBm using the new combining scheme. A similar performance is observed when the conventional Wilkinson combining scheme is used. In that case, PAE is about 34% at 28.83 dBm output power. Notice, the maximum PAE occurs at 19.5 dBm input power level for both combining schemes.

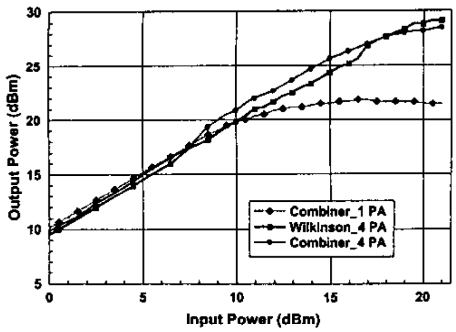


Fig. 4 Output power Vs. input power at 2.2 GHz.

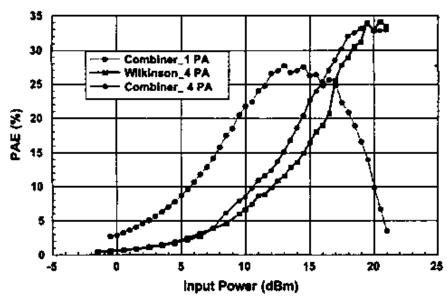


Fig. 5 PAE Vs. input power at 2.2 GHz.

In principal, the new combining scheme has a constant gain for the two operating states. This is the major advantage of this scheme over some other efficiency enhancement techniques. Fig. 6 shows both the simulated and measured gain of the dual-state combiner under the two operating states. From the simulation data, it is clear that the values of maximum gain for the two states are the same, as we expected. The measured results show good agreement between the two states at lower input power level. When the input level is high, the gain of the amplifier using the higher state combining scheme has jumped about 0.8 dB. This could be contributed by an experimental error.

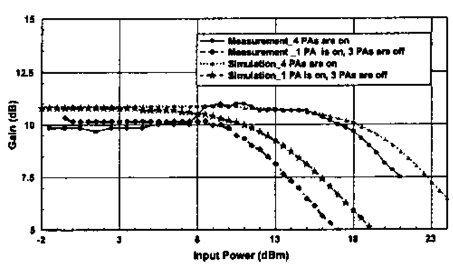


Fig. 6 Simulated and measured gain of amplifier under the dual-state operation at 2.2 GHz

This dual-state combiner is proposed to be used for power combining scheme that can handle variable output power. To properly gauge the effect of efficiency improvement using this dual-state combiner, the distribution of power usage as a function of output power must be used to calculate the overall system efficiency. If the output power level is discretely divided into n-level, and the percentage of distribution of the i^{th} output power level is ρ_i. Then, the overall DC power consumption of the amplifier system can be calculated as

$$P_{DC,total} = \sum_{i=1}^{n} \rho_i P_{DC,i} \tag{1}$$

Similarly, the corresponding input power and output power of the overall system are

$$P_{in,total} = \sum_{i=1}^{n} \rho_i P_{in,i} \tag{2}$$

$$P_{out,total} = \sum_{i=1}^{n} \rho_i P_{out,i} \tag{3}$$

Then, the power added efficiency for the overall system is

$$PAE = \frac{P_{out,total} - P_{in,total}}{P_{DC,total}} \tag{4}$$

Assuming the power levels of a 3ASK input signal are equally distributed at 0, 13-dBm, and 19.5-dBm. By using equations 1-4, the calculated overall power added efficiency is 14.9% for a single amplifier, 18.3% for using the Wilkinson combiner, and 28.2% for using the dual-state combiner. 10% improvement is observed.

IV. POSSIBLE APPLICATION

One type efficiency enhancement amplifier design is the so called "envelope tracking" amplifier [5]. It has been demonstrated that by dynamically varying the power supply voltage in accordance with the output signal, the overall efficiency of the amplifier system can be improved. The experimental data shown in previous sections demonstrated that the newly proposed dual-state combiner can be used in an envelope tracking amplifier design. Fig. 7 shows the schematic diagram for the proposed system utilizing the dual-state combiner.

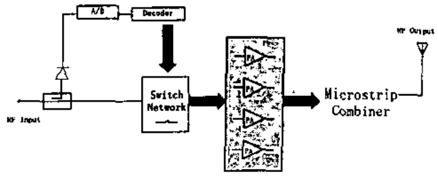


Fig. 7 Proposed envelope amplifier system design utilizing the dual-state combiner.

V. CONCLUSION

In this paper, a new power combining scheme with optimum efficiency is demonstrated using a dual-state combiner. Promising experimental data indicates that if the combiner is implemented in a system with variable outputs, the overall efficiency of amplifier can be improved.

REFERENCES

[1] J. Sevic, "Statistical characterization of RF Power Amplifier Efficiency for IS-95 CDMA Digital Wireless Communication systems," *IEEE Wireless Comm. Conf. Dig.*, pp. 110-113, 1997.

[2] C. F. Campbell, "A fully Integrated Ku-Band Doherty Amplifier MMIC," *IEEE Microwave and Guided wave letters*, vol. 9, no. 3, pp. 114-116, March 1999.

[3] H. Patterson, "Enhanced Efficiency CDMA Power Amplifier using Gain Stage Switching," 2000 *IEEE Topical Workshop on Power Amplifiers for Wireless Communications.*

[4] M. Kim, J. B. Hacker, R. E. Mihailovich, and J. F. DeNatalein, "A monolithic MEMS Switched Dual-Path Power Amplifier," *IEEE Microwave and Wireless Components letters*, vol. 11, no. 7, pp. 285-286, July 2001.

[5] G. Hanington, P. F. Chen, P. M. Asbeck, and L. E. larson, "High-Efficiency Power Amplifier Using Dynamic Power-Supply Voltage for CDMA Applications," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-47, no. 8, pp. 1471-1476, Aug. 1999.