Highly Efficient Power Amplifier for CDMA Base Stations Using Doherty Configuration

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Abstract — **We have extended the classical Doherty amplifier to support CDMA base station power amplifiers that require high efficiency and good linearity. At first, we have estimated three transistors, Motorola's MRF21085, MRF5S21090 and MRF5P21180 LDMOS's, to confirm the suitability for Doherty operation. Since the MRF21085 transistor is not suitable, we have excluded it. Two 2.14GHz high power Doherty amplifiers are implemented using two MRF5S21090 and a MRF5P21180, respectively, and are optimized at 40W for high efficiency and good linearity using IS95A 8FA CDMA signal. The performances of the Doherty amplifiers are compared with a conventional balanced class AB amplifier using two MRF5S21090. At 40W average output power, the MRF5S21090 and MRF5P21180 Doherty amplifiers deliver the efficiencies of 34.8% and 40.0%, which represent 11.2% and 16.4% enhancements, respectively, compared to the conventional amplifier. The linearities of all the amplifiers are adjusted to about –31dBc.**

I. INTRODUCTION

For present wireless communication systems such as IS-95 series, CDMA-2000, WCDMA, and so on, highly efficient base station power amplifiers are in great demand. Doherty amplifier, among the various efficiency enhancement techniques, is one of the most promising solution [1]-[10].

In the case of the classical Doherty amplifier, the peaking amplifier is normally biased to class B or C mode, while the bias of the carrier amplifier is set to class AB mode. The Doherty amplifier with this biasing strategy can deliver a high efficiency due to the low average bias current and efficient asymmetric power combining using the load modulation scheme. Additionally, the late gain expansion of the class B or C peaking amplifier can compensate for the gain compression of the class AB carrier amplifier. Due to the gain expansion and compression characteristics, linear operation of the Doherty amplifier can be achieved [5], [6]. Actually, many research works about the Doherty amplifier have demonstrated a high efficiency with a good linearity [5]-[10]. Moreover, the Doherty amplifier has been extended to N-way configuration [7], [8] and bias adaptation for performance enhancement [9], [10]. However, most of the prior works have employed relatively low power transistors. As the power capacity of the amplifier increases and the operating frequency bandwidth is widened, undesired characteristics of the amplifier such as low impedances and memory effects can be big problems [11].

In this paper, we have extended the Doherty amplifier to support CDMA base station power amplifiers by achieving high efficiency and good linearity at a high power level. Within the author's knowledge, the data described in this paper is believed to be a state-of-the-art performance among the base station power amplifiers.

II. SELECTION PROCEDURE FOR PROPER POWER TRANSISTORS

Operation principal of the Doherty amplifier is well described in many literatures and the main core is the use of the load modulation technique for asymmetric power combining [1]-[10]. In our earlier works, we have demonstrated that the load-line of the carrier amplifier can be properly modulated by employing offset transmission line. Besides the load modulation, the output impedance of the peaking amplifier should be transformed to nearly open for pinch-off mode using another offset line at the junction of the carrier and peaking amplifiers. Based on the technique, we could achieve highly efficient amplifiers [5], [6], [8]-[10].

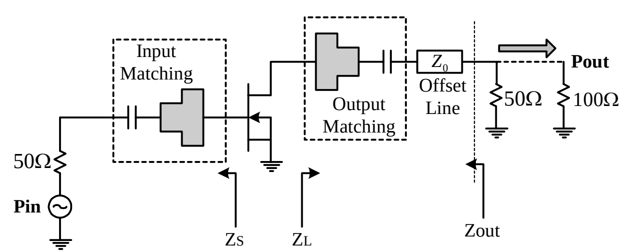

Fig. 1. Test circuit diagram for load modulation of the carrier amplifier

TABLE I
Characteristics of four fully matched power amplifiers measured with the test method shown in Fig. 1

	MRF281SR1	MRF21085	MRF5S21090	MRF5P21180 (single-ended)
Matching Impedances	Z_S = 3.10-j3.50 Z_L =11.36+j7.94	Z_S = 2.24-j7.00 Z_L = 1.08-j3.02	Z_S = 3.10-j9.00 Z_L = 1.03-j2.95	Z_S = 5.14-j9.07 Z_L = 2.12-j6.94
Offset Line Length	12.6°	150.2°	35.0°	85.1°
Zout,peaking	344Ω	294Ω	691Ω	450Ω
Low Power Gain	15dB → 17.2dB	12.4dB → 13.5dB	12.8dB → 14.9dB	13.7dB → 16.0dB
P1dB	35.1dBm → 33.0dBm	48.0dBm → 47.5dBm	48.3dBm → 46.4dBm	48.4dBm → 47.0dBm
DC Current	Reduced	Reduced	Reduced	Reduced

Figure 1 shows a circuit diagram for Doherty operation test. In this work, we have evaluated three transistors, Motorola's MRF21085, MRF5S21090 and MRF5P21180 LDMOS's, which are recommended for operation at 2.14GHz frequency band. At first, the selected transistors are fully power matched to obtain their maximum output powers for 50ohm load. Then, the offset line is adjusted for the proper load modulation. Since we cannot measure the load line for the carrier amplifier, we have observed the transformations of a low power gain, P1dB, and DC current at P1dB, when their load impedances change from 50Ω to 100Ω. For the change, the class AB carrier amplifiers have to satisfy the following three conditions;

1. Gain at a low power should be increased by 3dB.
2. P1dB should be decreased by 3dB.
3. DC current at P1dB for 100Ω load should be reduced significantly.

On the other hand, the transformed output impedance of the peaking amplifier should be open when it is turned off. For the peaking amplifier, the input port is terminated to 50Ω and then the transformed output impedance (denoted by Zout in Fig. 1) is measured with a network analyzer at 2.14GHz. This impedance should be high enough to block the output power leakage from the carrier amplifier to the peaking amplifier at a low power operation.

Table I shows the measured results for the matching impedances of the four transistors, the optimum lengths of the offset lines, the transformed output impedances for the peaking amplifier, the low power gains (measured at 25dBm input power except for MRF281SR1), P1dB's and DC currents. For comparison, we include the data for MRF281SR1 with P1dB of 35.1dBm because, in our earlier works, we have demonstrated the Doherty amplifier operation employing MRF281SR1 transistors [8]-[10].

Our measured data show that MRF5S21090 and MRF5P21180 transistors are suitable to the Doherty operation, but the MRF21085 is not. It may be related to the internal matching of each transistor. Thus, we have excluded MRF21085 from this work.

III. Implementations and Measurements

Two 2.14GHz high power Doherty amplifiers have been implemented using the transistors selected in section II. One is the Doherty amplifier employing two MRF5S21090 for the carrier and peaking amplifiers, the other employing a MRF5P21180. For the MRF5P21180 LDMOS, the data sheet recommends the push-pull configuration but we have utilized it for the Doherty configuration. Due to the configuration, the MRF21180 Doherty amplifier can be implemented with small size compared to the MRF5S21090 Doherty amplifier. Figure 2 shows a photograph of the implemented MRF5P21180 Doherty amplifier. Circuit configuration of the MRF5S21090 Doherty amplifier is very similar to that of the MRF5P21180 Doherty amplifier.

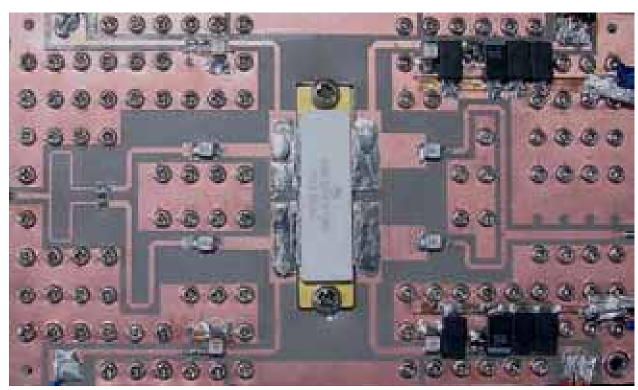

Fig. 2. Photograph of the implemented MRF5P21180 Doherty amplifier.

The implemented Doherty amplifiers have been further optimized experimentally to achieve high efficiency and good linearity at 40W (46dBm) average output power for IS95A 8FA signal. For the performance comparison, we have constructed a balanced class AB amplifier using two

MRF5S21090. In these experiments, quiescent current for the MRF5S21090 balanced amplifier is set to 1.7A (850mA*2). On the other hand, the optimized quiescent currents for the MRF5S21090 and MRF5P21180 Doherty amplifiers are set to 850mA and 300mA, respectively, for the class AB carrier amplifier and the class C peaking amplifier with V_{DD}=26V. The performances optimized at 46dBm using IS95A 8FA CDMA signal are shown in Table II. There, frequency offset –2.25MHz means the point separated 2.25MHz left from center frequency of the lowermost FA and the +2.25MHz the point separated 2.25MHz right from center frequency of the uppermost FA. The linearity performances for the three power amplifiers are nearly identical. Figure 3 shows the spectrum of the MRF5P21180 Doherty amplifier at 46dBm average output power. At the average output power, the drain efficiencies of the MRF5S21090 and MRF5P21180 Doherty amplifiers have been enhanced to 34.8% and 40.0%, which represent 11.2% and 16.4% improvements over the balanced amplifier, respectively.

TABLE II
Measured performance at Pout=46dBm for IS95A 8FA signal

	Gain [dB]	Eff. [%]	ACLR [dBc]	
			-2.25MHz	+2.25MHz
Balanced _21090*2	11.16	23.6	-31.5	-31.0
Doherty _21090*2	9.86	34.8	-31.5	-31.3
Doherty _21180	10.30	40.0	-31.3	-31.6

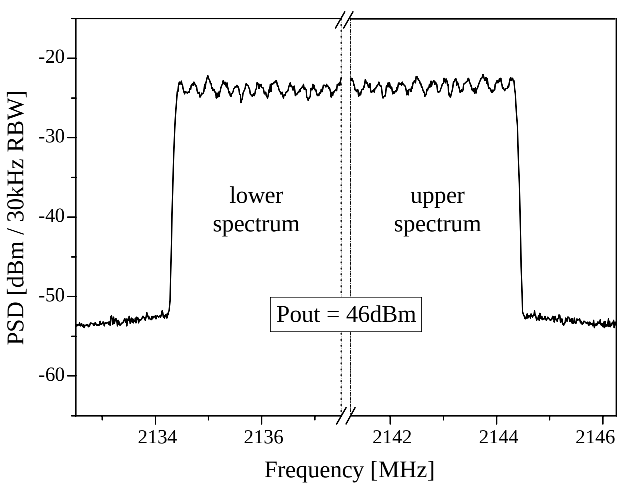

Fig. 3. Output spectrum of the MRF5P21180 Doherty amplifier for IS95A 8FA CDMA signal.

Figure 4 shows the gain characteristics measured at several average power levels for the three amplifiers using IS95A 8FA signal. From the data, we can see that power gain of the Doherty amplifier is degraded due to the lowered bias compared to the conventional class AB amplifier. In this work, we have experienced the gain degradation of 0.9 ~ 1.5dB for the Doherty amplifiers. Figure 5 shows the ACLR’s measured at ±2.25MHz offsets for the three amplifiers. At low power levels, the linearity of the MRF5S21090 Doherty amplifier is poor than the balanced amplifier and that of the MRF5P21180 Doherty amplifier is degraded further. However, these degradations may not be a problem since the ACLR’s of the Doherty amplifiers are more than –30dBc for all output power levels.

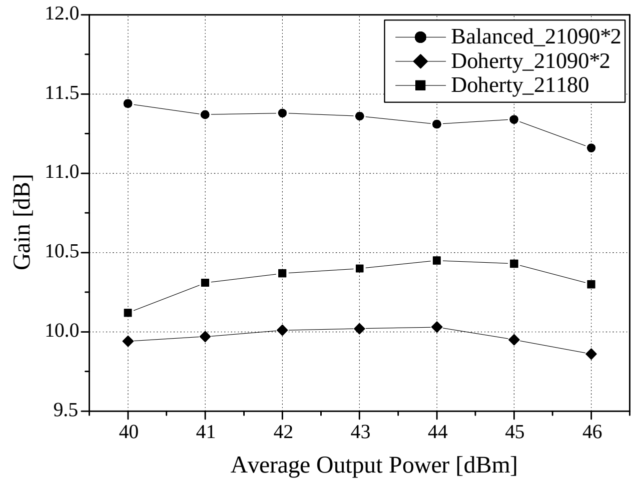

Fig. 4. Measured gain characteristics of the three amplifiers when IS95A 8FA signal is applied.

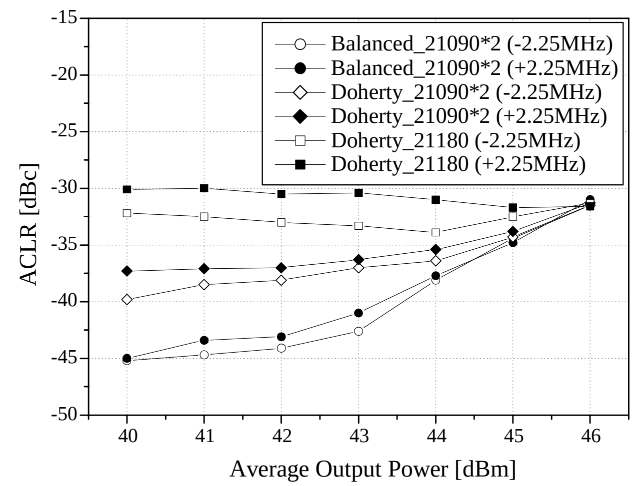

Fig. 5. Measured upper and lower ACLR's of the three amplifiers when IS95A 8FA signal is applied.

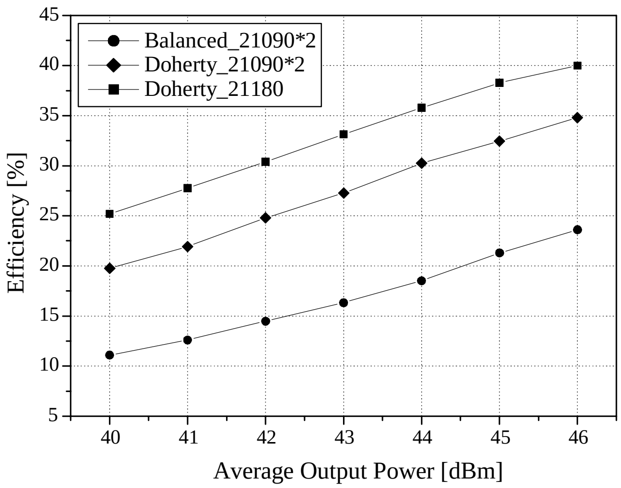

Fig. 6. Drain efficiencies of the three amplifiers with IS95A 8FA signal test.

Figure 6 shows the drain efficiencies of the three amplifiers. The Doherty amplifiers have significantly improved the efficiencies for all power levels compared to the conventional class AB amplifier.

IV. CONCLUSIONS

For highly efficient base station power amplifiers, we have extended the Doherty concept to support high output power, wide bandwidth and good linearity. We have described the experimental method for selection of proper transistors. In this paper, the three LDMOS high power transistors, Motorola's MRF21085, MRF5S21090 and MRF5P21180, have been investigated for the suitability to Doherty operation. Our evaluated results show that the MRF5S21090 and MRF5P21180 are suitable to the Doherty configuration, but the MRF21085 is not.

We have implemented two high power Doherty amplifiers at 2.14GHz using the selected transistors (MRF5S21090 and MRF5P21180) and optimized them at 40W average output power using IS95A 8FA signal. For performance comparison, we have constructed the conventional class AB amplifier with a balanced structure using two MRF5S21090. At 40W average output power, the efficiencies of the MRF5S21090 and MRF5P21180 Doherty amplifiers have been enhanced to 34.8% and 40.0%, which represent 11.2% and 16.4% improvements in efficiency over the balanced amplifier, respectively. The linearity performances for the three amplifiers are nearly identical to ACLR of about 31dBc.

These experimental results clearly demonstrate that the microwave Doherty amplifier is a good candidate for power amplifier of CDMA base station application that requires high efficiency as well as good linearity.

ACKNOWLEDGEMENT

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