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DESIGN OF LINEARITY IMPROVED ASYMMETRICAL GAN DOHERTY POWER AMPLIFIER USING COMPOSITE RIGHT/LEFT-HANDED TRANSMISSION LINES

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Abstract—A highly efficient asymmetrical GaN Doherty power amplifier using traditional $\lambda/4$ transmission line and an asymmetrical GaN Doherty power amplifier (DPA) using composite right/left-handed transmission lines (CRLH-TL) for linearity improvement are presented in this paper. The CRLH-TL is designed to suppress the second harmonic of the output of the carrier amplifier. This DPA using CRLH-TL is designed for 3.5 GHz LTE-Advanced Application with 100 MHz bandwidth and 37 dBm average output power, the carrier and peaking amplifiers are fabricated with the same 30 W GaN HEMT and unevenly driven in purpose of maintaining high efficiency at back-off power (BOP) region. At 9-dB and 6-dB BOP, the DE achieves 30% and 40.1%, respectively, and the adjacent channel power ratio (ACPR) are less than −37.1 dBc for 40 MHz 16 QAM signal at 37 dBm. In addition, the further linearization of the DPA is realized by using digital predistortion (DPD), the ACPRs are improved to −49.6 dBc for 40 MHz 16 QAM signal. The measured results show linearity improvement compared with the traditional DPA.

1. INTRODUCTION

With the application of new wireless communication technology such as the third generation (3G) and fourth generation (4G), wireless communication systems are developing to the direction of wide bandwidth, large capacity, high efficiency and high linearity [1]. As one of the most promising next-generation wireless communication technologies, LTE-Advanced has high spectrum utilization efficiency

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and high peak transmission data rate, which is able to provide a high quality user experience [2–4].

As one of the most important components in wireless communication systems, power amplifier has directly influence on the performance of the whole communication system. Power amplifier with high efficiency can reduce system power consumption, and with high linearity can eliminate amplitude clipping, improve the quality of wireless communication service. At present, the application of multi-carrier technique and many kinds of modulation has enlarged the peak-to-average power ratio of signals, as a result, the efficiency enhancement technology with linearity improvement technology is becoming more and more important, and the high efficiency with high linearity power amplify technique is gradually becoming a hot issue in today's research [5–8].

Consequently, power amplifier should be designed with efficiency and linearity enhancement technologies to achieve high efficiency and high linearity simultaneously. To improve efficiency, many kinds of Doherty power amplifiers have been designed to achieve high efficiency in a wide dynamic range [9–12]. Furthermore, as one of the most promising semiconductor technique, GaN HEMT has been used for recent power amplifier designs, and it is an ideal choice in order to meet the requirement of wide bandwidth of LTE-Advanced system [13–15]. On the other hand, in order to improve the linearity of Doherty power amplifier, one of the possible and simplified techniques is Composite Right/Left-Handed Transmission Lines (CRLH-TL) for its character of suppressing the second harmonic of the carrier amplifier of the Doherty power amplifier. Linearity can be improved by replacing the traditional $\lambda/4$ transmission line with CRLH-TL [16, 17].

In this paper, two different Doherty power amplifiers are designed and implemented, DPA with traditional $\lambda/4$ transmission line and DPA with CRLH-TL, experimental results and comparisons between the two DPAs are also presented. The frequency bands of the DPAs are 3.4–3.5 GHz, 100 MHz bandwidth for LTE-Advanced system. These two DPAs are all consisted of two identical GaN HEMT as carrier amplifier and peaking amplifier, the power ratio of the power divider is $2:1$ in order to improve efficiency in a wide dynamic range of back-off power region.

The structure of this paper is as follows. In Section 2, the theory and design process of the conventional DPA are discussed. In Section 3, the design of DPA using CRLH-TL is presented. In Section 4, the measurement results are presented and analyzed. At last, the conclusions are summarized in Section 5.

2. DESIGN AND IMPLEMENTATION OF THE TRADITIONAL DOHERTY POWER AMPLIFIER

Traditional DPA consists of carrier amplifier, peaking amplifier, power divider and offset transmission lines. Normally, the carrier amplifier works in class AB mode and the peaking amplifier works in class C mode, the $\lambda/4$ transmission line at the output of carrier amplifier works as impedance transformer and the transmission line at the input of peaking amplifier works as phase compensator. The essential theory of DPA is load modulation technique, which is able to change impedance according to the power of input signal [18].

In the low power region, the output impedance of the carrier amplifier $2R_{opt}$ is two times as large as its optimum load R_{opt}, as the output voltage of carrier amplifier reaches maximum, the output current of carrier amplifier reaches only half of its maximum. In this condition, the carrier amplifier reaches half of its maximum output power while also resulting in maximum efficiency (e.g., 78.5% if ideal Class AB condition).

With the power of input signal increasing, the carrier amplifier saturated gradually and the peaking amplifier starts to work, according to load modulation theory, the output impedance of the carrier amplifier will be modulated from $2R_{opt}$ to R_{opt} while the output current of the carrier amplifier and peaking amplifier increase up to maximum, respectively. Consequently, the DPA reaches its maximum output power which is two times as large as the maximum power of the carrier amplifier. The load modulation keeps the carrier amplifier in saturation condition resulting in constant high efficiency. The load modulation for both amplifiers, together with the efficiency of the traditional symmetrical DPA and Class AB PA are shown in Figures 1(a) and (b).

The schematic of the proposed traditional DPA is shown in Figure 2. The carrier amplifier works in class AB mode and the peaking amplifier works in class C mode with the same GaN HEMT. In order to obtain high efficiency, the input circuit of the proposed traditional DPA is designed with uneven Wilkinson power divider, the ratio between the input power of carrier amplifier and peaking amplifier is 2 : 1, which makes the saturation point of the carrier amplifier ahead of the even DPA's at the same input power level, and also result in the saturation delay of the peaking amplifier, which is able to maintain high efficiency of the DPA in a wide dynamic range of the back-off power region [19].

The carrier amplifier and peaking amplifier are designed using the same Cree CGH35030F GaN HEMT. The carrier amplifier is biased in class AB mode ($V_{GS} = -3.0\,\text{V}$, $V_{DS} = 28\,\text{V}$ and $I_{GS} = 120\,\text{mA}$), the

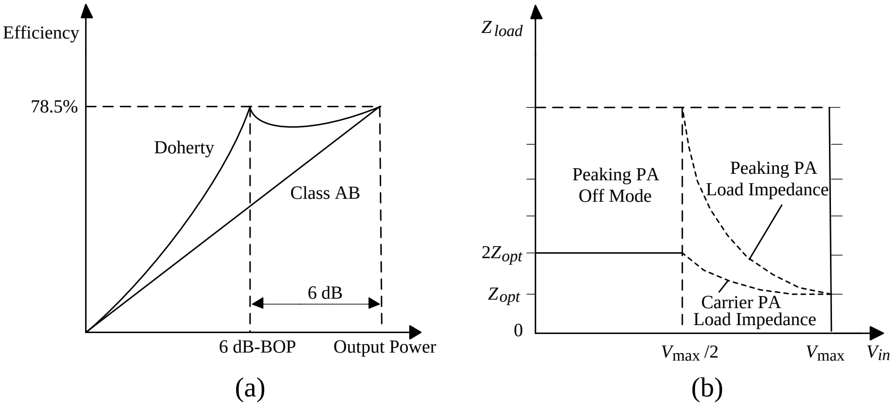

Figure 1. Efficiency and impedance of the symmetrical DPA. (a) The efficiency of the traditional symmetrical DPA and class AB PA. (b) The impedance of the carrier amplifier and peaking amplifier according to input signal voltage.

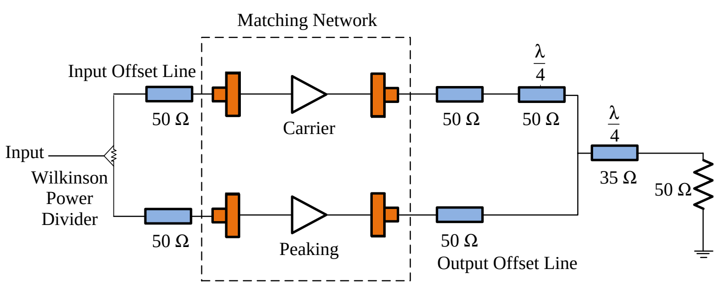

Figure 2. Schematic of the proposed traditional Doherty power amplifier with matching networks.

input and output match circuit consist of simplified series transmission lines which is able to reduce the complication of the schematic. The input offset line in front of the input match circuit is used to adjust the phase delay. With the output offset line and the $\lambda/4$ impedance transformer behind the output match circuit, the carrier amplifier can attain the needed output load impedance in the whole power level range.

The peaking amplifier is biased in class C mode ($V_{GS} = -4.8\,\text{V}$, $V_{DS} = 28\,\text{V}$) with the same input and output match circuit as the carrier amplifier. The input offset line is used to compensate the phase delay of the peaking amplifier. Moreover, the output offset line is able to avoid power leakage of the carrier amplifier when the peaking amplifier is turned off. The peaking amplifier connects the carrier amplifier with a $\lambda/4$ impedance transformer to match the output load impedance.

In this design, the DPA is designed, simulated and optimized using Agilent ADS, the Z_{opt} and the characteristic impedance of the $\lambda/4$ transmission line are both chosen as $50\,\Omega$. The layout is implemented using Rogers R4350B substrate which has 0.762 mm thickness and 3.48 dielectric constant.

More importantly, by using ADS, the optimization of the offset lines of the conventional Doherty power amplifier can be realized. The optimization methods are as follows:

1. Tuning the electrical length of the $\lambda/4$ offset line of the carrier amplifier to optimize the load modulation [20].
2. Tuning the electrical length of the input transmission lines of the carrier and peaking amplifiers to make proper phase compensation [21].
3. Tuning the electrical length of the output transmission lines of the peaking amplifier in order to prevent the power leakage of the carrier amplifier.
4. Changing the bias of the class C peaking amplifier in order to improve the efficiency of Doherty structure [22].

The characteristic impedances of the offset lines and the phase compensation lines of the proposed conventional Doherty power amplifier are all $50\,\Omega$, the widths are 1.69 mm (66.37 mil). After optimized the lengths of the offset lines and the phase compensation lines, the Doherty power amplifier achieves the best performance, shows the best efficiency and linearity.

The detailed simulation lengths of the offset lines and phase compensation lines after optimization are shown in Table 1, the real lengths of the offset lines in tuning are on the basis of the simulation

Table 1. The lengths of the offset lines after optimization (According to the offset lines and phase compensation lines in Figure 2).

Offset or Compensation Line	Length
Carrier PA's Input Line	38.1 mm
Carrier PA's Output Line	3.81 mm
Carrier PA's $\lambda/4$ Offset Line	15.75 mm
Peaking PA's Input Line	55.88 mm
Peaking PA's Output Line	10.16 mm

results, and the measurement results fit the simulation well after tuning the real circuit. The simulated phases of the carrier and peaking amplifier after optimization are shown in Figure 3, the output signal phases of the carrier and peaking amplifier are similar at 3.4–3.5 GHz and approximately identical at the center frequency of 3.45 GHz. The best bias of the class C peaking amplifier is $V_{GS} = -4.8\,\text{V}$ in tuning. After adopting the proposed optimization methodologies, the conventional Doherty power amplifier of this work achieves the best

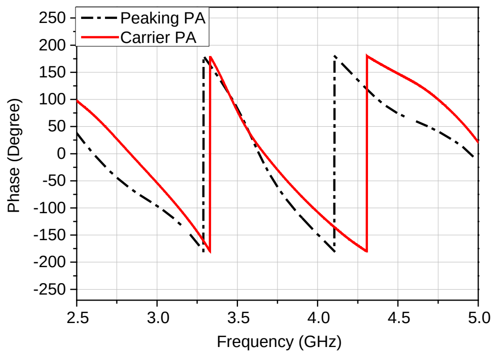

Figure 3. The simulated phases of the carrier and peaking amplifier after optimization.

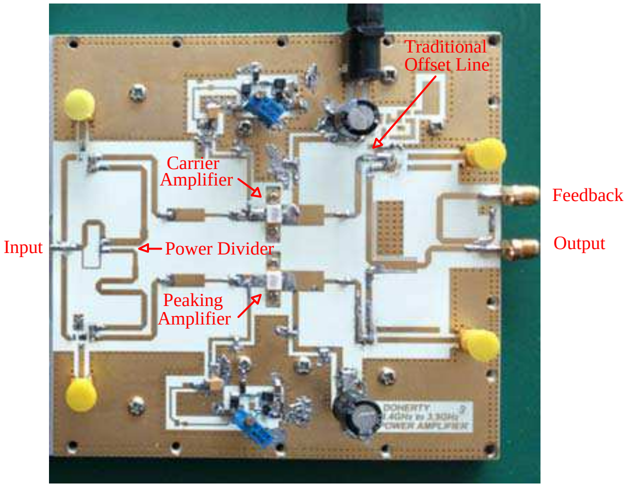

Figure 4. The photograph of the proposed traditional Doherty power amplifier.

efficiency and linearity performance. Figure 4 shows the photograph of the proposed traditional Doherty power amplifier.

In addition, in order to amplify the input signal linearly and provide an appropriate power level to the DPA, a driver amplifier is implemented in front of the DPA. In this work, the driver amplifier is implemented using Freescale MRF7S38010HR3 MOSFET with transmission lines matching network, operating in Class AB mode ($V_{GS} = 2.7\,\text{V}$, $V_{DS} = 28\,\text{V}$). The layout is realized using a substrate which has 0.8 mm thickness and 2.65 dielectric constant. Furthermore, an isolator is employed between the driver amplifier and the DPA in order to prevent the signal of the DPA from entering into the driver amplifier inversely.

3. DESIGN AND IMPLEMENTATION OF DOHERTY POWER AMPLIFIER USING CRLH-TL

A CRLH-TL is the series combination of left-handed transmission line (LH-TL) and right-handed transmission line (RH-TL), the LH-TL can be implemented by using capacitors and inductors while the RH-TL can be realized by using transmission line [17]. Figure 5 shows the lumped elements model of the two unit cells ($N = 2$) used for CRLH-TL.

The phase response of the CRLH-TL and the RH-TL are shown in Figure 6. The phase of CRLH-TL and RH-TL are identically $-\pi/2$ at the fundamental frequency f_1, nevertheless, at the second harmonic frequency $2f_1$, the phase of CRLH-TL and RH-TL are approximately -2π and $-\pi$, respectively, consequently, the phase difference is approximately π. Therefore, it is possible to suppress the second harmonic of DPA by using CRLH-TL, resulting in a linearity improvement of the DPA [16].

In this paper, $\lambda/4$ transmission line is replaced by CRLH-TL in order to suppress the second harmonic of the output of DPA. If the operating frequency of the DPA is chosen to be f_1, the CRLH-TL can be designed by using the following approximate expression [17].

$$P \approx \frac{\pi}{2}\frac{3f_2 - f_1}{f_2^2 - f_1^2} \tag{1}$$

$$Q \approx \frac{\pi}{2}\frac{\frac{3}{f_2} - \frac{1}{f_1}}{\frac{1}{f_1^2} - \frac{1}{f_2^2}} \tag{2}$$

$$Z_{0R} = \sqrt{\frac{L_R}{C_R}} \tag{3}$$

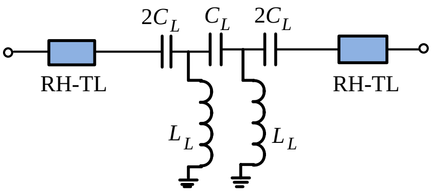

Figure 5. The schematic of the composite right/left-handed transmission lines (CRLH-TL) ($N = 2$).

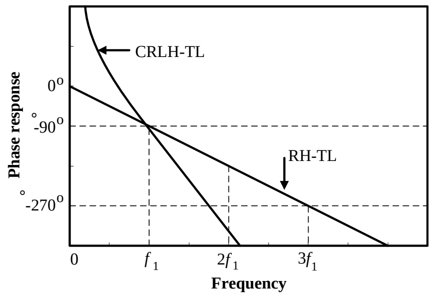

Figure 6. Phase responses of the CRLH-TL and RH-TL.

$$Z_{0L} = \sqrt{\frac{L_L}{C_L}} \tag{4}$$

f_1 is the fundamental frequency while f_2 is the second harmonic frequency. The subscripts R and L refer to RH and LH, respectively. Z_{OR} and Z_{OL} are the characteristic impedances of RH-TL and LH-TL. Using N and Q to obtain $C_L L_L$ according to the following approximate expression:

$$Q = \frac{N}{2\pi\sqrt{L_L C_L}} \tag{5}$$

C_L and L_L can be determined by using P, Q, Z_{OR} and Z_{OL}, the electrical length of the RH-TL can be obtained by using [17, 23] and standard microstrip line formulas.

$$\phi_R = P f_1 \tag{6}$$

The schematic of the proposed DPA using CRLH-TL is shown in Figure 7. The carrier amplifier works in class AB mode and the peaking amplifier works in class C mode, same as the proposed traditional DPA in Section 2. Using the design method proposed, the calculated

Table 2. Component values of CRLH-TL.

	Calculated	Real	Part Number
C_L	0.88 pF	1.0 pF	GRM1885C2A1R0CZ01
L_L	2.2 nH	2.2 nH	LQW18AN2N2D00
Φ_{RH}	210°	173°	-

values of C_L, L_L and Φ_{RH} are 0.88 pF, 2.2 nH and 210°, respectively. The real employed values of C_L, L_L and Φ_{RH} are 1.0 pF, 2.2 nH and 173°, respectively. Details of the CRLH-TL components used for the proposed design are listed in Table 2.

In this design, the Z_{opt} and the characteristic impedance of the

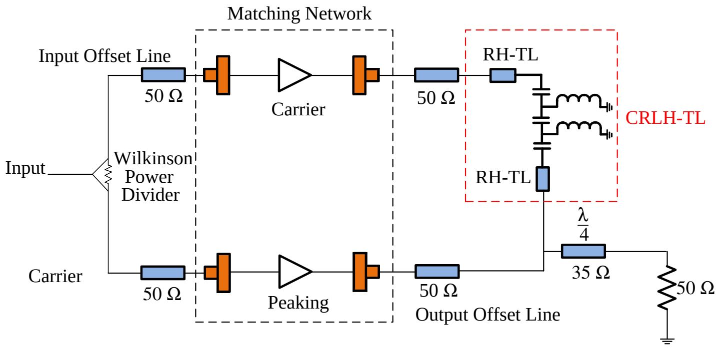

Figure 7. The schematic of the proposed Doherty power amplifier using CRLH-TL with matching networks.

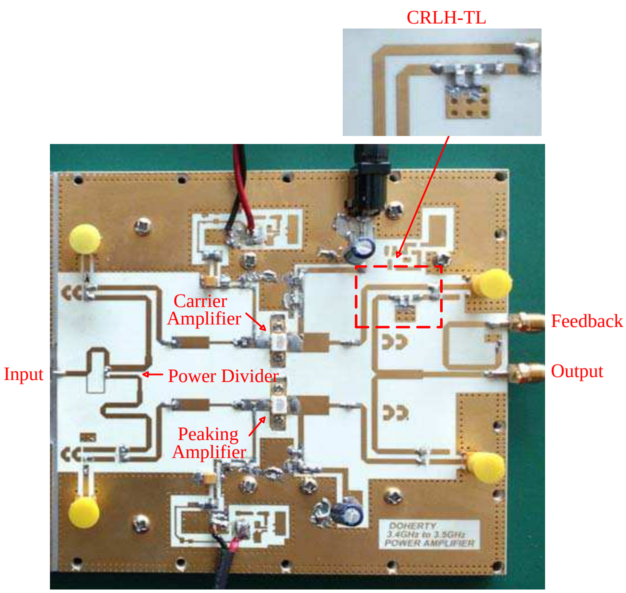

Figure 8. The photograph of the proposed Doherty power amplifier using CRLH-TL.

CRLH-TL are also both chosen as 50 Ω. The driver amplifier is the same as the design in Section 2. Figure 8 shows the photograph of the entire amplifier module and details of CRLH-TL.

4. MEASUREMENT RESULTS

The bandwidths of the proposed DPAs are designed with 100 MHz, operating from 3.4 GHz to 3.5 GHz, which is able to amplify wide band LTE-Advanced signals. Figure 9 shows the measured output power and DE as function of input power of the traditional DPA and the DPA using CRLH-TL. The measured P_{sat} and maximum DE of the traditional DPA are 46 dBm and 74.5%, respectively, furthermore, the DEs also achieved 46% and 31.8% at 6 dB and 9 dB BOP, respectively. On the other hand, the measured P_{sat} and maximum DE of the DPA using CRLH-TL are 46 dBm and 67%, respectively, moreover, the DEs also achieved 40.1% and 30% at 6 dB and 9 dB BOP, respectively. Figure 12 shows the ACPR of the traditional DPA and the DPA using CRLH-TL, respectively. The details of the ACPRs are shown in Table 3.

Table 3. The ACPR of the traditional DPA and the DPA using CRLH-TL.

Signal A	16 QAM 40 MHz 37 dBm (6.4 dB PAPR)
Signal B	16 QAM 40 MHz 40 dBm (6.4 dB PAPR)
Signal C	LTE-Advanced 100 MHz 37 dBm (7.2 dB PAPR)
Signal D	LTE-Advanced 40 MHz 37 dBm (9.8 dB PAPR)

	The DPA using CRLH-TL ACPR Without DPD (dBc)	The Traditional DPA ACPR Without DPD (dBc)	The DPA using CRLH-TL ACPR With DPD (dBc)	The Traditional DPA ACPR With DPD (dBc)
Signal A	−37.1/− 38.4	−31.8/− 37.8	−49.6/− 50.1	−43.6/− 42.9
Signal B	−37.6/− 33.1	−29.6/− 32.4	−46.4/− 46.1	−40.3/− 40
Signal C	−30.9/− 31.8	−27.2/− 29.1	−40.6/− 40.4	−35.7/− 35.3
Signal D	−32.5/− 31	−24.9/− 27.2	−40.1/− 41.8	−34.3/− 37.2

Comparison between the traditional DPA and the DPA using CRLH-TL has also been made in this paper. Figure 9 shows that the DE of the DPA using CRLH-TL is lower than the DE of the traditional DPA, which is because the capacitors and inductances of the CRLH-TL have larger power losses than the microstrip line of the traditional DPA at high frequency circumstance.

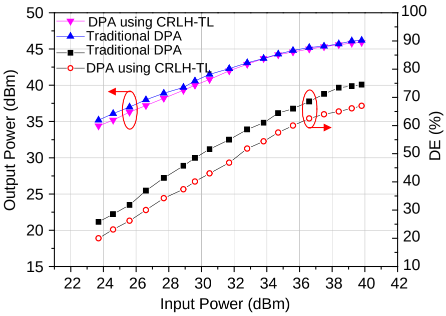

Figure 9. Measured output power, DE characteristics of the DPA using CRLH-TL and the traditional DPA at frequency of 3.45 GHz (Using CW signal).

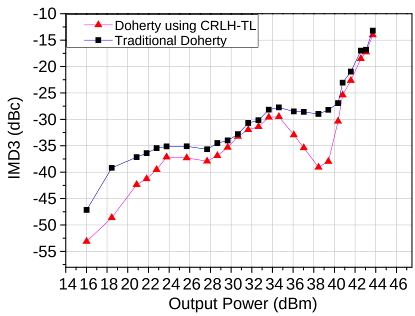

Figure 10. Measured IMD3 of the DPA using CRLH-TL and the traditional DPA (10 MHz offset).

Figure 10 shows the measured IMD3 of the DPA using CRLH-TL and the traditional DPA, the IMD3 of the DPA using CRLH-TL was improved through the whole output power range compared to the traditional DPA, the maximum improvement was 10 dB at 38.5 dBm (The IMD3 of DPA using CRLH-TL and traditional DPA are −39 dBc and −29 dBc at 38.5 dBm, respectively). The reason of IMD3 improvement was that the second harmonic was suppressed by introducing CRLH-TL, the measured second harmonic of DPA using CRLH-TL are 8.9 dBm and 11.3 dBm at 37 dBm and 40 dBm, respectively, while the second harmonic of traditional DPA are 16.8 dBm and 17.2 dBm at 37 dBm and 40 dBm, respectively, which shows a 7.9 dB suppression at 37 dBm and a 5.9 dB suppression at 40 dBm. Furthermore, as shown in Table 3 and Figure 12, for 40 MHz 16 QAM signal, the measured results shows a 5.3 dB maximal ACPR improvement at 37 dBm and a 8 dB maximal ACPR improvement at 40 dBm by introducing CRLH-TL. While for 100 MHz LTE-Advanced signal, the maximal ACPR improvement is 3.7 dB by introducing CRLH-TL. For 40 MHz LTE-Advanced signal, the maximal ACPR improvement is 7.6 dB by introducing CRLH-TL. All the measured results show linearity improvement by introducing CRLH-TL at the cost of acceptable efficiency reduction.

In order to further improve the linearity of the DPA, the DPD was implemented in the experimental system shown in Figure 11. The system consists of a vector signal generator (VSG, Agilent N5182A), a vector signal analyzer (VSA, Agilent N9030A), a 50 dB attenuator, a PC with Agilent 89600 Series Vector Signal Analysis Software and

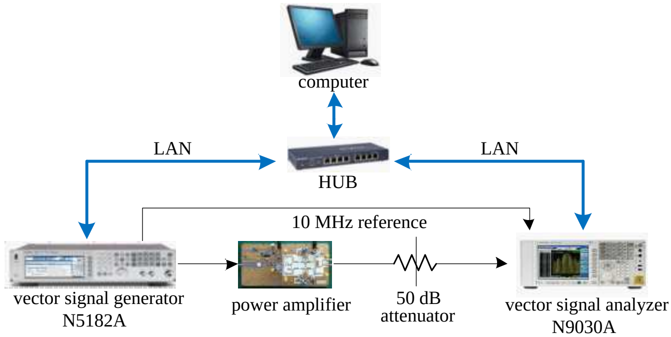

Figure 11. Configuration of the DPD system.

Matlab. A 40 MHz 16 QAM signal (6.4 dB PAPR with crest factor reduction), a 5 CCs 100 MHz LTE-Advanced signal (7.2 dB PAPR with crest factor reduction) and a 2 CCs 40 MHz LTE-Advanced signal (9.8 dB PAPR without crest factor reduction) were employed in DPD experiments.

Table 3 and Figure 12 show the ACPRs of the traditional DPA and the DPA using CRLH-TL after DPD. For 40 MHz 16 QAM signal, at most 7.2 dB and 6.1 dB ACPR improvements were obtained by introducing CRLH-TL at 37 dBm and 40 dBm, respectively. For 100 MHz LTE-Advanced signal, at most 5.1 dB ACPR improvement was obtained by introducing CRLH-TL at 37 dBm. For 40 MHz LTE-Advanced signal, at most 5.8 dB ACPR improvement was obtained by introducing CRLH-TL at 37 dBm.

The Error Vector Magnitude (EVM) results of the traditional DPA and the DPA using CRLH-TL are also presented in this paper. Under license and test module restrictions of the Agilent 89600 Series Vector Signal Analysis Software (VSA) in laboratory, the EVM of LTE-Advanced signal could not be measured directly, but EVM could be calculated according to the data measurement results by using the following equation [24]:

$$\mathrm{EVM}=\sqrt{\frac{\sum\limits_{n=0}^{N-1}\left|\vec{r}(n)-\vec{m}(n)\right|^2}{\sum\limits_{n=0}^{N-1}\left|\vec{r}(n)\right|^2}}\times 100\%=\sqrt{\frac{\sum\limits_{n=0}^{N-1}\left|\vec{e}(n)\right|^2}{\sum\limits_{n=0}^{N-1}\left|\vec{r}(n)\right|^2}}\times 100\% \quad (7)$$

$\vec{m}(n)$ and $\vec{r}(n)$ are the measured signal vector and the referenced signal vector, respectively, $\vec{e}(n)$ is the error signal vector. EVM is able to evaluate a power amplifier system in a more comprehensive way.

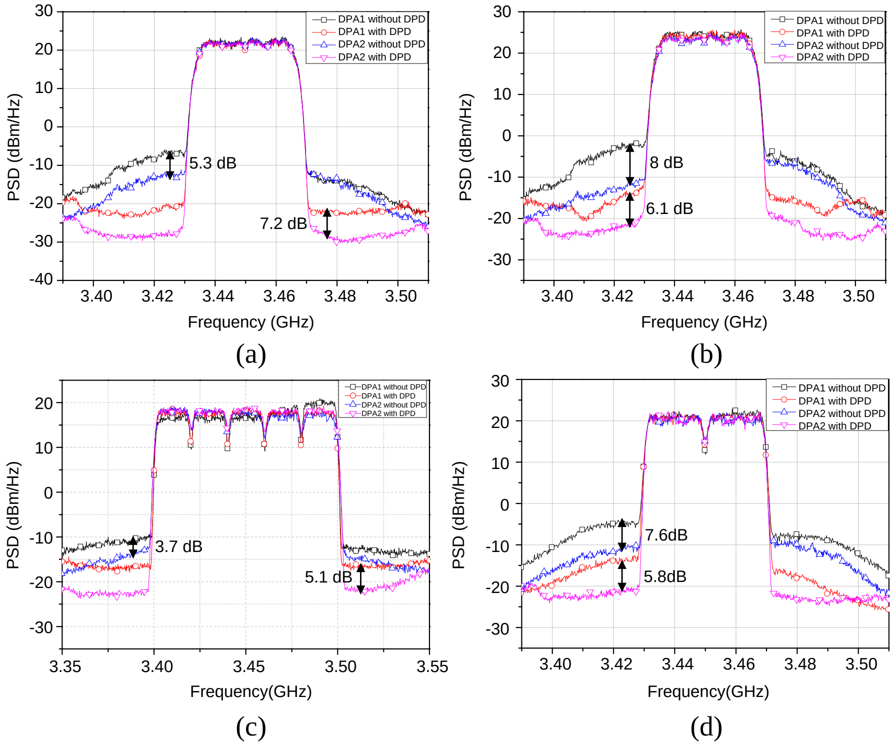

Figure 12. Measured PSD with and without DPD of the traditional DPA and the DPA using CRLH-TL. (a) 40 MHz 16 QAM signal at 37 dBm. (b) 40 MHz 16 QAM signal at 40 dBm. (c) 100 MHz LTE-Advanced signal at 37 dBm. (d) 40 MHz LTE-Advanced signal at 37 dBm. (DPA1: the traditional DPA, DPA2: the DPA using CRLH-TL).

By collecting the plural data of the input and output LTE-Advanced signal, the EVM could be calculated. Because of the restrictions of experiment condition, the calculated EVM may not be accurate compared with the direct measurement EVM. The calculated EVMs of 100 MHz LTE-Advanced signal at 37 dBm are shown in Table 4, the EVMs of the DPA using CRLH-TL are better than the Traditional DPA with or without DPD.

Table 5 shows the performance of the proposed DPAs compared to other works [16, 25–27]. In addition, the design's strengths of the proposed DPAs as compared to existing techniques listed in Table 5 have also been described. First, compared with the other amplifiers in

Table 4. The calculated EVMs of 100 MHz LTE-Advanced signal at 37 dBm.

	EVM without DPD	EVM after DPD
Traditional DPA	32.11%	13.33%
DPA using CRLH-TL	29.17%	11.23%

Table 5. Performance comparison.

Work	Frequency	Efficiency	Max P_{out}	Linearity	Signal
[16]	2.3 GHz	Max PAE: 32.1%	31 dBm	Max IMD3: –47 dBc	CW
[25]	2.14 GHz	PAE: 46% 6 dB-BOP	44.5 dBm	ACPR: –30 dBc @ 38 dBm	W-CDMA
[26]	2.5 GHz	PAE: 43% 8 dB-BOP	47 dBm	ACPR: –35 dBc @39 dBm	UMTS-LTE (10 MHz)
[27]	2.01 GHz	Max PAE: 43.6%	42.5 dBm	IMD3: –40 dBc @ 38 dBm	Two Tone Signal
This work CRLH-TL	3.4–3.5 GHz	DE: 40.1% (6 dB) 30% (9 dB)	46 dBm	ACPR (With DPD): –49.6 dBc @ 37 dBm	16 QAM (40 MHz)
This work Traditional	3.4–3.5 GHz	DE :46% (6 dB) 31.8% (9 dB)	46 dBm	ACPR (With DPD): –42.9 dBc @ 37 dBm	16 QAM (40 MHz)

Table 5, the proposed two DPAs have 100 MHz bandwidth, which is able to operate in wider frequency bands, the operation frequency is also higher, which is more appropriate for LTE-Advanced applications Second, the input and output matching networks of the proposed two DPAs completely consist of simplified and optimized series transmission lines, compared with the lumped component matching networks used in [25, 26] and the parallel transmission line matching networks used in [16, 27], the simplified series transmission lines matching networks result in a reduction of the complication of the schematic structure and tuning. Last, the linearity is improved by suppressing second harmonic in [16] and this work (CRLH-TL), the max P_{out} of [16] is 15 dB smaller than that of this work (CRLH-TL), but this work (CRLH-TL) still maintaining a comparable IMD3. In [25, 26], although the test signals are 20 MHz and 10 MHz, which are smaller than the bandwidth of this work (CRLH-TL), the ACPRs are still no more than that of this work (CRLH-TL); The IMD3 of this work (CRLH-TL) is approximate -40 dBc at 38 dBm, same as the IMD3 of [27], but the proposed DPA of this work (CRLH-TL) is able to operate in a higher power level, and the linearity also improved significantly after DPD. According to Table 5, the proposed DPA using CRLH-TL shows comparable performance.

5. CONCLUSION

In this paper, a traditional 100 MHz GaN Doherty power amplifier and a 100 MHz GaN Doherty power amplifier using composite right/left-handed transmission lines for LTE-Advanced application are proposed. For the proposed traditional DPA, the DE achieves 31.8% at 9 dB-BOP and 46% at 6 dB-BOP, the ACPR achieves −42.9 dBc for 40 MHz 16 QAM signal and −35.3 dBc for 100 MHz LTE-Advanced signal at 9 dB-BOP with DPD. For the proposed DPA using CRLH-TL, the DE achieves 30% at 9 dB-BOP and 40.1% at 6 dB-BOP, the ACPR achieves −49.6 dBc for 40 MHz 16 QAM signal and −40.4 dBc for 100 MHz LTE-Advanced signal at 9 dB-BOP with DPD. Besides, the DPA using CRLH-TL also shows a better performance of EVM. The comparison between these two DPAs verifies considerable improvement of the linearity by using CRLH-TL for its second harmonic suppression character, meanwhile, the proposed DPA can still maintaining an acceptable efficiency. In addition, compared with other existing linearity improvement techniques of Doherty power amplifier, the proposed DPA using CRLH-TL in this work has higher operation frequency, wider frequency band, more simplified matching networks and better ACPR, there are also a significant linearity improvement after DPD. Measured results show better performance than the referenced DPAs, which verifies the strength and advantage of the proposed DPA using CRLH-TL.

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