Harmonic-Controlled Three-Way Doherty Amplifier with Improved Linearity

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Abstract: – In this paper the efficiency and linearity behavior of three-way Doherty amplifier is analyzed. The amplifier is designed in the configuration with two quarter-wave impedance transformers in the output combining circuit with LDMOSFETs in carrier and peaking amplifiers. The signals for linearization (the fundamental signals' second harmonics-IM2 and fourth-order nonlinear signals-IM4 at frequencies that are close to the second harmonics) are extracted at the output of peaking cells biased at various points. The Doherty amplifier is designed with the frequency diplexer at the outputs of the Doherty cells that separates the fundamental signals for linearization. The diplexer includes harmonic control circuit (HCC) which in combination with matching circuits, provides an optimal impedance for an adequate power level of signals for linearization, and either open circuit for the third harmonics (HCC class-3F) or short circuit for the third harmonics (HCC class-3F). The linearization technique results in the suppression of the third- and fifth-order intermodulation products of Doherty amplifier.

Key-Words: – Doherty amplifier, class-F, harmonic control circuit (HCC), linearization, power-added-efficiency, second harmonics, fourth-order nonlinear signals, third- and fifth-order intermodulation products

1 Introduction

More than modern wireless ever. the communication industry has increased interest for high-efficient and linear amplifiers the to accommodate current communication standards. The third generation (3G) and beyond communication standards offer high data rate transmission and transmit power that carries highpeak-to-average ratio signals. Therefore, basestation amplifiers operate most of their time at lower power level than their maximum, which consequently degrades the efficiency. The Doherty amplifier that is capable of achieving the requirements of the power amplifiers in base station concerning high efficiency becomes attractive for wireless industry.

The linearity of high power Doherty amplifier was improved using "post-distortion-compensation" [1], the feedforward linearization technique [2], the predistortion linearization technique [3]-[5] and combination of those two linearization techniques [6]. The linearization effects of the fundamental signals' second harmonics (IM2) and fourth-order nonlinear signals at frequencies that are close to the second harmonics (IM4) to the Doherty amplifier were investigated in [7]. In that paper standard (two-way) Doherty amplifier, as well as two configurations of three-way Doherty amplifiers, were linearized by applying the approach where IM2 and IM4 signals are injected together with the fundamental signals into the carrier amplifier input and put at its output [8].

In papers [9] and [10] standard two-way Doherty amplifier was extended to support class-F operation in order to achieve higher efficiency. Additionally, feedforward and digital feedback predistortion linearization technique were implemented in [9] and [10], respectively, to improve the linearity.

In this paper, for the first time according to the authors' best knowledge, the linearity and efficiency of three-way Doherty amplifier loaded with harmonic control circuit (HCC) for improved linearity is analyzed. The carrier and peaking cells in three-way Doherty amplifier are loaded by the diplexers with harmonic control circuit, which separate fundamental signals and signals for linearization. The loading of the carrier and peaking cells, together with the matching circuits, provides an optimal impedance for an adequate power level of signals for linearization, and either open circuit for the third harmonics (HCC class-3F) or short circuit for the third harmonics (HCC class-3IF). Linearization is carried out by the approach that uses IM2 and IM4 signals.

The signals for linearization are extracted at the output of the peaking cells in Doherty amplifier that are biased at various points to provide the appropriate power levels and phase relations of IM2 and IM4 signals. After been adjusted in amplitude and phase the signals from the output of one peaking amplifier are injected at the input of carrier amplifier while ones appeared at the output of another peaking cell are put to the carrier amplifier output.

A theory relating to the proposed linearization approach is given in the section 2 for digitally modulated fundamental signals. Section 3 includes the design of three-way Doherty amplifier with control harmonic circuit and circuit for linearization. All referring results to the intermodulation products and efficiency obtained in simulation for two sinusoidal as well as digitally modulated signals by applying the linearization approach are included in section 4. The conclusions are reported in section 5.

2 Theoretical Analysis

Theoretical analysis of the proposed linearization approach is based on the nonlinearity of drainsource current that is expressed by a polynomial model up to the third-order [11]. The polynomial model is convenient to express large-signal behaviour of field-effect-transistors. It uses truncation method that fixes the degree of the polynomial model and let the polynomial coefficients vary with the signal amplitude.

The expression for the nonlinearity of LDMOSFET in amplifier circuit, under the assumption of neglecting the memory effect, is represented by eleven terms as given by Eq. (1). The drain-source current is dependent upon two control voltages: v_{gs} voltage between gate and source and v_{ds} -voltage between drain and source of the transistor. The Eq. (1) introduces the nonlinearity of the drain-source current, i_{ds} , in reference to the voltage v_{gs} , which is represented by the coefficients K_{10} to K_{50} . The higher order nonlinear terms K_{40} and K_{50} are included into the analysis according to the theory given in [12] that favours the terms of output current as function of v_{gs} up to the fifth-order.

The nonlinearity of drain-source current in terms of v_{ds} is included in Eq. (1) over the coefficients K_{01} to K_{03} . Also, the equation encompasses "mixing" terms K_{11} , K_{12} and K_{21} .

$$\begin{split} i_{ds} \left(v_{gs}, v_{ds} \right) &= K_{10} v_{gs} \left(t \right) + K_{20} v_{gs}^2 \left(t \right) + K_{30} v_{gs}^3 \left(t \right) + \\ &+ K_{40} v_{gs}^4 \left(t \right) + K_{50} v_{gs}^5 \left(t \right) + \\ &+ K_{01} v_{ds} \left(t \right) + K_{02} v_{ds}^2 \left(t \right) + K_{03} v_{ds}^3 \left(t \right) + \\ &+ K_{11} v_{gs} \left(t \right) v_{ds} \left(t \right) + K_{21} v_{gs}^2 \left(t \right) v_{ds} \left(t \right) + \\ &+ K_{12} v_{gs} \left(t \right) v_{ds}^2 \left(t \right) + \dots \end{split}$$
(1)

A carrier supplemented with a baseband spectrum $V_B(j\omega)$ represents the spectrum of a digitally modulated fundamental signal:

$$V_B(j\omega)\otimes \frac{1}{2}\delta(\omega\pm\omega_0).$$

The drain-source current at frequencies of the thirdorder (IM3) and fifth-order intermodulation products (IM5) can be written by the Eqs. (2) and (3), where ρ_2 , ϕ_2 , ρ_4 and ϕ_4 are the amplitudes and phases of IM2 and IM4 signals driven at the amplifier input, whereas $\rho_2^{(F)}$, $\phi_2^{(F)}$, $\rho_4^{(F)}$ and $\phi_4^{(F)}$ represent amplitudes and phases of the IM2 and IM4 signals put at the amplifier output (feedforwarded). The nonlinearity of the drain-source conductance

The nonlinearity of the drain-source conductance expressed by coefficients K_{01} , K_{02} , K_{03} is assumed to have a negligible contribution to the intermodulation products according to [11] and [12].

$$I_{ds}(j\omega)|_{IM3} \approx \left\{ \left[\frac{3}{4} K_{30} + \frac{1}{4} K_{20} \rho_2 e^{-j\varphi_2} - \frac{1}{4} K_{11} \rho_2^{(F)} e^{-j\varphi_2^{(F)}} - \frac{1}{4} K_{11} \rho_1 \rho_2 e^{-j\varphi_2} \right] \right\}$$
(2)
$$\left(V_B(j\omega) \otimes V_B(j\omega) \otimes V_B(j\omega) \right) \right\} \otimes \frac{1}{2} \delta(\omega \pm \omega_0)$$

The signal distorted by the cubic term of the amplifier, K_{30} , is included into analysis by Eq. (2) as the first term. The cubic term is considered as a dominant one according to [11] and [12] in causing

IM3 products and spectral regrowth. The mixing product of the fundamental signal and IM2 signal injected at the amplifier input is expressed as the second term. The mixing term K_{11} (third term) exists due to the reaction between the fundamental signal at input and IM2 signal fed at the amplifier output. Additionally, the fundamental signal at the output of amplifier mingles with IM2 signal that exists at the amplifier input generating K_{11} term. The amplitude of output voltage at fundamental signal frequency that is 180° out of phase in reference to the input signal is denoted as ρ_1 . According to this, it is possible to reduce spectral regrowth caused by the third-order distortion of fundamental signal by choosing the appropriate amplitude and phase of both the injected IM2 signals (ρ_2 and ϕ_2) and feedforwarded ones ($\rho_2^{(F)}$

and $\varphi_2^{(F)}$).

The mixing terms between drain and gate, K_{12} and K_{21} , produce drain-source current at IM3 frequencies with the opposite phases, so that they reduce each other [12].

$$\begin{split} I_{ds}(j\omega)|_{IM5} \approx \\ &\left\{ \left[\frac{5}{8} K_{50} + \frac{1}{4} K_{20} \rho_4 e^{-j\varphi_4} - \frac{1}{4} K_{11} \rho_4^{(F)} e^{-j\varphi_4^{(F)}} + \right. \\ &\left. - \frac{1}{4} \rho_1 K_{11} \rho_4 e^{-j\varphi_4} + \frac{1}{8} K_{30} \rho_2^2 e^{-j2\varphi_2} + \right. \\ &\left. + \frac{1}{8} K_{12} \rho_2^{(F)2} e^{-j2\varphi_2^{(F)}} + \frac{1}{8} K_{12} \rho_1 \rho_2 \rho_2^{(F)} e^{-j(\varphi_2 + \varphi_2^{(F)})} + \right. \\ &\left. - \frac{1}{8} K_{21} \rho_2 \rho_2^{(F)} e^{-j(\varphi_2 + \varphi_2^{(F)})} - \frac{1}{8} K_{21} \rho_1 \rho_2^2 e^{-j2\varphi_2} \right] \\ &\left. V_B(j\omega) \otimes V_B(j\omega) \otimes V_B(j\omega) \otimes \right. \\ &\left. \otimes V_B(j\omega) \otimes V_B(j\omega) \right\} \otimes \frac{1}{2} \delta(\omega \pm \omega_0) \end{split}$$

$$\tag{3}$$

In Eq. (3) the first term expresses the drain-source current of the fifth-order intermodulation products that is formed between the fundamental signals due to the amplifier nonlinearity of the fifth-order, K_{50} . The second term is made by the reaction between the fundamental and IM4 signal at the amplifier input. The third term is the mixing product between the fundamental signal at amplifier input and IM4 signal fed to its output. Also, the fundamental signal at the amplifier output reacts with the IM4 signal injected at the amplifier input over K_{11} term producing IM5 product (fourth term). Therefore, the original IM5 product (the first term) can be reduced by adjusting the amplitude and phase of IM4 signals that are injected at the amplifier input and put at its output.

The IM5 products are also expressed in terms of K_{30} coefficient-the fifth term in Eq. (3) which is made by a reaction between two IM2 signals and fundamental one. It is obvious that for the larger amplitude of the fundamental signal the injected IM2 signals are supposed to have greater amplitudes

as well, according to Eq. (2). Since φ_2 should be equal to 180° to reduce IM3 products, the phase of K_{30} term in Eq. (3) is 360°. Accordingly, with the rise in amplitudes of IM2 signals, mixing K_{30} term (the fifth term in Eq. (3)) starts increasing the power of IM5 products. Due to the overlapping of IM3 and IM5 spectra the power raise in the range of IM3 spectrum is unavoidable. Therefore, the power of IM2 signals run at the amplifier input should be kept at the reasonable level.

All mixing terms, which stand by K_{12} and K_{21} coefficients in Eq. (3), are generated due to the reaction between two IM2 signals and fundamental signal. The signals taken in consideration are observed at the input and output of amplifier. The K_{12} and K_{21} terms produce current at the frequencies of IM5 products with the opposite phases so that they reduce each other. Consequently, their influence to the power of IM3 and IM5 products can be cancelled. As a result, IM2 signals fed at the amplifier output are allowed to have power levels that are high enough to reduce IM3 products.

It should be pointed out that if IM2 and IM4 signals are put only at the amplifier output the IM2 and IM4 signals at the amplifier input will have sufficient power (i.e. the second and fourth terms in Eqs. (2) and (3) will exist as well as the fifth term in Eq. (3)) so that they can raise the power of IM3 and IM5 products. Therefore, it is necessary to inject IM2 and IM4 signals at the amplifier input which will set the adequate amplitudes and phases of the second and fourth terms in Eqs. (2) and (3) to cancel their undesirable influence to the IM3 and IM5 products.

In case when both amplitudes and phases of IM2 and IM4 signals are not related so that can suppress the IM3 and IM5 products simultaneously one kind of intermodulation products will not be lowered sufficiently or, unfortunately, they can increase in power. This situation is more probable when only one source of IM2 and IM4 signals is used that is the case in standard two-way Doherty amplifier [7].



Fig. 1. Three-way Doherty amplifier with additional circuit for linearization

3 Design of Three-Way Doherty Amplifier

The amplifier is designed in configuration with two quarter-wave impedance transformers in the output combining circuit [13]-[14]. The output impedances of the amplifier cells are selected to satisfy the output power relations between the carrier and peaking cells. Also, the transmission lines in the output combining circuit are practical for realization with not too high or too low characteristic impedances as shown in Fig. 1.

The carrier and peaking amplifying cells are Freescale's designed using **MRF281SR1** LDMOSFET with a 4-W peak envelope power level (PEP) according to the non-linear MET model included in ADS library. In case when the influence of additional circuit for linearization is not considered two different cases are analysed: the carrier and peaking cells in Doherty amplifier are loaded as a short circuit for the second harmonics and an open circuit for the third harmonics (Doherty at class-3F), and all cells are terminated to be an open circuit for the second harmonics and a short circuit for the third harmonics (Doherty at class-3IF).

The proposed linearization technique is implemented through the diplexer with harmonic control circuit (HCC), which separates fundamental and signals for linearization (IM2 and IM4). The output matching circuits are placed after the diplexer at two independent branches of the fundamental and signals for linearization, Fig 1. The diplexer with HCC shown in Fig. 2a), together with the matching circuit, provides the optimal impedance for adequate power of the signals for linearization as well as an open circuit for the third harmonics (HCC class-F loading). The three-way Doherty amplifier configuration where all cells are terminated at the output with such a loading is denoted as HCC class-3F. The diplexer shown in Fig. 2b), together with the matching circuit, enables the optimal impedance for IM2 and IM4 signals and short circuit for the third harmonics (HCC class-IF loading). In case when all cells are loaded in that way three-way Doherty amplifier operates in HCC class-3IF.

The matching impedances for source and load of the amplifying cells at 2.14GHz (fundamental signal) are obtained in load- and source-pull analysis for high drain-efficiency. They are:

 $Z_s = (2.75 - j1.26)\Omega$ and $Z_L = (5.59 + j3.73)\Omega$, respectively, in case of class-3F and HCC class-3F for improved linearity. The amplifying cells are terminated with source and load impedances:

 $Z_s = (3.023 - j1.396)\Omega$ and $Z_L = (5.13 + j9.53)\Omega$ in case of class-3IF and HCC class-3IF.

A quiescent bias of carrier cell for class-3F and class-3IF Doherty operation is 3.8V (pinch-off). In case when linearization technique is applied, the carrier cell is biased at class-AB with $V_G = 5.1$ V (13.5%I_{DSS}). Two peaking amplifiers operate in class-C, (peaking 1 amplifier $V_G = 2.8$ V and peaking 2 $V_G = 0.8$ V). The drain bias voltage $V_D = 26$ V is the same for all cells.

At the frequencies of fundamental signals, the input matching is performed for 50Ω , while the output matching circuits are designed to transform the optimum output impdance of the carrier and two peaking cells to 100Ω , 40Ω and 30Ω , respectively.





Fig.2. Frequency diplexer with harmonic control circuit a) HCC class-F; b)HCC class-IF

Offset lines are incorporated at the output of peaking amplifier cells to minimize the effective loading of the peaking amplifiers in state when those amplifiers do not operate (low-power range). In order to compensate for phase relation distortion in Doherty amplifier an appropriated offset line is adjusted at the output of the carrier amplifier. The length of offset lines at carrier and peaking amplifer outputs are 48°, 50° and 52° at (HCC) class-3F¹, and 45°, 63° and 65° at (HCC) class-3IF Doherty amplifier.

The peaking amplifiers are driven by signals with 1dB higher power than that of the carrier amplifier according to the analysis of uneven power drive performed in [15]. Maximum output power achieved by this Doherty configuration is nearly 41dBm.

4 Simulated Results of Linearization

The designed configuration of Doherty amplifier provides the linearization by simultaneous injection of the second harmonics and fourth-order nonlinear signals (IM2 and IM4) at the input and output of the carrier amplifier. The peaking amplifiers are biased at different points to produce adequate amplitude and phase relations between IM2 and IM4 signals. The signals for linearization generated at the outputs of the peaking cells are extracted by the diplexer with the appropriated harmonic control circuit. The IM2 and IM4 signals are tuned in amplitude and phase by the amplifier and phase shifter over two paths as given in Fig. 1.



Fig. 3. Frequency diplexer

Also, the frequency diplexer in configuration given in Fig. 3 is inserted at the carrier amplifier input

¹ HCC in brackets in front of denotation of class of operation means that conditions are valid for both class-3F\3IF and HCC class-3F\3IF

with the independent matching circuits for the fundamental and signals for linearization, Fig. 1. Consequently, the carrier amplifier is harmonically controlled at input and output. This configuration enables higher gain of class-AB carrier amplifier with lower power of intermodulation products in reference to the standard class-F (class-IF) amplifier biased at pinch-off [16].

The results of linearization for two-tone test of HCC class-3F three-way Doherty amplifier at frequencies 2.139GHz and 2.141GHz are given in Fig. 4. It compares output spectra before and after the linearization in case of 20dBm input power of fundamental signals. It can be noticed that IM3 products are asymmetrically suppressed for 17dB and 20dB, while IM5 products are lessened 6dB and 10dB. The intermodulation products of Doherty amplifier before linearization (dashed line) refer to the case when amplifying cells are terminated for class-F operation but biased as for HCC class-F (5.1V gate bias of carrier cell etc.).



Fig. 4. Output spectra of three-way Doherty amplifier before (dashed line) and after the linearization (solid line) for HCC class-3F

Fig. 5 gives result of linearization (the power of IM3 and IM5 products in reference to the power of fundamental signals) for a range of average output power (31dBm-37dBm). These results are compared to the intermodulation products of class-3F Doherty amplifier when linearization is not carried out (3.8V gate bias of carrier cell etc.). The presented results relate to the case when the amplitudes and phases of IM2 and IM4 signals are adjusted on the optimal values at 33.3dBm average output power where IM3 are suppressed for 21dB, while IM5 products are lower for 18dB and 10dB.

It is evident from the figure that the linearization with the proposed approach gives satisfactory results in the reduction of IM3 products in the observed range of output power. It is noticed that suppression of IM5 products is more asymmetrical, but generally IM5 products are reduced to the lower power levels than those achieved for IM3 products in whole considered power range.



Fig. 5. Output spectra of HCC class-3F three-way Doherty amplifier before (dashed line) and after the linearization (solid line) for: a) IM3 products; b) IM5 products

Power-added-efficiency for three-way Doherty amplifier designed with HCC class-3F loading is presented in Fig. 6 showing PAE of 53.2% at maximum power (0dB back-off) and 32.4% at 6dB back-off (35dBm total output power). Fig. 6 shows that PAE in case of the additional linearization circuit drops for 12.8% at maximum power point and 7.4% at 6dB back-off point in reference to the case of class-3F Doherty without linearization. Additionally, PAE of standard three-way Doherty amplifier which results of linearization are included into [7] shows lower PAE than linearized HCC Doherty to -10dB back-off. Also, the linearized HCC Doherty has higher PAE in the range -1dB to -9dB back-off than a balanced structure consisting of three class-F amplifiers biased at pinch-off.



Fig. 6. Power-added-efficiency of three-way Doherty amplifier

The results of linearization for HCC class-3IF threeway Doherty amplifier in case of two-tone test at frequencies 2.139GHz and 2.141GHz and 20dBm input power are illustrated in Fig.7.



Fig. 7. Output spectra of three-way Doherty amplifier before (dashed line) and after the linearization (solid line) for HCC class-3IF

It can be noticed that in case of HCC class-3IF Doherty amplifier IM3 and IM5 products decrease for approximately 10dB. However, the output power of fundamental useful signals is reduced by 1dB.

The results shown in Fig. 8 relate to two-tone test of HCC class-3IF three-way Doherty amplifier for a

range of average output power of fundamental signals (31dBm-37dBm). Additionally, figure includes IM3 and IM5 products for class-3IF Doherty that is not linearized. The results are attained for the amplitudes and phases of IM2 and IM4 signals obtained in optimization for 31.8dBm average output power. At this point IM3 and IM5 products go down for approximately 10dB.



Fig. 8. Output spectra of HCC class-3IF three-way Doherty amplifier before (dashed line) and after the linearization (solid line) for: a) IM3 products; b) IM5 products

It follows from Figs. 5 and 8 that IM3 products descend for a larger grade after the linearization in case of HCC class-3F Doherty comparing to HCC class-3IF. Also, the linearization influences IM5 products almost equally in both configurations of Doherty amplifier.

Power-added-efficiency for three-way Doherty designed for operation in classes amplifier mentioned before with and without applied linearization technique are presented in Fig. 9. It is seen that PAE of three-way Doherty amplifier designed for class-3IF is 65% at maximum power (0dB back-off) and 42.7% at 6dB back-off (35dBm total output power) that is higher than PAE for class-3F in almost entire power range considered. Also, HCC loading for class-3IF operation with linearization rieches PAE of 56.7% at maximum power and 34.5% at 6dB back-off, which is the better results in reference to HCC class-3F configuration, which includes the linearization.



Fig. 9. Power-added-efficiency of three-way Doherty amplifier at class-3F, class-3IF, and with HCC circuits that include the linearization

The output spectra obtained in simulation before and after linearization for OQPSK digitally modulated signal with 1.25MHz spectrum width, carrier at frequency 2.14GHz and input power 23dBm are compared in Fig. 10a) for HCC class-3F and Fig.10b) for HCC class-3IF. It should be noticed that peak-to-average power ratio in this case is 6dB. Also, obtained results are included in Table I for a detailed insight. For 35.62dBm average output power (5.2dB back-off), ACPR is improved for approximately 11dB and 14dB at \pm 900kHz offsets, and 11dB and 20dB at \pm 2100kHz offsets for HCC class-3F. It follows from Fig. 6 and 9 that PAE at this power level is 36%.

The improvement in case of HCC class-3IF is around 11dB at \pm 900kHz, and 6dB and 3dB at \pm 2100kHz, whereas the average output power of fundamental signals dropes down from 35.1dBm to





Fig. 10. Simulated spectrum of the output signal for three-way Doherty amplifier for OQPSK digitally modulated signal before (dashed line) and after linearization (solid line) in case of a) HCC class-3F; b) HCC class-3IF

Туре	ACPR (dB)			ACPR (dB)			Fun. signals (dBm)	
HCC	Offset	Bef.	Aft.	Offset	Bef.	Aft.	Bef.	Aft.
	(MHz)			(MHz)				
Class-3F	+0.9	-41.06	-52.41	+2.1	-51.50	-62.01	35.96	35.62
	-0.9	-40.35	-54.35	-2.1	-49.04	-69.33		
Class-3IF	+0.9	-36.96	-47.98	+2.1	-46.92	-53.11	35.1	34.26
	-0.9	-35.72	-46.94	-2.1	-45.41	-48.17		

Table I. Average output power and ACPR at offsets ±900kHz and ±2100kHz from carrier frequency for threeway Doherty amplifier before and after the linearization for HCC class-3F and HCC class-3IF in case of OQPSK digitally modulated signal

It should be pointed out that the intermodulation products in case of (HCC) class-3IF have higher power level than in (HCC) class-3F. Even though the power-added-efficiency of HCC class-3IF Doherty amplifier is better in reference to the HCC class-3F amplifier, the greater reduction of intermodulation products are accomplished in latter case without a substantial degradation of fundamental signal power level.

5 Conclusion

This paper presents the design of three-way Doherty amplifier with LDMOSFETs loaded with the frequency diplexer at the outputs that separates the fundamental signals and signals for linearization (the second harmonics and the fourth-order nonlinear signals at frequencies close to the second harmonics). The diplexer includes harmonic control circuit that, together with the matching circuit, provides the optimal impedance for the signals for linearization. Additionally, when third harmonics are considered HCC enables an open or short circuit at the output of amplifying cells in Doherty amplifiers; therefore, depending on a termination for the third harmonics two configurations of Doherty amplifier were analyzed in terms of the efficiency and linearity: HCC class-3F and HCC class-3IF.

For these configurations of three-way Doherty amplifier the linearization was carried out by the simultaneous injection of the second harmonics and fourth-order nonlinear signals at the input and output of the carrier amplifier. The linearization approach achieves very good results in the reduction of both IM3 and IM5 products (improvement in ACPR for digitally modulated signals) for configurations considered retaining the high efficiency of Doherty amplifier. It should be stressed that HCC class-3IF three-way Doherty amplifier reaches the higher power-aided-efficiency in comparison with HCC class-3F. However, in latter case the linearization accomplishes greater suppression of thirdand fifth-order intermodulation products. Moreover. the intermodulation products in case of (HCC) class-3IF have higher power level than in (HCC) class-3F so that the linearization in latter case achieves better relation of IM products in reference to the power of the fundamental signals.

On the top of that, since the peaking amplifiers are sources of signals for Doherty amplifier linearization, there is no need for the additional nonlinear sources, which leads to lower energy consumption and simpler linearization circuit topology.

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