Improvement in ACLR Asymmetry for W-CDMA InGaP/GaAs HBT Power Amplifier

Koichi Kimura, Masato Seki, Nobuhisa Matsumura*, Kazuhiko Honjo

University of Electro-Communications, Department of Information and Communication Engineering,
1-5-1 Chofugaoka, Chofushi, 182-8585 Japan
* New Japan Radio Corporation, 2-1-1, fukuoka, kamifukuoka, 356-8510 Japan

Abstract **— Asymmetry in Adjacent Channel Leakage power Ratio (ACLR) has been often observed in high power amplifiers for digital wireless communication systems such as W-CDMA. This paper describes a method for reducing the asymmetry by controlling bias circuit impedance at sub harmonics. By shortening both at 4MHz and 8MHz at the bias circuits, an 8.37-dB ACLR asymmetry could be suppressed to a 5.05-dB ACLR asymmetry, where a 10.5-dB 3rd order Inter Modulation Distortion (IMD3) asymmetry could also be successfully improved to a 1.8-dB IMD3 asymmetry.**

I. Introduction

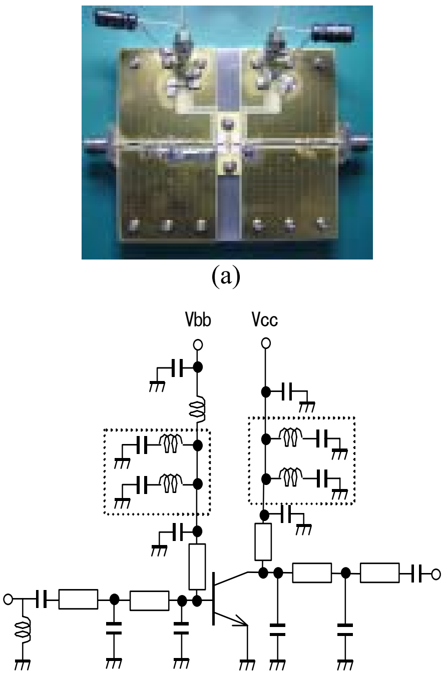
Asymmetry in ACLR as well as in IMD3 has been often observed in high power amplifiers for mobile communication systems such as W-CDMA [1]. Distortion levels in power amplifiers are determined by the largest adjacent channel leakage power. Therefore by reducing the asymmetry, the distortion levels are considered to be suppressed. Distortion generation mechanism for ACLR and IMD3 are due to nonlinear characteristics of transistors.

In this paper, two steps were taken to improve the asymmetry in ACLR. The first, a generation mechanism for the asymmetry in IMD3 is analyzed using the Volterra series [2], taking account of up to the 5th order nonlinear transfer functions. The analysis results brings about that the asymmetry is generated through the 2nd and 4th order nonlinear transfer functions, where difference frequency of two tones (4MHz: equivalent to a chip rate) takes an important role [3]. Therefore, by cutting this mechanism by shortening the bias circuits both at an input port and an output port at 4MHz and 8MHz, the asymmetry in IMD3 can be improved. The second, due to the similarity of generation mechanism for ACLR asymmetry, the same shortening circuits are applied to suppress the asymmetry in ACLR. By means of this method, an 8.37-dB ACLR asymmetry could be suppressed to a 5.05-dB ACLR asymmetry, where a 10.5-dB 3rd order Inter Modulation Distortion (IMD3) asymmetry could also be successfully improved to a 1.8-dB IMD3 asymmetry.

II. Observation Of Asymmetric ACLR and IMD3

A W-CDMA power HBT amplifier, used in this experiment, consists of InGaP/GaAs HBT whose emitter size is 2.6µm × 30µm × 48units, and input/output matching circuits fabricated on low loss resin circuit boards (MEGTRON5). The relative dielectric constant, ε_r, for the resin board, is 3.6 and the loss tangent, $\tan\delta$, is 0.004. The metal (Cu 32µm thick) conductance, σ, is 2.9×10^7 S/m (@1GHz). Low loss chip capacitors (Murata Mfg. : GQM series chip capacitors) are also used. The maximum oscillation frequency, f_{max}, for a single unit HBT, is 57 GHz and the current gain cutoff frequency, f_T, is 32 GHz. An amplifier operation frequency is 1.95GHz, which is used for W-CDMA. Saturated power output was 32.3 dBm, and power gain at output power level of 27dBm was 11.3dB, measured at the bias condition of the base bias voltage V_{bb} = 1.27V, the collector DC voltage V_{cc} = 3.4V, the quiescent collector current I_q = 40mA. The maximum power added efficiency, PAE_{max}, and the maximum collector efficiency, η_{cmax}, were 50.5% and 64.5%, respectively.

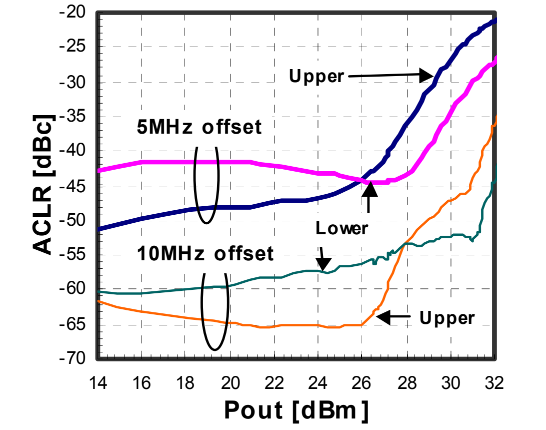
The measured results for the asymmetry in ACLR and that in IMD3 are shown in Fig.2 (a) and Fig.2 (b), respectively. It was observed that when the power output level is low, the lower ACLR is larger than the upper ACLR and when the power output level is high, the upper ACLR is larger than the lower ACLR. Similar phenomenon was seen in IMD3 measurements.



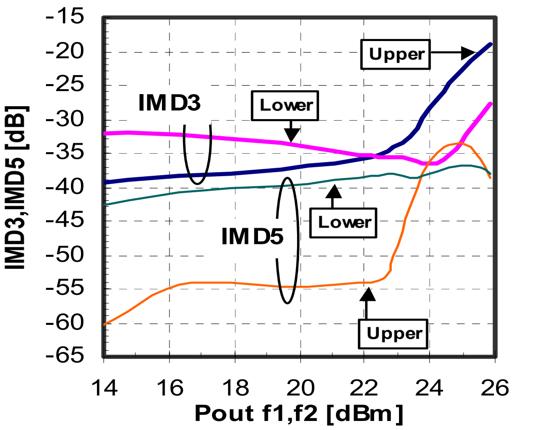
(a)

(b)

Fig. 1. (a) InGaP/GaAs HBT power amplifier. (b) Equivalent circuit model of the power amplifier.



(a)



(b)

Fig. 2. (a) Measured ACLR and (b) Measured intermodulation distortion for the power amplifier shown in Fig.1.

III. Generation Mechanism for Asymmetry

The Volterra-series considering up to the 5 th order nonlinear transfer functions is applied to an HBT amplifier equivalent circuit as shown in Fig.3. Overall 3 rd order intermodulation distortions are calculated as a summation of vectors generated by nonlinear transfer functions.

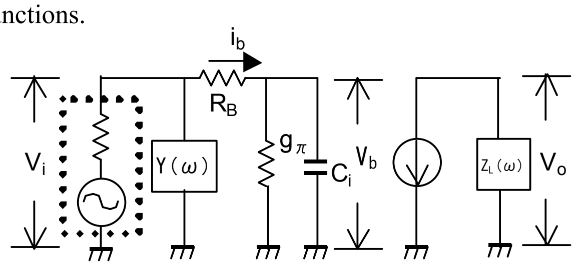


Fig. 3. Equivalent circuit model of HBT for asymmetry analysis.

The nonlinear transfer function denoted $H_{nc}(\omega_{1,\ldots,}\omega_n)$, relating the input voltage, V_i , to the internal voltage, V_b, is obtained as an intermediate step for deriving the overall transfer function denoted $H_{nc}(\omega_{1,\ldots,}\omega_n)$, relating the input voltage, V_i , to the output voltage, V_o. The 3rd order nonlinear transfer function is expressed as follows;

$$H_{1c}(\omega_1) = \frac{1}{1+R_B(g_{\pi 1}+j\omega_1 C_{i1})} = \frac{1}{1+R_B Y_{b1}(\omega_1)} \quad (1)$$

$$H_{2c}(\omega_1,\omega_2) = -R_B Y_{b2}(\omega_1+\omega_2) H_{1c}(\omega_1+\omega_2) H_{1c}(\omega_1) H_{1c}(\omega_2) \quad (2)$$

$$H_{3c}(\omega_1,\omega_2,\omega_3) = \frac{-R_B}{3!} H_{1c}(\omega_1+\omega_2+\omega_3)\cdot \{Y_{b2}(\omega_1+\omega_2+\omega_3)(2\cdot\overline{H_{1c}(\omega_1)H_{2c}(\omega_2,\omega_3)}) + Y_{b3}(\omega_1+\omega_2+\omega_3)(3!H_{1c}(\omega_1)H_{1c}(\omega_2)H_{1c}(\omega_3))\} \quad (3)$$

where

$$Y_{bn}(\omega) = g_{\pi n} + j\omega C_{in}$$

The 3 rd order nonlinear transfer functions at $2\omega_2$-ω_1 and the at $2\omega_1$-ω_2 can be represented as,

$$H_3(\omega_1,\omega_1,-\omega_2) = Z_L\{2\cdot(g_{m2}-g_{m1}R_B D_2(2\omega_1-\omega_2))\overline{H_{1c}(\omega_1)H_{2c}(\omega_1,-\omega_2)} + 3!(g_{m3}-g_{m1}R_B D_3(2\omega_1-\omega_2))H_{1c}(\omega_1)H_{1c}(\omega_1)H_{1c}(-\omega_2)\} \quad (4)$$

$$H_3(\omega_2,\omega_2,-\omega_1) = Z_L\{2\cdot(g_{m2}-g_{m1}R_B D_2(2\omega_2-\omega_1))\overline{H_{1c}(\omega_2)H_{2c}(\omega_2,-\omega_1)} + 3!(g_{m3}-g_{m1}R_B D_3(2\omega_2-\omega_1))H_{1c}(\omega_2)H_{1c}(\omega_2)H_{1c}(-\omega_1)\} \quad (5)$$

where

$$D_n(\omega) = Y_{bn}(\omega)H_{1c}(\omega)$$

Assuming the difference angular frequency (ω_2-ω_1) is much lower than the fundamental angular frequencies, ω_1, ω_2, the following relations are derived; $H_{1c}(\omega_1)\cong H_{1c}(\omega_2)$, $H_{1c}(2\omega_1)\cong H_{1c}(2\omega_2)$, $H_{1c}(2\omega_1-\omega_2)\cong H_{1c}(2\omega_2-\omega_1)$, $Y_{bn}(2\omega_1-\omega_2) \cong Y_{bn}(2\omega_2-\omega_1)$, $H_{1c}(\omega_1-\omega_2)=H_{1c}^*(\omega_2-\omega_1)$. The difference between the value calculated from Eq. (4) and that calculated from Eq. (5) can be expressed by Eq.(6) and includes imaginary part of $D_2(\omega_1-\omega_2)$: $\mathrm{Im}(D_2(\omega_1-\omega_2))$.

$$H_3(\omega_2,\omega_2,-\omega_1) - H_3(\omega_1,\omega_1,-\omega_2) = Z_L\cdot 2\cdot(g_{m2}-g_{m1}R_B D_2(2\omega_2-\omega_1))H_{1c}(\omega_1)\{-2\cdot 2\cdot R_B\cdot \mathrm{Im}(D_2(\omega_2-\omega_1))\} \quad (6)$$

Considering up to the 5th order, the difference also includes $\mathrm{Im}(D_2(2\omega_1-2\omega_2))$.

The lower IMD3 at $2\omega_1$-ω_2 can be represented as follows,

$$V_o|_{\omega=2\omega_1-\omega_2} = \frac{3}{4}V_s^3|H_3(\omega_1,\omega_1,-\omega_2)|\cos[(2\omega_1-\omega_2)t+\angle H_3(\omega_1,\omega_1,-\omega_2)] + \frac{20}{2^4}V_s^5|H_5(\omega_1,\omega_1,-\omega_2,\omega_1,-\omega_1)|\cos[(2\omega_1-\omega_2)t+\angle H_5(\omega_1,\omega_1,-\omega_2,\omega_1,-\omega_1)] + \frac{30}{2^4}V_s^5|H_5(\omega_1,\omega_1,-\omega_2,\omega_2,-\omega_2)|\cos[(2\omega_1-\omega_2)t+\angle H_5(\omega_1,\omega_1,-\omega_2,\omega_2,-\omega_2)] \quad (7)$$

The upper IMD3 can also be expressed by replacing ω_1 with ω_2 and replacing ω_2 with ω_1 in Eq. (7). According to the result calculated above, the difference between the lower IMD3 and the upper IMD3 also includes $\mathrm{Im}(D_2(\omega_1-\omega_2))$ and $\mathrm{Im}(D_2(2\omega_1-2\omega_2))$. Therefore, an asymmetry distortion is improved by eliminating these terms. In order to eliminate $Im(D_2(\omega_1-\omega_2))$ and $Im(D_2(2\omega_1-2\omega_2))$, $H_{1c}(\omega_1-\omega_2)$ and $H_{1c}(2\omega_1-2\omega_2)$ should be zero because $Y_{bn}(\omega_1-\omega_2)$ and $Y_{bn}(2\omega_1-2\omega_2)$ are considered as given HBT parameters in this paper.

IV. Reduction for Simulated IMD3 Asymmetry

As described in III, by shortening the difference frequencies of 4MHz and 8MHz in bias circuits, the asymmetry can be suppressed. LC series resonant circuits, whose resonance frequencies are 4MHz and 8MHz, were used for shortening the second-order difference angular frequency of $\omega_2-\omega_1$, and the fourth-order difference angular frequency of $2\omega_2-2\omega_1$, respectively. A chip capacitor of 3300pF (self resonance frequency (SRF)=100MHz) and a 470nH chip inductor (SRF=1GHz) are used for a 4MHz resonance circuit. A chip capacitor of 3300pF (self resonance frequency (SRF)=100MHz) and a 120nH chip inductor (SRF=2.55GHz) are used for an 8MHz resonant circuit. Measured frequency characteristics are shown in Fig.4. Each resonant circuit is added to both input bias circuit and ouput bias circuit as shown in Fig.1 (b) where are surrounded by dotted line. The 3rd and 5th order intermodulation distortions were evaluated for the InGaP/GaAs HBT amplifier with the resonant circuits using a harmonic balance simulator (ADS). Simulated input/output power responses were shown in Fig.6. As seen, it is necessary that the 4th order difference frequency be eliminated for improving the asymmetry.

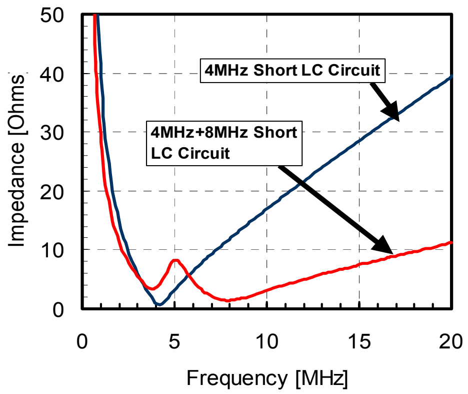


Fig. 4. The frequency characteristic for LC series resonant circuits.

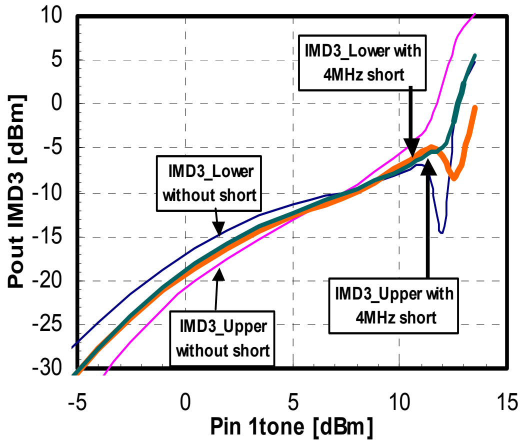


Fig. 5. Simulated IMD3 with 4MHz short circuit and simulated IMD3 without 4MHz short circuit.

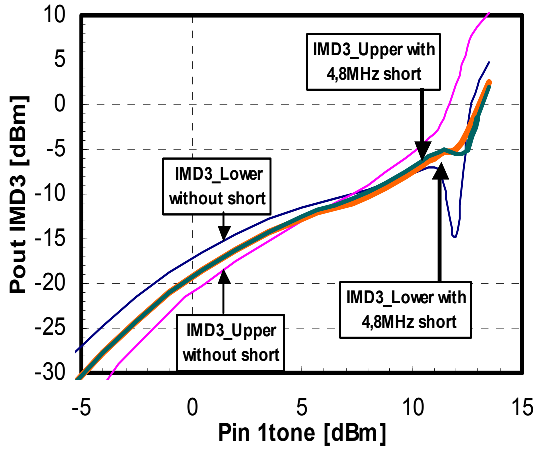


Fig. 6. Simulated IMD3 with 4MHz and 8MHz short circuits and simulated IMD3 without 4MHz and 8MHz short-circuits.

V. Experimental Reduction for ACLR and IMD3 Asymmetry

Measured IMD3 asymmetry for the amplifier with the shortening resonators are shown in Fig. 7 and Fig.8. The measured characteristics are similar to the simulated results. For the IMD3 asymmetry, shortening the bias circuits at 4MHz and 8MHz is more suppressible than shortening the bias circuits only at 4MHz. In consideration of the similarity of generation mechanism for the ACLR asymmetry, ACLR in the power amplifier with the 4MHz and 8MHz short circuits is measured, and the results are shown in Fig.9. As seen, ACLR itself could be suppressed, especially at output power level lower than 26dBm. An 8.7-dB improvement in maximum IMD3 asymmetry and a 3.3-dB improvement in maximum ACLR asymmetry were obtained, as shown in table.1.

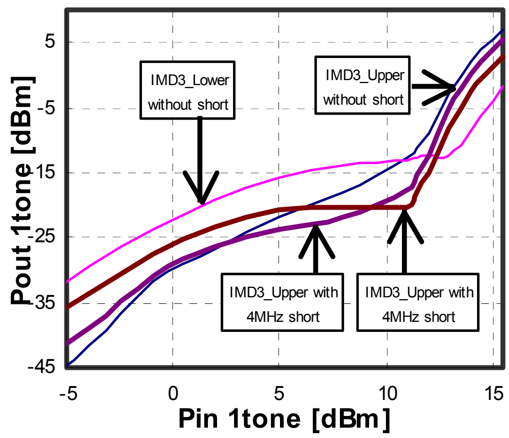


Fig. 7. Measured IMD3 with 4MHz short circuit and measured IMD3 without 4MHz short circuit.

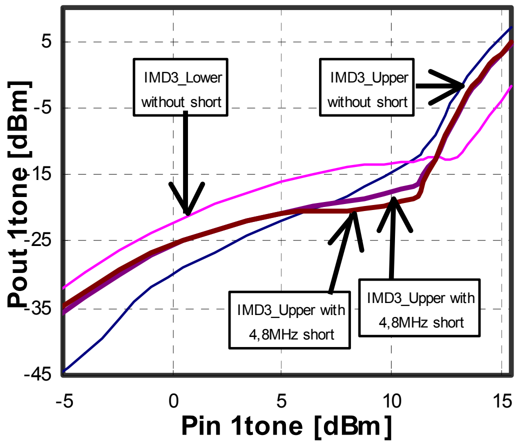


Fig. 8. Measured IMD3 with 4MHz and 8MHz short-circuits and measured IMD3 without 4MHz and 8MHz short-circuits.

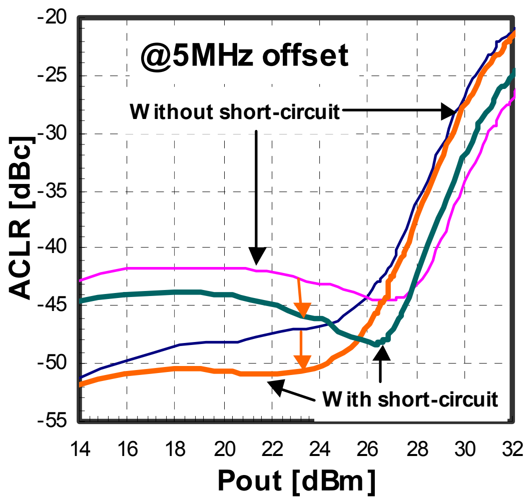


Fig. 9. Measured ACLR for the power amplifier with the 4MHz and 8MHz short circuits and measured ACLR without the short circuits.

Table.1. Comparison of asymmetry

	maximum IMD3 asymmetry [dB]	maximum ACLR asymmetry [dB]
witout resonant circuit	10.5	8.37
with 4MHz short circuit	3.13	5.38
with 4MHz short circuit and 8MHz short circuit	**1.81**	**5.05**

VI. Conclusion

A generation mechanism for the asymmetry in IMD3 is analyzed using the Volterra series, taking into account up to the 5th order nonlinear transfer functions. IMD3 asymmetry is suppressed by shortening at the bias circuits both at the input port and the output port at 4MHz and 8MHz. The asymmetry in ACLR is also improved using the same short circuits as well as ACLR itself. By shortening both at 4MHz and 8MHz at the bias circuits, an 8.37-dB ACLR asymmetry could be suppressed to a 5.05-dB ACLR asymmetry, where a 10.5-dB IMD3 asymmetry could be also successfully improved to a 1.8-dB IMD3 asymmetry. Thus, the generation mechanism for the ACLR asymmetry is considered to be similar to that for the IMD3 asymmetry.

Acknowledgement

The authors would like to express gratitude to A. Satou for preparing low loss resin circuit boards. This project was partly supported by Agilent Technology University Relations Philanthropy Grant Program.

References

[1] Nuno Borges Carvalho and Jose Carlos Pedro, "Two-tone IMD Asymmetry in Microwave Power Amplifiers," *IEEE Trans. MTT*, pp. 445-448, 2000.

[2] S.A.Maas, *Nonlinear Microwave Circuit*, Artech house, 1988.

[3] Youngoo Yang and Bumman Kim,"A New Linear Amplifier Using Low-Frequency Second-Order Intermodulation Componet Feedforwarding,"IEEE Microwave and Guided Wave Letters,vol.9,No.10,pp419-421,1999