APPLICATION NOTE

Two-tone Linearity in a 900 MHz Silicon Bipolar Class AB Amplifier

AN98026

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CONTENTS

1 INTRODUCTION

In order to achieve the highest channel capacity available in wireless communications bands, power amplifiers used in these systems must have a carrier-to-intermodulation distortion (IMD) ratio of –60 dBc. The most common way to reach these IMD levels is the feedforward compensation method. With a dualloop feedforward system, a 30 dB improvement in IMD can be achieved. Therefore, the power amplifier in the feedforward system should have at least an IMD of –30 dBc.

When a power amplifier is operated in class A, the –30 dBc IMD can be met. However, collector efficiency of such an amplifier is low. As a result, it is preferable to operate the power amplifier in class AB mode, which gives a higher collector efficiency (typically 35 to 40 percent under two-tone conditions) that improves overall system efficiency considerably. When a bipolar amplifier is operated in class AB, the IMD caused by a combination of the nonlinearities in the RF power transistors' transfercharacteristics (both amplitude and phase) and the amplifier's circuit parameters under certain circumstances results in the amplifier falling short of the –30 dBc IMD that is required.

This article shows the typical behaviour of a 900 MHz amplifier operating in the class AB mode and describes a method to create suppression of the intermodulation products to better than –30 dBc over a 40 dB dynamic range (1 mW to 10 W peak envelope power (PEP)). A 10 W PEP amplifier is used as an example. The used power transistor[1] is a 10 W device for 900 MHz applications operating at 26 V supply voltage. The amplifier has been designed for the 869 to 894 MHz band. Tuning was not applied when the data were recorded.

2 IMD AND POWER GAIN

IMD is related to the output power level (P_{out}) of an RF power device. An RF power amplifier operating in class AB, with a 1 dB compression point of 10 W CW should be able to deliver a PEP of 10 W with a two-tone IMD of –30 dBc. The amplifier's 1 dB compression point is the point where the power gain G_p is decreased by 1 dB when compared to G_p in the linear region. The P_{sat} saturation power is the point where $\Delta P_{out}/\Delta P_{in} = 1$ as shown in Fig.1. Figure 2 shows the method of defining two-tone IMD.

The most common way to specify two-tone intermodulation is to relate it to the level of one of the two carriers f_1 or f_2. The two-tone IMD is expressed in dBc, meaning dB below one carrier. In cases where two-tone IMD is related to the PEP level, the IMD X is a figure that is 6 dB better. In case the transistor is operated in the linear region, the PEP is 3 dB above the average power. The average power is the addition of the average power levels of the carriers f_1 and f_2. For example, $P(f_1) = 1$ W and $P(f_2) = 1$ W, therefore PEP = 4 W.

In class A operation, the IMD will get worse as the output power levels increase. However, when a silicon bipolar transistor is operated in the class AB mode, interesting effects are observed when the device's quiescent current (I_{cq}), that is, the DC collector current when no RF is applied at the input of the amplifier, is varied.

Figure 3 shows the third-order IMD d3 of the devices as a function of the PEP and I_{cq}. The test is performed with a 60 kHz carrier separation. I_{cq} variations change the shape of the d3 curve. A low (5 mA) I_{cq} gives a better d3 at power levels above 8 W PEP. Higher I_{cq} (50 mA) gives better d3 at lower power levels. The effects on the fifth- and seventh-order distortion products is not shown. The change in I_{cq} also affects these IMD products, but the final results show that IMD suppression is sufficient. At the same time, G_p is affected by the change in I_{cq}, as shown in Fig.4.

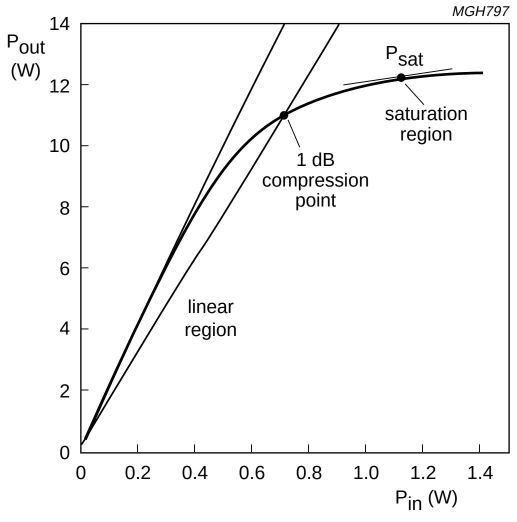


Fig.1 The power amplifier’s typical transfer characteristics.

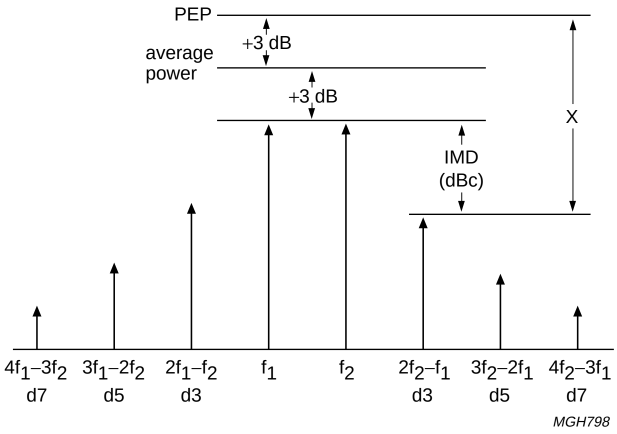
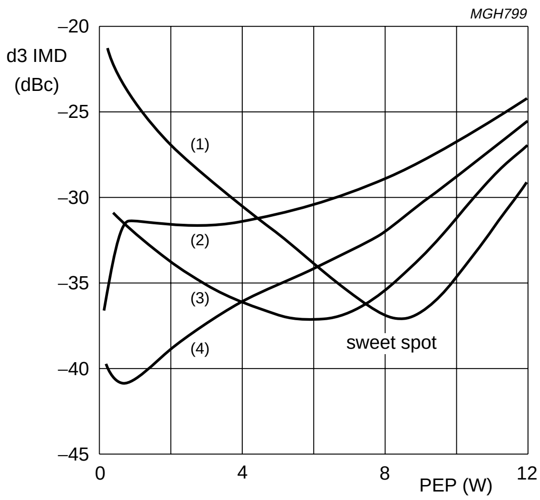
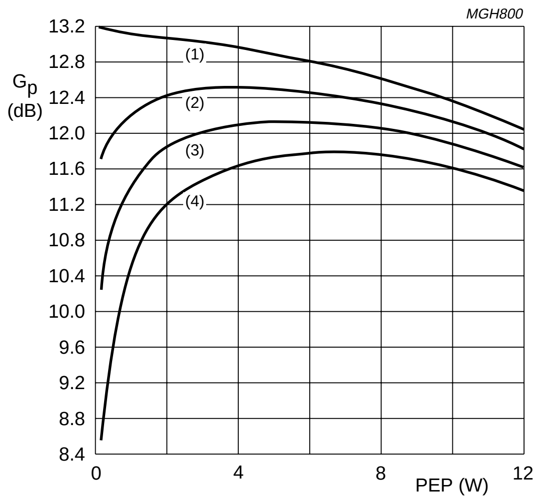


Fig.2 Two-tone IMD.



(1) 5 mA.
(2) 20 mA.
(3) 50 mA.
(4) 100 mA.

Fig.3 Two-tone, third-order IMD vs. PEP and I_{cq}.



(1) 100 mA.
(2) 50 mA.
(3) 20 mA.
(4) 5 mA.

Fig.4 Power gain vs. PEP and I_{cq}.

3 IMD IMPROVEMENT

The ideal situation is an amplifier with a flat response on G_p (gain as a function of output power and gain as a function of frequency) to ensure perfect intermodulation cancellation and an IMD better than –30 dBc over a 40 dB dynamic range to meet the –60 dBc IMD requirement for the complete feedforward amplifier. Considering two-tone, third-order IMD and G_p, a 50 mA I_{cq} is a good choice for power levels below 6 W PEP. For higher power levels the sweet spot (dip in the IMD curve) can be used to obtain a good IMD. However, the sweet spot moves when different I_{cq} are used. A 5 mA I_{cq} gives lower IMD at higher power levels, but will cause more gain compression over the total dynamic range of the amplifier. A sliding I_{cq} as a function of output power is the solution where a range of output power levels is expected. This solution can be achieved by adding a series resistor after the base bypass network, as shown in Fig.5. An increase in RF output power causes an increase in the DC collector current, and thus an increase in the DC-base current. This resistor is marked R. The allowed G_p compression and the desired IMD behaviour as a function of output power determine the value of R. The best way to determine the value of R is to set a goal for the IMD at both low and high power levels. By changing I_{cq}, the desired IMD at these two power levels can be reached. The voltage and the current at point Y have to be recorded for both the low and high power levels, which can be done without the series resistor present. The value of the resistor can be calculated with

$$R = \frac{\Delta V_{be}}{\Delta I_b} = \frac{V_{be1} - V_{be2}}{I_{b2} - I_{b1}} \; (\Omega)$$

where

R = series resistor (Ω)

V_{be1} = DC voltage a low power level (mV)

V_{be2} = DC voltage at high power level (mV)

I_{b1} = DC base current at lower power level (mA)

I_{b2} = DC base current at high power level (mA).

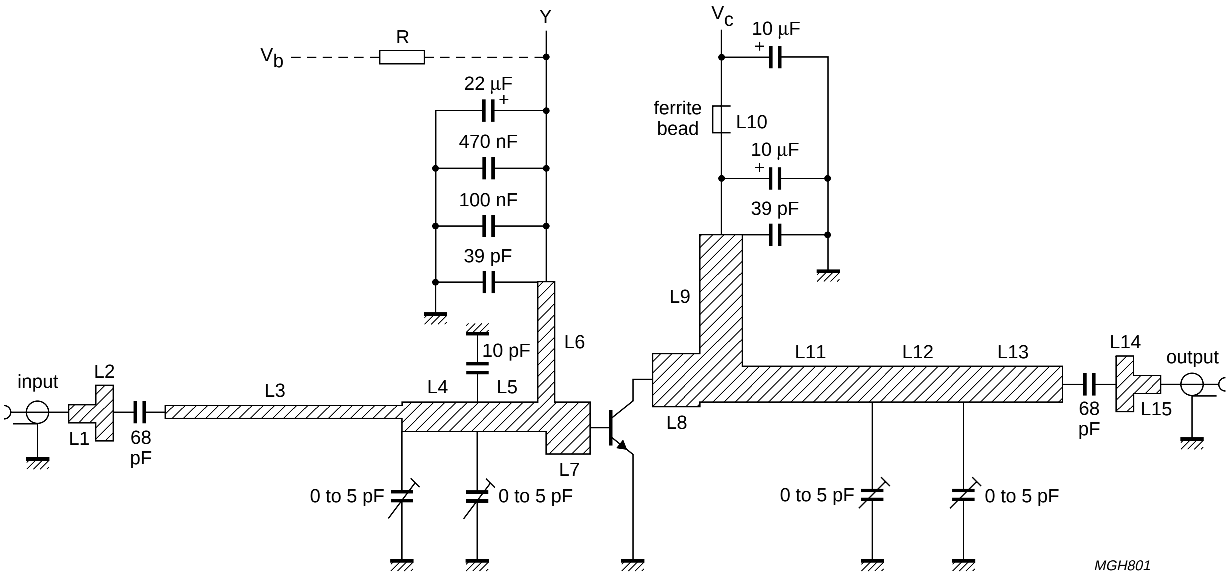
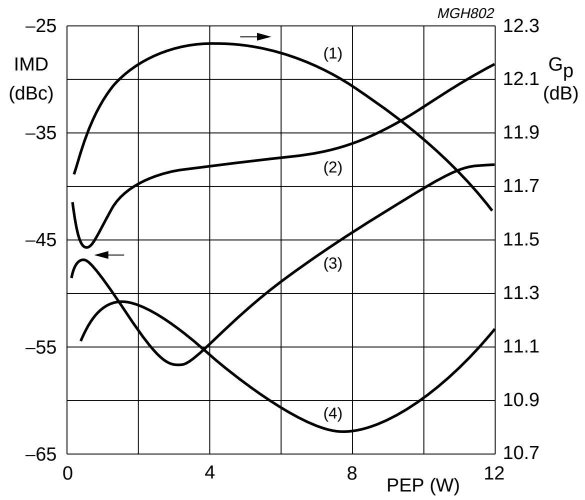


Fig.5 Schematic diagram of the 869 to 894 MHz base station amplifier.

As an example, a power amplifier's desired IMD at 0.4 PEP is < –40 dBc, which means I_{cq} should be 50 mA. The recorded data are V_{be1} = 746 mV and I_{b1} = 1072 mA. The desired IMD and 10 W PEP is < –30 dBc, which means I_{cq} must be 20 mA. The results are V_{be2} = 710 mV and I_{b2} = 5417 mA. Therefore $R = \frac{(746 - 710)}{(5417 - 1072)}$, which approximately equals 8.29 Ω.

Figure 6 shows the G_p and the third-, fifth- and seventh-order IMD products as a function of PEP when an 8.2 Ω resistor is added to the circuit at I_{cq} = 50 mA. Comparison of the IMD data with and without the 8.2 Ω resistor for I_{cq} = 50 mA shows that d3 increases by 4 dB at a P_{out} of 10 W. However, the G_p decreases by 0.3 dB when the 8.2 Ω series resistor is used. In the case where less G_p compression is required, the transistor value should be lowered since this reduces the shift in I_{cq} as a function of output power.

A lower resistor value also impacts the shapes of the IMD curves (d3, d5 and d7). A higher I_{cq} is needed to increase the G_p at low output power levels, impacting IMD.



(1) G_p.
(2) d3.
(3) d5.
(4) d7.

Fig.6 IMD and G_p vs. PEP with the added 8.2 Ω series resistor.

4 CONCLUSION

Using the typical characteristics of a silicon bipolar transistor in the class AB mode, it is possible to improve IMD for medium and high output power levels by adding a series resistor in the base bias network. This simple and reliable method allows the power amplifier to be operated in the class AB mode, which increases amplifier and overall system efficiency considerably. The presented class AB amplifier shows an IMD performance of better then –32 dBc over a 40 dB dynamic range up to 10 W PEP. This performance makes it possible to use the amplifier in a feedforward system, meeting a –60 dBc IMD requirement. The trade-off is a slight increase in gain compression over the total dynamic range. A good selection of I_{cq} and the series resistor value will give a usable compromise.

5 REFERENCES

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3. Eid E. Eid, Fadhel M. Ghannouchi, Francois Beauregard, ‘Optimal Feedforward Linearization System Design,’ Microwave Journal, Vol. 38, No. 11, November 1995, pp. 78-86.

Korne Vennema received his B Eng degree in electrical engineering from the Hogere Technische School in Utrecht, the Netherlands in 1987. In March 1987, he joined Philips Semiconductors in Nijmegen, the Netherlands, where he worked as a development engineer on the design of RF power transistors. Since July 1993, Vennema has been with Philips Semiconductors, Slatersville, RI, as an RF application and product engineer.

Philips Semiconductors – a worldwide company

Argentina: see South America

Australia: 34 Waterloo Road, NORTH RYDE, NSW 2113, Tel. +61 2 9805 4455, Fax. +61 2 9805 4466

Austria: Computerstr. 6, A-1101 WIEN, P.O. Box 213, Tel. +43 160 1010, Fax. +43 160 101 1210

Belarus: Hotel Minsk Business Center, Bld. 3, r. 1211, Volodarski Str. 6, 220050 MINSK, Tel. +375 172 200 733, Fax. +375 172 200 773

Belgium: see The Netherlands

Brazil: see South America

Bulgaria: Philips Bulgaria Ltd., Energoproject, 15th floor, 51 James Bourchier Blvd., 1407 SOFIA, Tel. +359 2 689 211, Fax. +359 2 689 102

Canada: PHILIPS SEMICONDUCTORS/COMPONENTS, Tel. +1 800 234 7381

China/Hong Kong: 501 Hong Kong Industrial Technology Centre, 72 Tat Chee Avenue, Kowloon Tong, HONG KONG, Tel. +852 2319 7888, Fax. +852 2319 7700

Colombia: see South America

Czech Republic: see Austria

Denmark: Prags Boulevard 80, PB 1919, DK-2300 COPENHAGEN S, Tel. +45 32 88 2636, Fax. +45 31 57 0044

Finland: Sinikalliontie 3, FIN-02630 ESPOO, Tel. +358 9 615800, Fax. +358 9 61580920

France: 51 Rue Carnot, BP317, 92156 SURESNES Cedex, Tel. +33 1 40 99 6161, Fax. +33 1 40 99 6427

Germany: Hammerbrookstraße 69, D-20097 HAMBURG, Tel. +49 40 23 53 60, Fax. +49 40 23 536 300

Greece: No. 15, 25th March Street, GR 17778 TAVROS/ATHENS, Tel. +30 1 4894 339/239, Fax. +30 1 4814 240

Hungary: see Austria

India: Philips INDIA Ltd, Band Box Building, 2nd floor, 254-D, Dr. Annie Besant Road, Worli, MUMBAI 400 025, Tel. +91 22 493 8541, Fax. +91 22 493 0966

Indonesia: see Singapore

Ireland: Newstead, Clonskeagh, DUBLIN 14, Tel. +353 1 7640 000, Fax. +353 1 7640 200

Israel: RAPAC Electronics, 7 Kehilat Saloniki St, PO Box 18053, TEL AVIV 61180, Tel. +972 3 645 0444, Fax. +972 3 649 1007

Italy: PHILIPS SEMICONDUCTORS, Piazza IV Novembre 3, 20124 MILANO, Tel. +39 2 6752 2531, Fax. +39 2 6752 2557

Japan: Philips Bldg 13-37, Kohnan 2-chome, Minato-ku, TOKYO 108, Tel. +81 3 3740 5130, Fax. +81 3 3740 5077

Korea: Philips House, 260-199 Itaewon-dong, Yongsan-ku, SEOUL, Tel. +82 2 709 1412, Fax. +82 2 709 1415

Malaysia: No. 76 Jalan Universiti, 46200 PETALING JAYA, SELANGOR, Tel. +60 3 750 5214, Fax. +60 3 757 4880

Mexico: 5900 Gateway East, Suite 200, EL PASO, TEXAS 79905, Tel. +9-5 800 234 7381

Middle East: see Italy

Netherlands: Postbus 90050, 5600 PB EINDHOVEN, Bldg. VB, Tel. +31 40 27 82785, Fax. +31 40 27 88399

New Zealand: 2 Wagener Place, C.P.O. Box 1041, AUCKLAND, Tel. +64 9 849 4160, Fax. +64 9 849 7811

Norway: Box 1, Manglerud 0612, OSLO, Tel. +47 22 74 8000, Fax. +47 22 74 8341

Philippines: Philips Semiconductors Philippines Inc., 106 Valero St. Salcedo Village, P.O. Box 2108 MCC, MAKATI, Metro MANILA, Tel. +63 2 816 6380, Fax. +63 2 817 3474

Poland: Ul. Lukiska 10, PL 04-123 WARSZAWA, Tel. +48 22 612 2831, Fax. +48 22 612 2327

Portugal: see Spain

Romania: see Italy

Russia: Philips Russia, Ul. Usatcheva 35A, 119048 MOSCOW, Tel. +7 095 755 6918, Fax. +7 095 755 6919

Singapore: Lorong 1, Toa Payoh, SINGAPORE 1231, Tel. +65 350 2538, Fax. +65 251 6500

Slovakia: see Austria

Slovenia: see Italy

South Africa: S.A. PHILIPS Pty Ltd., 195-215 Main Road Martindale, 2092 JOHANNESBURG, P.O. Box 7430 Johannesburg 2000, Tel. +27 11 470 5911, Fax. +27 11 470 5494

South America: Al. Vicente Pinzon, 173, 6th floor, 04547-130 SÃO PAULO, SP, Brazil, Tel. +55 11 821 2333, Fax. +55 11 821 2382

Spain: Balmes 22, 08007 BARCELONA, Tel. +34 3 301 6312, Fax. +34 3 301 4107

Sweden: Kottbygatan 7, Akalla, S-16485 STOCKHOLM, Tel. +46 8 632 2000, Fax. +46 8 632 2745

Switzerland: Allmendstrasse 140, CH-8027 ZÜRICH, Tel. +41 1 488 2686, Fax. +41 1 488 3263

Taiwan: Philips Semiconductors, 6F, No. 96, Chien Kuo N. Rd., Sec. 1, TAIPEI, Taiwan Tel. +886 2 2134 2865, Fax. +886 2 2134 2874

Thailand: PHILIPS ELECTRONICS (THAILAND) Ltd., 209/2 Sanpavuth-Bangna Road Prakanong, BANGKOK 10260, Tel. +66 2 745 4090, Fax. +66 2 398 0793

Turkey: Talatpasa Cad. No. 5, 80640 GÜLTEPE/ISTANBUL, Tel. +90 212 279 2770, Fax. +90 212 282 6707

Ukraine: PHILIPS UKRAINE, 4 Patrice Lumumba str., Building B, Floor 7, 252042 KIEV, Tel. +380 44 264 2776, Fax. +380 44 268 0461

United Kingdom: Philips Semiconductors Ltd., 276 Bath Road, Hayes, MIDDLESEX UB3 5BX, Tel. +44 181 730 5000, Fax. +44 181 754 8421

United States: 811 East Arques Avenue, SUNNYVALE, CA 94088-3409, Tel. +1 800 234 7381

Uruguay: see South America

Vietnam: see Singapore

Yugoslavia: PHILIPS, Trg N. Pasica 5/v, 11000 BEOGRAD, Tel. +381 11 625 344, Fax.+381 11 635 777

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