International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES),(UGC APPROVED)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
National Conference on
Innovative Technologies in Electrical Engineering (NCITEE2K19)
Volume 5, Special Issue 05, May-2019.

ANALYSIS OF VARIATION OF THE BIAS POINT WITH VOLTERRA SERIES METHOD IN CLASS-AB RF POWER AMPLIFIER

Pennapati Nagamallaiah[1], P.V.Kusuma [2], J.Nageswara Rao[3]

1. *Assistant Professor (Adhoc), Jntuacep, Pulivendula, India.*
2. *Assistant Professor (Adhoc), Jntuacep, Pulivendula, India.*
3. *Assistant Professor (Adhoc), Jntuacep, Pulivendula, India.*

Abstract—This paper presents a Volterra-series bias based circuit of Class-AB RF power amplifier. This circuit design is power and accurate for nonlinear circuits. In Class-AB RF PA design, and analyze with bias circuit and it makes balance between efficiency and linearity , which make the application of the Volterra-series bias ciruit is more flexible in practical applications. The measurement result verifies the effectiveness of this design and a test die is fabricated.

Keywords—Volterra Series bias circuit; Class AB power amplifier (PA); efficiency; nonlinearity.

I.INTRODUCTION

A power amplifier is basically an electronic circuit which transfers the RF power to the load by amplifying the input power . To meet the simultaneous requirements of high linearity and reasonable efficiency, RF power amplifiers are often operated in a class-AB mode which is a compromise between Class-A and Class-B in terms of efficiency and linearity. Class- A PA always operates at high collector current, result in high linearity and high power dissipation. Class-B PA is more efficient than Class-A PA, but the low bias point brings worse linearity. Class-AB PA operates at relative low bias point, however the bias point rise with the increased input power due to the self-biasing effect, the reason is in Class-AB operation the conduction angle is a function of drive level. In BJT or HBT PA, this effect is shown as rising average biasing current along with increasing input power.

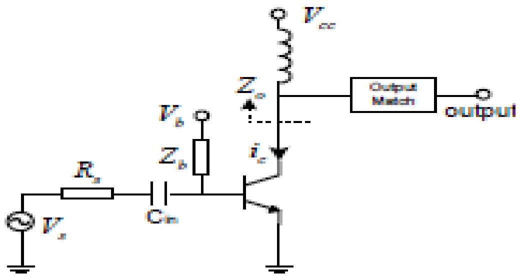
The working current is low at low input power can improve the efficiency and the bias point can rise at high input power to enhance the linearity of the PA. In order to improve the realization of Class-AB PA, it is essential to find out how the input power function with changes of bias point.

The reason of self-biasing effect with suffers both conduction and cut-off and the charge and discharge time constants are asymmetry in a signal period, the B-E junction of BJT or HBT .The bias point is nonlinear with input power. For small signal analysis, to determine the nonlinear distortions of PAs and BJT/HBT device in particular, the well-known Volterra series design technique is widely used [1-5]. Also, there are some papers that have discussed gaining an optimum linearity with optimized bias points or harmonic impedance terminations [6-8].

In this work, to analyze the variation of the bias point quantitatively, the Volterra series analysis method has been used in common emitter (CE) power amplifier. Consequently the period of PA's design and experiment can be shortened. According to the theoretical analysis, the optimum bias circuit parameters which promise the bias point varies with the input power sensitively is obtained, so the PA can reach higher performance. A test die is fabricated and the measurement result verifies the effectiveness of this design technique.

II.THE PRINCIPLE OF SELF BIASING EFFECT

The static bias point and dynamic bias point are two kinds of bias points in amplifier,. Static bias point is the bias voltage and current independent of input signal and which is totally determined by external static bias circuit. Dynamic bias point contains the static component and along with the components caused by average value of asymmetrical voltage or current at large input signal. So the dynamic bias point of PA is concern with the conduction angle. The larger bias point, the greater The higher bias point, the greater DC component of i_c . Saturation output power of PA is relative to the DC component of i_c , the higher of this component the greater of the output power.



In Fig1. CE power amplifier.

i_c is the collector current of CE amplifier transistor. In this amplifier, bias circuit impedance Z_b has great effect on the charge and discharge circuit of BE junction. Z_b is too small may cause much signal power dissipated in bias circuit and power input P_{in} is lower into the amplifier, so the self biasing is weaken and the amplifier's gain is reduced. When Z_b decreased to 0, where P_{in} =0 amplifier, the bias point is independent of P_{in} relative constant, so the variation of i_c is also small and the self biasing is insignificant too. When Z_b= too large and increased to the greatest limit, the bias circuit is equivalent to constant current bias circuit, and the bias point always keeps the same.

As above analysis, both too large and too small $Z_b$would prevent bias point increase with high input power. In order to obtain the optimum self biasing effect, Z_b value should be optimized in PA's design.

III. DERIVATION OF THE BIAS POINT WITH VOLTERRA SERIES

The movement of the bias point of PA is a nonlinear process, so we should use nonlinear analyze technique to do this studies.

A. Volterra Series Method

Volterra series is an effective mathematical design techniqe to analyze the nonlinear time-invariant system with memory [6].

Assume the input V_s to the nonlinear circuit is:

$V_s(t) = \sum_{r=1}^{R} E_r e^{jw_r t}$ ---------(1)

Then, the response V_o is:

$V_0(t) = \sum_{k=1}^{\infty} V_{o,k}(t)$ -------(2)

In which, $V_{o,k}$ is the k -th order response of the circuit

$V_{o,k}(t)= (\sum_{r1=1}^{R} E_{R1} \ldots\ldots \sum_{rK=1}^{R} E_{RK} \ldots.)$

GK(ωR1….ωRK)ej(ωR1+….ωRK) ---(3)

$G_K(\omega_{R1} \ldots. \omega_{RK})$ is k-th order transfer function.

B. Nonlinear Model For Common Emitter Amplifier:

The nonlinear equivalent model for CE power amplifier is shown in Fig. 2. In the equivalent circuit, base-emitter resistance r_{be}, base-emitter capacitance c_{be} and trans conductance, g_m are the major contributors to nonlinearity.

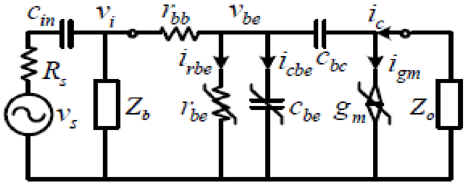


Fig2: Nonlinear equivalent model for CE power amplifier.

The current through r_{be} can be expressed as: [9]

$r_{be}=g_1v_{be}+ g_2v_{be}^2+ g_3v_{be}^3$ -------(4)

The current generated by g_m is β times of the current through r_{be} in which β denotes current gain [10].

$i_{gm}= \beta\, g_1 v_{be} + \beta\, g_2 v_{be}^2 + \beta\, g_3 v_{be}^3$ -------(5)

The charge of C_{be} can be expressed as:

$q_{cbe} = C_{be1} v_{be} + C_{be2} v_{be}^2 + C_{be3} v_{be}^3$ -------(6)

C. Volterra Series Derivation

Write the following equations for each node of Fig. 2 using Kirchoff's current laws (KCL):

$$\left.\begin{aligned} &\frac{Vbe-Vi}{rbb} = \frac{Vi}{Zb} + \frac{Vi-Vs}{Rs+1/jwCin} \\ &\frac{Vbe-Vi}{rbb} = i_{rbe}+i_{cbe}+j\omega C_{be}(V_{be}+i_c Z_o) \\ &j\omega C_{bc}(V_{be}+i_c Z_o)+i_c=i_{gm} \end{aligned}\right\} \text{-------(7)}$$

Based on the equations (7) above, V_{be} can be expressed as:

$$V_{be,1}(\omega)=\frac{1}{A1(\omega)} Z_b(\omega) /\{ [Z_b(\omega)+r_{bb}](R_s +1/j\, \omega C_{in})+ Z_b(\omega) r_{bb} \} \text{ -------(8)}$$

$$V_{be,2}(\omega_1, \omega_2)=\frac{A2(\omega1+\omega2)}{A1(\omega1+\omega2)} V_{be,1}(\omega_1)\, V_{be,1}(\omega_2 \text{ -(9)}$$

$$\left.\begin{aligned} &A_1(\omega) = (g_1 + j\omega c_{be}) + \frac{j\omega c_{bc}[Z_o(\omega)\beta g_1 + 1]}{j\omega c_{bc} Z_o(\omega)+1} + \\ &\frac{1}{r_{bb} + \dfrac{Z_b(\omega)\left(R_s + \dfrac{1}{j\omega c_{in}}\right)}{Z_b(\omega) + R_s + \dfrac{1}{j\omega c_{in}}}} \\ &A_2(\omega) = (g_2 + j\omega c_{be2}) + \frac{j\omega c_{bc} Z_o(\omega)\beta g_2}{j\omega c_{bc} Z_o(\omega)+1} \end{aligned}\right\} \text{--(10a \& 10b)}$$

$$I_{c,1}(\omega) = \frac{\beta g_1 - j\omega c_{bc}}{j\omega c_{bc} Z_o(\omega)+1} V_{be,1}(\omega)$$

$$I_{c,2}(\omega_1,\omega_2) = \frac{[\beta g_1 - j(\omega_1+\omega_2)c_{bc}]V_{be,2}(\omega_1/\omega_2)}{j(\omega_1+\omega_2)c_{bc} Z_o(\omega_1+\omega_2)+1} + \frac{\beta g_2 v_{be,2}(\omega_1) V_{be,2}(\omega_2)}{j(\omega_1+\omega_2)c_{bc} Z_o(\omega_1+\omega_2)+1} \text{ --(11a \&11b)}$$

While the input is sin V_s=A sin ωt which is the DC component of i_c can be expressed as:

$$i_{c0} = \frac{1}{2} A^2 I_{c,2}(\omega,-\omega) = \frac{A^2}{2} \frac{\beta g_2}{g_1 r_{bb} + g_1 Z_b(0)+1} \left|V_{be,1}(\omega)\right|^2 \text{ -(12)}$$

From the equation (14), Z_b has significant influence on i_c . Due to i_{c0} is in proportion to the source power, it can be normalized using source power:

$i_{c0}/P_{in} = 4R_s I_{c,2}(\omega,-\omega)$ ------(13)

i_{c0}/P_{in} has no concern with the strength of input power, so it could evaluated the variation range of the bias point with the input power.

D. Calculated Results And Analysis

Considering the output matching network is lossless, the power gain of PA is:

$A_P = 4| I_{c,1}(\omega)^2 | R_s Re(Z_0)$ -----(14)

The power gain is also closely connected with Z_b. The major parameters of a real 700MHz CE power amplifier are shown in Table I.

Table I: MAJOR PARAMETERS OF A REAL CE POWER AMPLIFIER

r_{bb} Ω	g_1 A/V	g_2 A/V^2	g_3 A/V^3	B
0.07	87	0.065	1.0	8.3
C_{bc}	C_{be1}	C_{be2}	C_{be3}	
5.3	42	0.32	4.3	

According to the formulas (13) and (14), the variation range of bias point and power gain of the amplifier are shown in Fig. 3. From Fig. 3, we can conclude the best value of Z_b is 6Ω, when Z_b <5Ω, power gain is low and when $_b Z$ >7Ω, the variation range of bias point is small.

IV. MEASUREMENTS AND CONCLUSION

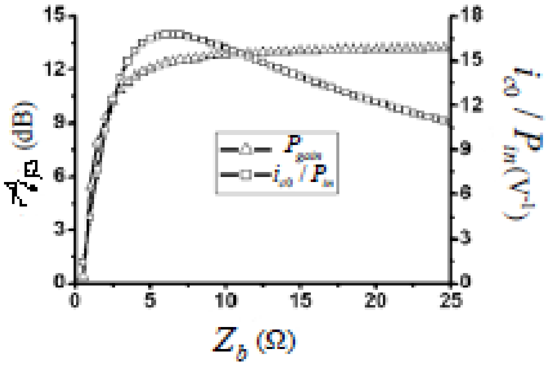


Fig. 3. Variation range of bias point and power gain of CE power amplifier.

Biasing the amplifier in Class AB mode through adjusting the external Z_b and V_b to make the static bias current density is equivalent to 2kA/cm2. Table II shows the measurement results in different Z_b , in which i_{c0}/ P_{in} is measured with 4dBm input power. As can be seen in table II, has the same variation law with the output power of 1dB compression point , so the AM-AM feature of the amplifier could be improved through optimizing i_{c0} /P_{in} value, and this improvement in linearity is achieved in the case of maintaining a constant quiescent bias current,

TABLE II. MEASUREMENT RESULTS OF CE AMPLIFIER

Z_b (Ω)	A_p (dB)	I_{c0} /P_{in} (V^{-1})	P_{-1} (dBm)
3.9	11.2	16	20.2
4.7	11.5	16.3	23.0
5.1	11.9	17	24.1
7.5	12.4	17.1	24.3
15	12.9	14.6	21.6
20	13.0	13.8	19.3

and therefore without increasing static power amplifier to ensure the efficiency of the amplifier.

Fig. 4. Die photo of the fabricated CE power amplifier and test bench.

Here, Fig. 4 is the die photo of CE power amplifier. The amplifier is fabricated with 2um InGaP/GaAs HBT process. The measurement result is compare with the theoretical analysis, so this design can be used in class AB PA to simplify the PA’s design and experiment.

ACKNOWLEDGMENT

This work was supported by the National Torch Program of China (Grant No. 2014GH010234)

V. REFERENCES

[1] D. D. Silveira, P. L. Gilabert, A. B. Santos and M. Gadringer “Analysis of variations of volterra series models for RF power amplifiers,” IEEE MWCL. 23 (2013) 442.

[2] M. Vaidyanathan, M. Iwamoto, L. E. Larson and P. S. Gudem, “A theory of high-frequency distortion in bipolar transistors,” IEEE Trans.51 (2003) 448.

[3] E. R. Srinidhi, A. Jarndal, G. Kompa, “A new method for identification and minimization of distortion sources in GaN HEMT devices based on volterra series analysis,” IEEE Electron Device Letters. 28 (2007) 343.

[4] C. I. Lee, W. C. Lin, Y. T. Lin and B. S. Yang, “Investigation of RF avalanche inductive effect on reduction of intermodulation distortion of MOSFETs using volterra series analysis,” IEEE Trans. 63 (2014) 367.

[5] J. T. Valliarampath and S. Sinha, “Designing linear PAs at millimeterwave frequencies using volterra series analysis,” CJECE. 38 (2015) 232.

[6] W. Kim, S. Kang, K. Lee and M. Chung, “Analysis of nonlinear behavior of power HBTs,” IEEE Trans. 50 (2002) 1714.

[7] M. Iwamoto, C. P. Hutchinson, J. B. Scott and T. S. Low, “Optimum bias conditions for linear broadband InGaP/GaAs HBT power amplifiers,” IEEE Trans. 50 (2002) 2954.

[8] Y. Yang, K. Choi and K. P. Weller, “DC boosting effect of active bias circuits and its optimization for class-AB InGaP-GaAs HBT power amplifiers,” IEEE Trans. 52 (2004) 1455.