DESIGN AND ANALYSIS OF HIGH GAIN DIODE PRE-DISTORTION LINEARIZER FOR TWTA

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ABSTRACT

This paper presents the design and analysis of a high gain, broadband Schottky and PIN diode based RF pre-distortion linearizer for TWTA. The circuit is using ABCD matrix approach. The simulation is performed using Agilent ADS software. We have proposed a new linearizer circuit which can achieve a high gain compared to existing linearizer designs.

KEYWORDS

PIN diode, Schottky diode, pre-distortion linearizer, gain

1. INTRODUCTION

Traveling wave tube amplifier (TWTA) is used to amplify RF signals in the microwave range. The major advantage of TWTA over some other microwave amplifiers is that it has substantial gain over a broad range of frequencies compared to klystron tubes. TWTA are commonly used in satellite transponders as amplifiers and also very much popular in high frequency ion sources for particle accelerators. TWTA suffer from a major drawback that at high frequencies the response becomes very non linear. Linearizers are electronic circuits which correct the non-linear behaviour of amplifiers to boost maximum output power and efficiency. One way to implement linearizers is to create a circuit with inverted behavior to that of the amplifier. These circuits counteract the non-linearity of the amplifier and minimize the distortion of the signal. This creates an increase in linear operating range of the amplifier. Linearized amplifiers have a quite higher efficiency with enhanced signal quality. There are various concepts to linearize an amplifier, which includes pre-distortion and post-distortion and also feedback linearization. Pre-distortion linearizer is the most popular type of linearizer which creates inverse amplitude and phase non linearity to that of TWTA, which improves the non-linearity of the communication system which operates the TWTAs.

Amplifiers when operated in saturation, due to decreasing amplification and changing phase, non-linearity occurs. This behavior is generally termed as gain or phase compression. These changes can be compensated by pre-distortion linearizers. The corresponding behavior is generally called gain expansion or phase expansion. Pre-distortion linearizer functions in the small signal area and boost the DC power consumption of the system slightly. Linearizers are favorably used in high power amplifiers which use electron tubes or solid state amplifiers. These systems are used in satellite communication or High Definition (HD) television which require high signal quality.
An analog linearizer employing an amplifier with series feedback connection and a high source inductance is small in size and very simple. Although this technique aids low DC power

consumption has the limitations that it can be used only in power amplifiers whose input power is above 20dBm. A linearizer made of a diode in series connection with a capacitor in parallel reduces the shortcomings of the aforesaid linearizer. This linearizer although simple and small in configuration needs an extra isolation mechanism to isolate it from the power amplifier which needs to be linearized. Furthermore this linearizer has a very narrow degree of control on the attained gain and phase characteristics distortions and hence is very limited in its applications. The advantage of the diode based linearizer is that it is flexible and gives us a high degree of control in attaining the gain and phase characteristics but still needs isolation mechanism between it and the power amplifier. There are methods to overcome the isolation issue by using hybrid couplers. Thus diode based linearizers has a distinct edge over analog linearizers. All these linearizers have certain benefits. However they lack the ability to linearize power amplifiers which exhibits dual-inflection points in their gain characteristics.

This paper presents a diode based pre-distortion linearizer with an aim to improve the overall gain of the linearizer. The PIN diode provides an added level of freedom in achieving the required amplitude level and depth of inflection in the characteristic. The quarter wave transmission line helps in providing the dual inflection points in the Output power vs. Input power characteristic.

Highly efficient and linear power amplifiers are in great demands with the advent of wireless standards. The transistor devices which are employed in power amplifiers are operated in saturation mode to attain high efficiency, but this also results in amplitude and phase distortions in the output.

2. DESIGN OF LINEARIZER

A quadrature hybrid coupler is used where port 1 is used for input signal, in port 2 and port 3 a circuit configuration L which is shown in Fig. 2 is connected, and port 4 is used as output.

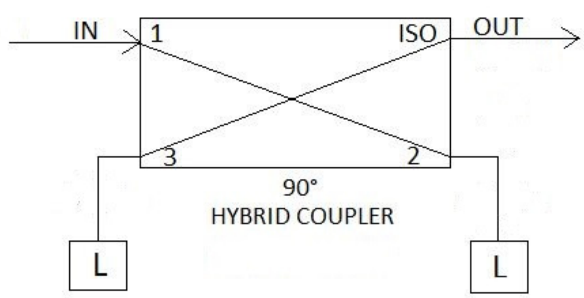

Fig. 1: Block diagram of the quadrature hybrid coupler

The circuit L consists of a quarter wave transmission line with a network of diodes on both sides of it. The biasing of the diodes are done with voltage source V_O through resistors R_{b1}, R_{b3} and R_{b3}.

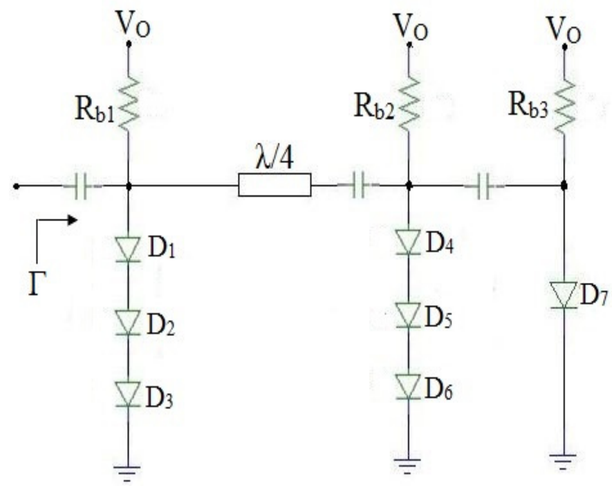

Fig. 2: Schematic Diagram of the circuit configuration L

Here D_1, D_2, D_3, D_4, D_5 and D_6 are Schottky diodes and D_7 is a PIN diode.
R_{b1}, R_{b2} and R_{b3} are biasing resistances.
Γ is the input voltage reflection coefficient S_{11}.

3. EQUIVALENT CIRCUIT OF LINEARIZER

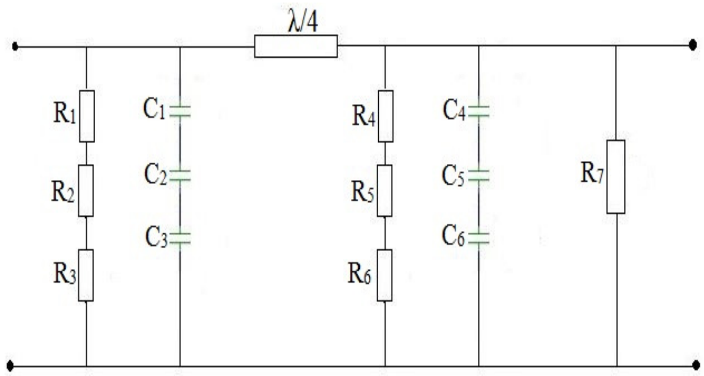

Fig. 3: Equivalent circuit of the Linearizer

R_1, R_2, R_3, R_4, R_5 and R_6 denote the dynamic resistances of the Schottky diodes.
C_1, C_2, C_3, C_4, C_5 and C_6 denote the junction capacitances of the Schottky diodes.

$$R_a = R_1 + R_2 + R_3 \tag{1}$$

$$C_a = 1/C_1 + 1/C_2 + 1/C_3 \tag{2}$$

$$\therefore Y_a = G_a + j\omega C_a \tag{3}$$

Here Y_a is the admittance of R_a and G_a is the conductance of R_a
.

$$R_b = R_4 + R_5 + R_6 \tag{4}$$

$$C_b = \frac{1}{C_4} + \frac{1}{C_5} + \frac{1}{C_6} \tag{5}$$

$$\therefore Y_b = G_b + j\omega C_b \tag{6}$$

Here Y_b is the admittance of R_b and G_b is the conductance of R_b.

$ABCD$ matrix of diodes D_1, D_2 and D_3:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_a & 1 \end{bmatrix} \tag{7}$$

$ABCD$ matrix of diodes D_4, D_5 and D_6:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_b & 1 \end{bmatrix} \tag{8}$$

$ABCD$ matrix of transmission line:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\beta\ell & jZ_0 \sin\beta\ell \\ j\frac{\sin\beta\ell}{Z_0} & \cos\beta\ell \end{bmatrix} \tag{9}$$

For quarter wave transmission line,

$$\beta\ell = \frac{\pi}{2} \tag{10}$$

Therefore equation (9) reduces to:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 0 & jZ_0 \\ j\frac{1}{Z_0} & 0 \end{bmatrix} \tag{11}$$

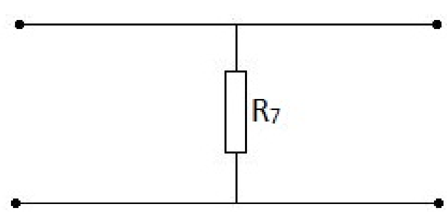

Fig. 4: Equivalent circuit of the PIN diode

$ABCD$ matrix of PIN diode D_7:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ G_7 & 1 \end{bmatrix} \tag{12}$$

Here G_7 is the conductance of the PIN diode R_7.

Total $ABCD$ matrix:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_a & 1 \end{bmatrix} \begin{bmatrix} 0 & jZ_0 \\ j\, 1/Z_0 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y_b & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ G_7 & 1 \end{bmatrix} \tag{13}$$

$$\Rightarrow \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} jY_2Z_0 + jG_3Z_0 & jZ_0 \\ j\dfrac{1}{Z_0} + jY_1Y_2Z_0 + jY_1G_3Z_0 & jY_1Z_0 \end{bmatrix} \tag{14}$$

To find the input voltage reflection coefficient, we have to find S_{11}. The relation between $ABCD$ parameters and S_{11} is:

$$S_{11} = \frac{AZ_0 + B - CZ_0 - DZ_0}{AZ_0 + B + CZ_0 + DZ_0} \tag{15}$$

$$\therefore |S_{11}| = |\Gamma| = \frac{-Z_0^2(Y_aY_b + Y_aG_7) + Z_0(-Y_a + Y_b + G_7)}{Z_0^2(Y_aY_b + Y_aG_7) + Z_0(Y_a + Y_b + G_7) + 2} \tag{16}$$

Equation (16) shows the magnitude of the input voltage reflection coefficient of the circuit.
To find the forward voltage gain, we have to find S_{21}. The relation between forward voltage gain S_{21} and $ABCD$ parameters is:

$$S_{21} = \frac{2Z_0}{AZ_0 + B + CZ_0^2 + DZ_0} \tag{17}$$

$$\therefore |S_{21}| = \frac{2}{Z_0^2(Y_aY_b + Y_aG_7) + Z_0(Y_a + Y_b + G_7) + 2} \tag{18}$$

$$\angle S_{21} = -90° \tag{19}$$

Equation (18) shows the magnitude of the forward voltage gain of the linearizer. Equation (19) shows the phase of the forward voltage gain of the linearizer.

3.1. SIMULATIONS

We have simulated the circuit shown in Fig. 2 using Agilent ADS software. The PIN and Schottky diodes used for simulation were from Agilent. The models were HMPP-3890 and HSMS-2820 respectively. We modelled a diode to match the specifications of HSMS-2820. The biasing resistances were chosen as 1kΩ and voltage sources as 10V. The characteristic impedance of the quarter wave transmission line was 45Ω and since ***S***-parameters were being measured two 'Port Impedance Termination for ***S***-parameters' were positioned on both ends of the circuit.
Here are some screenshots of ADS 2009 where we have simulated the circuit using one , three and five number of Schottky diodes in series connection.

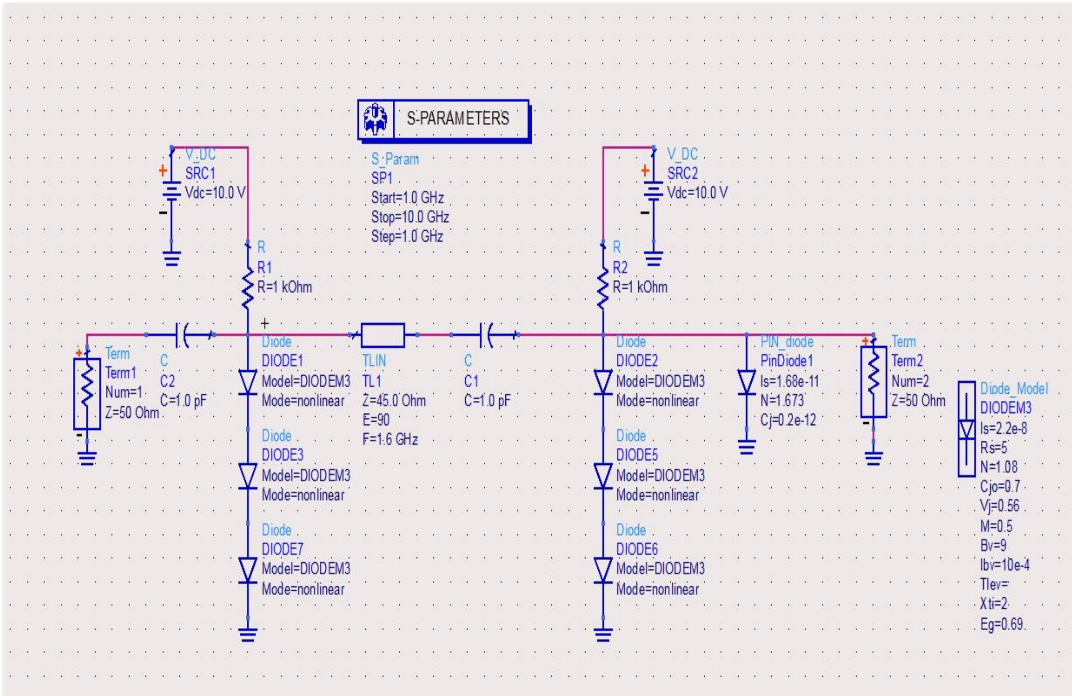

Fig. 5: ADS simulation screenshot for the simulation of three diodes in series

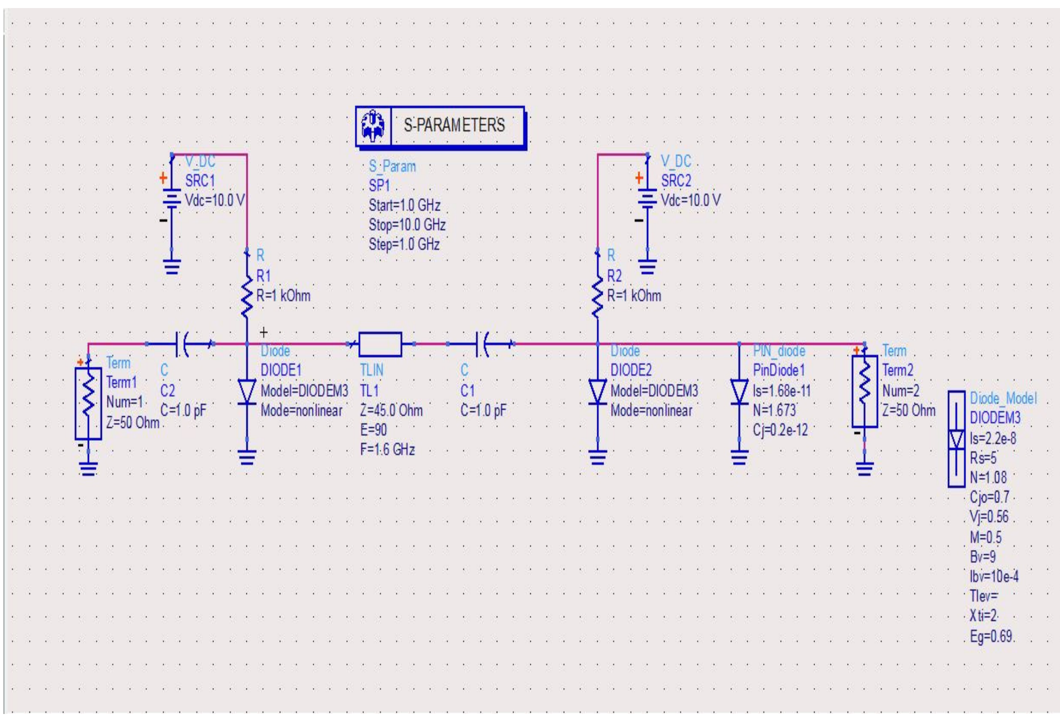

Fig. 6: ADS simulation screenshot for the simulation of one diode

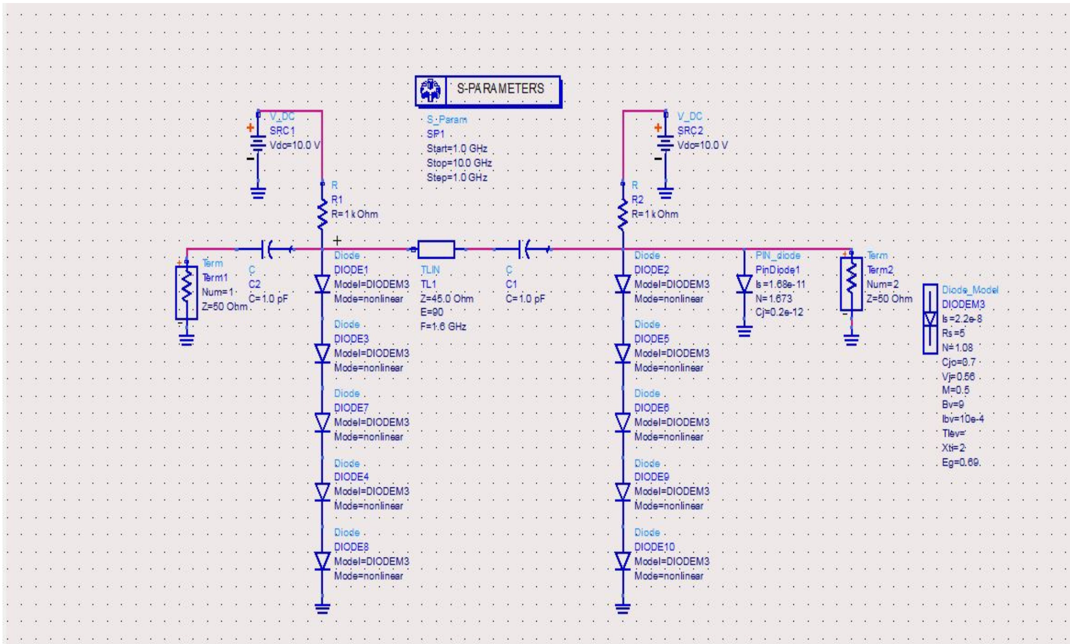

Fig. 7: ADS simulation screenshot for the simulation of five diodes in series

The corresponding graphs of the simulated circuits are shown below and it can be seen that the gain of the circuits is increasing as the number of Schottky diodes in series connection are being increased.

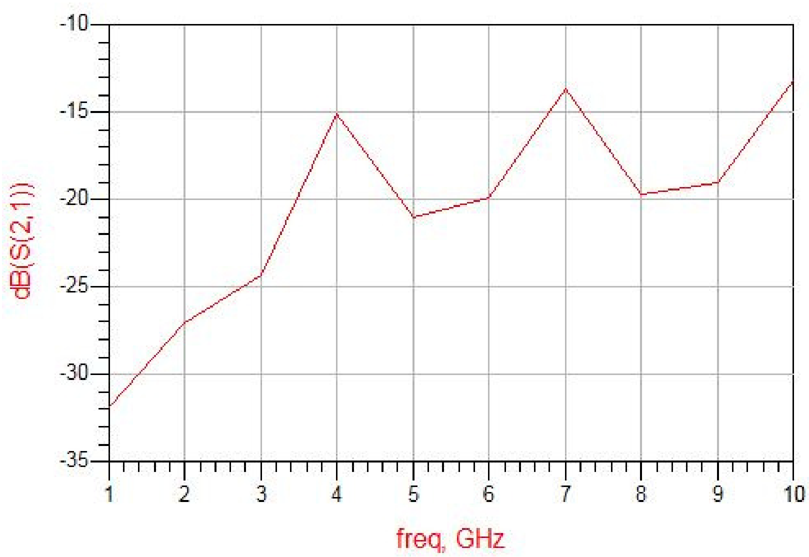

Fig. 8: $|S_{21}|$ at 1.6 GHz of circuit shown in Fig. 2

Here, while using 3 Schottky diodes in series, at frequency 4GHz the corresponding gain is approximately -15dB.

Fig. 9: $|S_{21}|$ at 1.6 GHz of circuit using one Schottky diode

Here, while using one Schottky diode, at frequency 4GHz the corresponding gain is approximately -24dB.

Fig. 10: $|S_{21}|$ at 1.6 GHz of circuit using 5 Schottky diodes

Here, while using five Schottky diodes in series, at frequency 4GHz the corresponding gain is approximately -12dB.

6. CONCLUSIONS

This paper presented the increase in overall gain of Schottky diode and PIN diode based pre-distortion linearizers operating at microwave frequencies. The results of the simulation demonstrate that the gain of the linearizer increases as we increase the number of diodes in series connection. Therefore, a high gain linearizer can be implemented using our proposed topology

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REFERENCES

[1] M. S. Hashmi, Z. S. Rogojan, and F. M. Ghannouchi, “A flexible dual-inflection point RF pre-distortion linearizer for microwave power amplifiers”, *Progress In Electromagnetics Research C*, Vol. 13, 1-18, 2010

[2] M. S. Hashmi, Z. S. Rogojan, S. R. Nazifi and F. M. Ghannouchi, “A broadband dual-inflection point RF pre-distortion linearizer using backward reflection topology”, *Progress In Electromagnetics Research C*, Vol. 13, 121-134, 2010

[3] S. C. Bera, R. V. Singh and V. K. Garg, “Temperature behavior and compensation of Schottky barrier diode”, *International Journal of Electronics,* Vol. 95, No. 5, May 2008, 457-465

[4] S. C. Bera, Virender Kumar, Surinder Singh and Dipak Kumar, “Temperature behavior and compensation of diode based pre-distortion linearizer”, *IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 23, NO. 4, APRIL 2013*

[5] Yamauchi, K., K. Mori, M. Nakayama, Y. Mitsui, and T. Takagi, “A microwave miniaturized linearizer using a parallel diode with a bias feed resistance," *IEEE Trans. on Microwave Theory Tech.*, Vol. 45, No. 12, 2431 - 2435, December 1997.

[6] F. M. Ghannouchi and J. S. Cardinal, “A new adaptive double envelope feedback linearizer for mobile radio power amplifiers", *IEEE MTT-S Int. Microwave Symp. Digest*, 573 - 576, San Diego, May 1994.

[7] K. Yamauchi, K. Mori, M. Nakayama, Y. Mitsui, T. Takagi, “A microwave miniaturized linearizer using a parallel diode”, *IEEE MTT-S Int. Digest*, Denver, CO, pp. 1199 - 1202, June 1997.

[8] Katz A, Gray R, and Dorval R. “Wide/multiband linearization of TWTAs using predistortion”, *IEEE Transactions on Electron Devices*, 2009, 56(5): 959 - 964.

[9] S. C. Bera, P. S. Bhardhwaj, R. V. Singh, and V. K. Garg, “A diode linearizer for microwave power amplifiers”, *Microw. J., vol. 46*, no. 11, pp. 102–113, Nov. 2003.

[10] Jacob Millman and Christos C. Halkias, “Integrated Electronics”, McGRAW – HILL Publications

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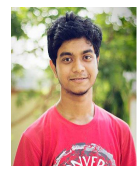

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