A WIDE-BAND PUSH-PULL AMPLIFIER UPGRADES IP2

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ABSTRACT

A novel design is described which utilizes Lange coupler baluns in a wide-band push-pull amplifier to improve its second order harmonic intercept point (IP2). Better than 10 dB of IP2 improvement has been demonstrated on a breadboard unit. The approach has potential applications for wide-band high-efficiency power GaAs FET amplifiers.

INTRODUCTION

In a low noise wide-band amplifier system, second-order intermodulation (IMD) products are a concern to an amplifier designer. These IMD products can lie in-band and be amplified in the communication system. IP2, the intercept point between the fundamental mode and the second-order intermodulation product, is one measure of these IMD products. This paper describes a new approach to improve the IP2 value.

The approach is based on the cancellation of the second-harmonics in a nonlinear FET amplifier. Second-harmonics cancellation has been treated extensively in the recent microwave literature due to the wide interest in the high-efficiency power GaAs FET amplifiers. Freitag, etc. [1] and Lane, etc. [2], reported high efficiency power FET amplifiers using narrow-band push-pull design. Kopp and Heston [3] used harmonic tuning to achieve a high-efficiency X-band amplifier. Nishiki and Nojima, [4] and [5], used harmonic reaction to improve the power-added efficiency of the GaAs FET amplifier. This paper first shows that cancellation of the second-harmonics improves IP2. Then a Lange coupler balun [6] is introduced which achieves wide-band 180 degree phase shift. Utilization of these wide-band coupler baluns in a push-pull amplifier yields improvement of IP2. Circuit design of a breadboard unit and its test results are also presented. This approach has a potential application in wide-band high-efficiency power GaAs FET amplifiers.

DESCRIPTION OF THE APPROACH

The transfer function of a GaAs FET amplifier can be expressed as:

$$E_o = K_1 E_i + K_2 E_i^2 + K_3 E_i^3 \qquad (1)$$

where E_i and E_o are the input and output signal amplitudes, K_1 is the linear gain coefficient and K_i's are the ith-order nonlinear coefficients. For a two-tone input signal, $E_i = A(\cos\omega_1 t + \cos\omega_2 t)$, the output amplitude of the signal becomes

$$E_o = \text{DC} + \text{1st-order terms} + \text{2nd-order terms} + \text{3rd-order terms} + \ldots \qquad (2)$$

where

$$\text{2nd-order terms} = K_2 A^2 \,[\text{2nd-order IMD products}] + 1/2\, K_2 A^2\, [\text{2nd-order harmonics}]$$

$$\text{2nd-order IMD products} = \cos(\omega_1 + \omega_2)t + \cos(\omega_1 - \omega_2)t$$

$$\text{2nd-order harmonics} = \cos(2\omega_1 t) + \cos(2\omega_2 t)$$

This mathematical expression shows that both the second harmonics and the second-order IMD products come from the second-order nonlinear coefficient, K_2. The second-order IMD product is 6 dB higher than the second harmonics.

To show that the second-order terms can be cancelled by a Lange coupler balun amplifier, let the input signal be

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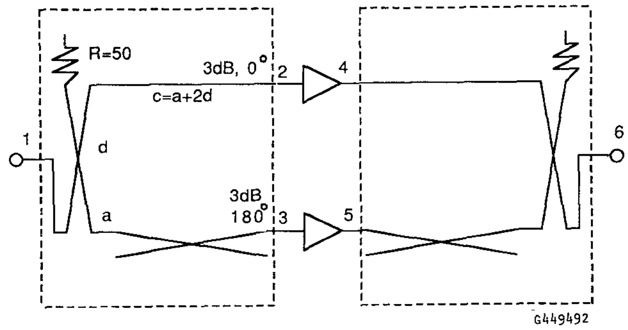

Fig. 1 Block Diagram of a Wide-Band Push-Pull Amplifier Using Lange Coupler Baluns

$$E_1 = A \cos(\omega t) \quad (3)$$

at point 1 of the circuit diagram, Fig. 1.

At points 2 and 3, the signals become

$$E_2 = A/\sqrt{2}\ \cos[\omega t + k(d + c)] \quad (4)$$
$$E_3 = A/\sqrt{2}\ \cos[\omega t + k(a + 3d - 180°)] \quad (5)$$

where k is the propagation constant, a is the physical length between the two Lange couplers, and d is the length of the Lange coupler.

To achieve the required 180° phase difference between points 2 and 3, the necessary condition is that

$$c = a + 2d. \quad (6)$$

The fundamental modes from points 2 and 3 to point 6 experience another 180 degree phase difference and combine at point 6. However, since the FET is the source of nonlinearity, the second-harmonics from points 4 and 5 are out-of-phase at point 6 and cancel each other at the output.

CIRCUIT DESIGN

A single-ended GaAs FET amplifier was designed to operate in the frequency range from 2.5 to 6.5 GHz. Raytheon's RPK2003 GaAs FET device was used. The FET matching network was a lumped-element shunt-L series-C band-pass filter configuration. Fig. 2 shows the circuit diagram and the predicted gain |S21|, of 8 +/- 0.5 dB. The matching elements, L1 & L2, (140 & 275 mils of 1 mil diameter wires), and C1 & C2 (1 & 8.2 pf) given in the circuit diagram Fig. 2 are critical inductance and capacitance parameters.

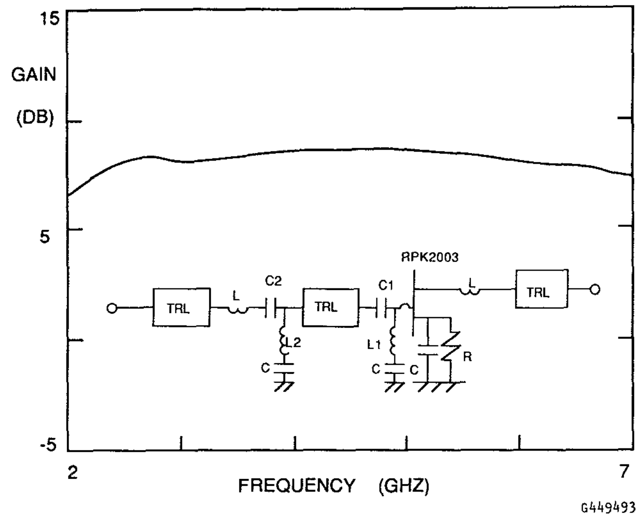

Fig. 2 Computed |S21| of a Single-Ended Amplifier and its Matching Network

The Lange coupler was designed and laid out on a 15 mil Alumina substrate. The width and gap of the coupler fingers are 1.2 mil and 1 mil respectively to achieve the best amplitude balance, return loss and isolation. The length of the coupler, d, is 280 mils. A second coupler balun was cascaded as shown in Fig. 1. To achieve the condition c = a + 2d, the 50-ohm line length, c, was to be 760 mils. Computed predicted gain |S21| of the overall amplifier and phase difference of the Lange coupler balun are shown in Fig. 3. The gain from 2.5 to 6.5 GHz is 7.5 +/- 0.5 dB. The phase difference is 180 (+10/-20) degrees.

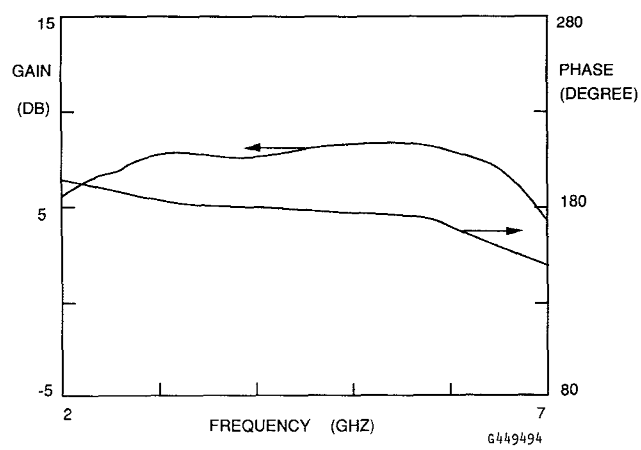

Fig. 3 Computed |S21| of the Overall Amplifier and Phase Difference of the 180 Degree Lange Coupler Balun

TEST RESULTS

Fig. 4 shows a photograph of a breadboard amplifier. Each of the components, including the single-ended amplifiers, the 90 degree Lange coupler, and the 180 degree balun hybrid, was tested separately. Fig. 5 shows the measured power split and its phase difference for the Lange coupler balun. The amplitude balance is -3.5 (+0.6/-1) dB in the frequency range, 2.5 to 6.5 GHz. The phase difference is 180 (+30/-10) degrees.

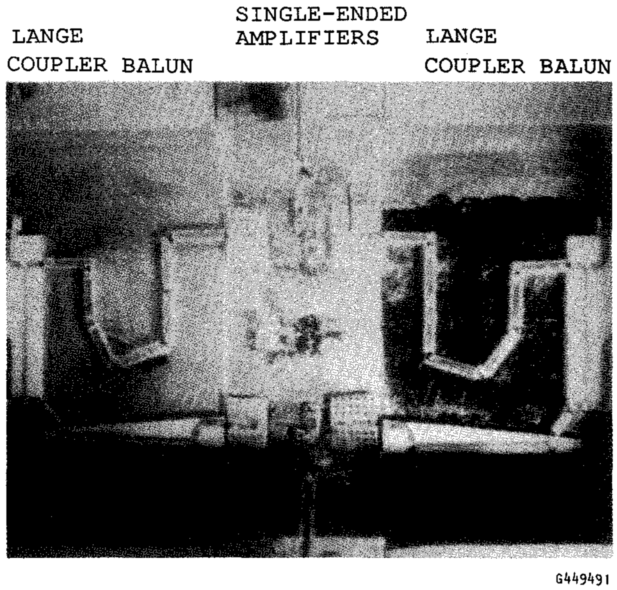

Fig. 4 Photograph of a Breadboard Amplifier Using Lange Coupler Baluns

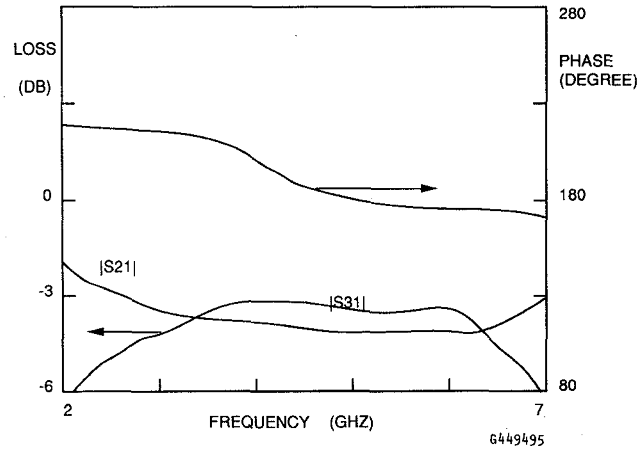

Fig. 5 Measured Amplitude Balance and Phase Difference of a Lange Coupler Balun

The single-ended amplifiers were tested for gain as shown in Fig. 6 and for IP2 as listed in Table 1. The average gain is 8 (+2/-1) dB. IP2 was tested at 3, 3.5, 6.5 GHz and 2.5, 3.5, 6 GHz. The IP2's were better for the DIFFERENCE frequencies, at about 36 dBm to 41 dBm. For the SUM frequencies, the IP2's are about 35 dBm to 39 dBm.

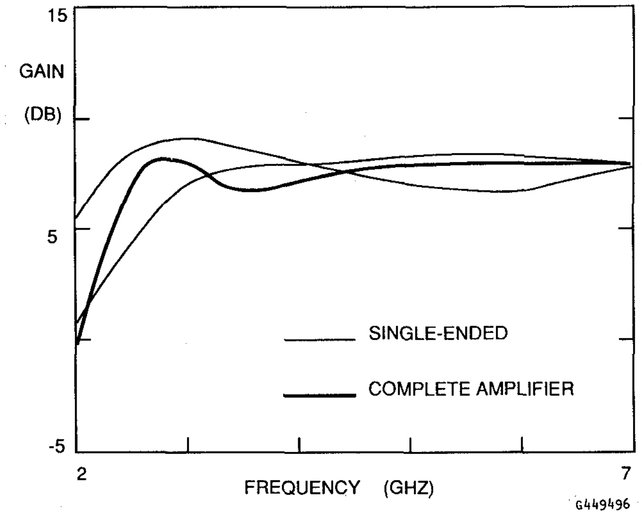

Fig. 6 Measured |S21| of a Two Single-Ended Amplifiers and the Overall Amplifier

Table 1. Comparison of IP2 for Single-Ended Amplifiers (S-E1 and S-E2) and the Overall Amplifier

Frequency (GHz)				IP2 (dBm)		
f1	f2	SUM	DIFFERENCE	S-E1	S-E2	OVERALL
2.5	3.5	6		37.1	35.5	49.3
6	2.5		3.5	37.6	36.6	56.8
6	3.5		2.5	39.3	41.3	55.3
3	3.5	6.5		38.7	37.1	47.1
6.5	3.5		3	39.8	39.5	55.3
6.5	3		3.5	39.9	39.1	51.2

The complete amplifier was also tested for gain and IP2. Test results are shown in Fig. 6 and Table 1 for comparison with the single-ended amplifiers. The gain and flatness is about 7.5 +/-1 dB. The IP2's for the DIFFERENCE are about 51 to 57 dBm and about 47 to 49 dBm for the SUM frequencies. The improvement of better than 10 dB in IP2 is significant.

CONCLUSION

A new approach to improve IP2 of a wide-band low noise amplifier has been described. The wide-band 180 degree hybrid was achieved by a Lange coupler balun. A breadboard unit was designed and tested to prove the concept. This approach can be applied to the wide-band high efficiency power GaAs FET amplifiers.

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