Simulation of Large-Signal Behavior of a GaAs Low Noise Amplifier *

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Abstract-- This paper investigates the linearity of a GaAs MESFET amplifier. A two-stage low noise amplifier is analyzed by PSPICE. The large-signal *S* parameters are determined for different load conditions, i.e. a resistive load, an active self-biased load and a cascode configuration. Additionally, the linearity is described in terms of two-tone intermodulation products of the 3rd and 5th order, as well as the 3rd order intercept point (IP_3).

I. Introduction

The linearity is of primary importance in wireless communication systems because of stringent regulatory emission requirements [1]. This paper investigates the linearity on the example of a two-stage intermediate frequency low noise amplifier. The analysis is performed by PSPICE [2]. The first stage is a common-source amplifier, which ensures necessary gain, and the second stage is a common-drain amplifier that ensures output match in a wide frequency range. The basic amplifier with a pure resistive load R_D is shown in Figure 1.

Firstly, an *S* parameter simulation setup is described and the results for *S* parameters are given as a function of the available input power. The *S* parameters are simulated for three different load conditions. Besides a pure resistive load, an active self-biased load and a cascode configuration is used. These configurations are shown in Figure 2.

Additionally, the intermodulation products of the 3rd and 5th order are calculated for the amplifier with a resistive load at 100 MHz for a wide range of input power levels. Finally,

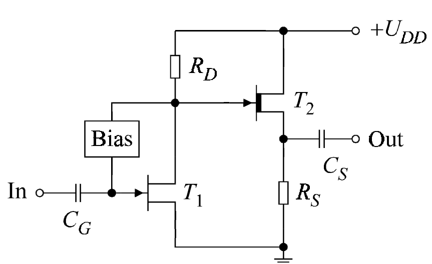

Fig.1. Low noise amplifier with a resistive load.

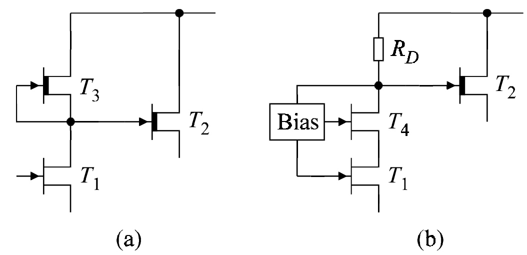

Fig.2. Different loads: (a) self-biased, (b) cascode.

the output intercept point is calculated at 100 MHz for all three types of load.

II. *S* Parameters

The *S* parameters are defined with the set of equations

$$b_1 = S_{11}\, a_1 + S_{12}\, a_2\,, \tag{1}$$

$$b_2 = S_{21}\, a_1 + S_{22}\, a_2\,, \tag{2}$$

where a_1 and a_2 are the incident and b_1 and b_2 are the reflected waves at the input port 1 and output port 2. The waves are related to the voltages and currents at the same ports by [3]

$$a_1 = \frac{u_1 + Z_0\, i_1}{2\sqrt{Z}}, \qquad b_1 = \frac{u_1 - Z_0\, i_1}{2\sqrt{Z}}, \tag{3}$$

$$a_2 = \frac{u_2 + Z_0\, i_2}{2\sqrt{Z}}, \qquad b_2 = \frac{u_2 - Z_0\, i_2}{2\sqrt{Z}}. \tag{4}$$

For most applications the characteristic impedance of the system $Z_0 = 50\,\Omega$.

The parameters S_{11} and S_{21} are extracted using the circuit shown in Figure 3a [4], with two identical source voltages u_g. The output port is terminated with the characteristic impedance Z_0 so the incident wave $a_2 = 0$. From this circuit

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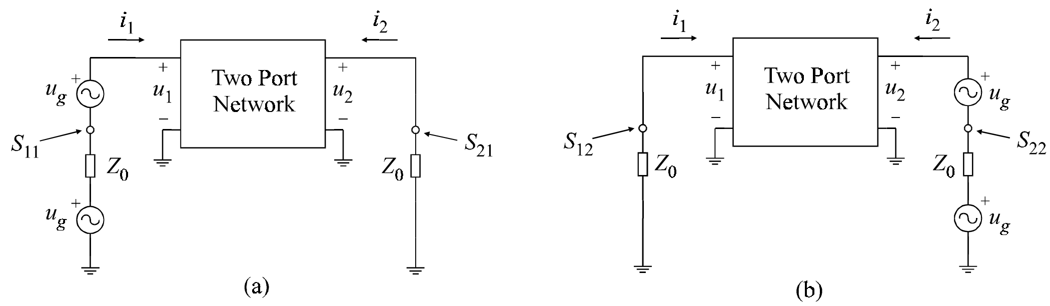

Fig.3. Schematics of the circuits used for extraction of S parameters:
(a) S_{11} and S_{21}, (b) S_{12} and S_{22}.

$$S_{11} = \frac{b_1}{a_1} = \frac{u_1 - Z_0\, i_1}{u_1 + Z_0\, i_1} = \frac{u_1 - u_g}{u_g}, \tag{7}$$

$$S_{21} = \frac{b_2}{a_1} = \frac{u_2 - Z_0\, i_2}{u_1 + Z_0\, i_1} = \frac{u_2}{u_g}. \tag{8}$$

It is clear that the parameters S_{11} and S_{21} are calculated as the voltages at the correspondent points normalized to the source voltage u_g.

The parameters S_{12} and S_{22} are extracted in a similar way by using the circuit in Figure 3b

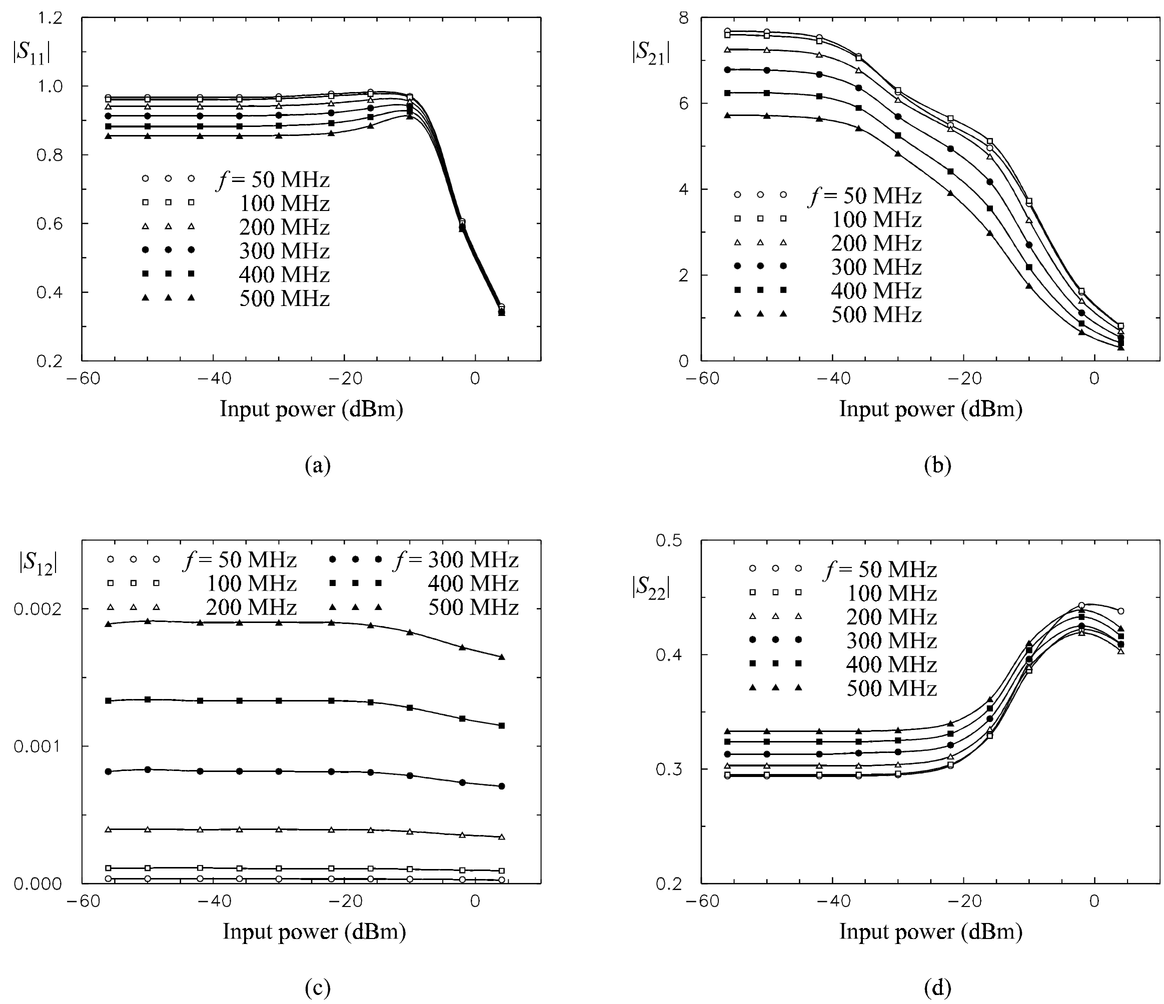

Fig.4. Magnitudes of S parameters: (a) S_{11}, (b) S_{21}, (c) S_{12}, (d) S_{22}.

$$S_{12} = \frac{b_1}{a_2} = \frac{u_1}{u_g}, \quad (9)$$

$$S_{22} = \frac{b_2}{a_2} = \frac{u_2 - u_g}{u_g}. \quad (10)$$

Figure 4 presents the magnitudes of S_{11}, S_{21}, S_{12}, and S_{22} obtained when the simulations are performed using a pure resistive load.

The simulations performed by using an active self-biased and cascode load show very similar behavior, except for the forward transmission S_{21} that is larger in the case of the cascode load at lower frequencies, as expected. However, the gain of the cascode load actually falls below the value of the gain obtained for the pure resistive load at higher frequencies, which was quite unexpected as the cutoff frequency of the simulated MESFETs is around 20 GHz. Figure 5 shows the magnitude of S_{21} for resistive, active and cascode load as a function of frequency for the input levels of –56 dBm and –36 dBm.

III. Intermodulation products

For the sake of completeness, the intermodulation products, (see e.g. [5]), are calculated for the case of a pure resistive load using the input signals at 100 and 110 MHz. The power of the fundamental component shows the expected increase of 1 dB when the input power is increased 1 dB, at low input power levels, while the IM_3 product shows the expected slope of 3 dB (see Table I and Fig. 6).

Calculating from the results in Table I, the output intercept point of the 3rd order (OIP_3) is –1.35 dBm (resistive load). In the case of the active load $OIP_3 = 0.1\,\mathrm{dBm}$, and OIP_3 is +0.5 dBm for the cascode load. These results are obtained by using the single tone frequencies of 100 and 110 MHz, thus, higher OIP_3 values result from a higher gain (i.e. S_{21}) of active and cascode load. However, that would change at higher frequencies, which can be concluded from the results for $|S_{21}|$ shown in Fig. 5.

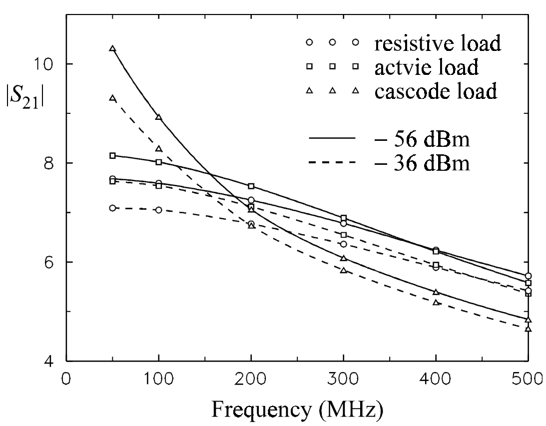

Fig.5. Magnitudes of S_{21} parameter for different loads at two input levels.

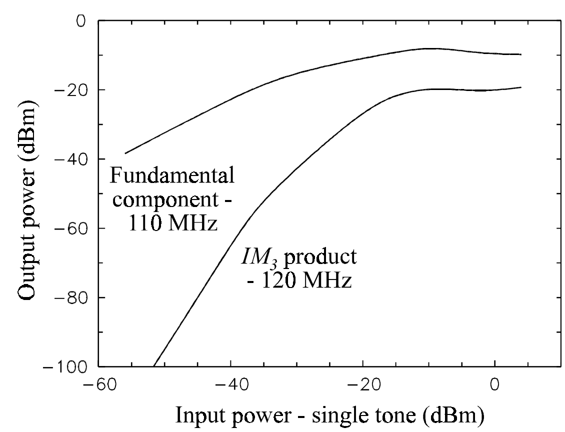

Fig.6. Output power of the fundamental component and IM_3 product.

Table I Fundamental component and intermodulation products.

Available input power - single tone (dBm)	Fundamental component - 110 MHz (dBm)	IM_3 product - 120 MHz (dBm)	IM_5 product - 130 MHz (dBm)
– 56	– 38.45	– 112.7	– 146.0
– 50	– 32.45	– 95.0	– 131.0
– 42	– 24.68	– 71.1	– 119.0
– 36	– 19.32	– 54.4	– 79.0
– 30	– 15.32	– 42.8	– 57.9
– 22	– 11.72	– 29.7	– 38.2
– 16	– 9.53	– 22.5	– 31.5
– 10	– 8.10	– 19.9	– 26.1
– 2	– 9.33	– 20.2	– 27.2
4	– 9.83	– 19.3	– 24.2

IV. CONCLUSION

The linearity of a low noise intermediate frequency GaAs amplifier is investigated by calculating the large-signal S parameters, for the resistive, self-biased active and cascode load in the frequency range from 50 MHz to 500 MHz. The S parameters are found to behave similarly, except for the forward transmission S_{21} that is larger for active and cascode load at lower frequencies, and unexpectedly lower at higher frequencies. Additionally, the IM_3 and IM_5 products are simulated for the amplifier with the resistive load at 100 MHz. Furthermore, the output intercept point is calculated for all three types of load and it is found that the results conform to the simulated large-signal S parameters. It is worth noting that the amplitude and phase characteristics of S_{21} may be used to obtain AM-to-AM and AM-to-PM characteristics used in behavioral modeling of the systems that use wideband modulated signals, e.g. CDMA [6].

V. REFERENCES

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