GaAs MESFET Small Signal Amplifier Intermodulation Distortion Sensitivity to the Ports Terminations

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Abstract - The third-order intermodulation distortion in small signal MESFET amplifier has been analyzed by means of the Volterra series representation. The Volterra series expansion is accepted as being useful for weak and mild nonlinearities. Some of the results for reactively terminated amplifier ports at the second harmonic frequency are presented hereby. It has been shown that the third-order IMD products are sensitive to the second harmonic reactance at the transistor input and output terminals.

I INTRODUCTION

Many nonlinear transistor models and analysis methods have been proposed in literature. The Volterra series approach has been found to be very useful to predict the intermodulation distortion in GaAs MESFET small-signal amplifiers [1]-[3]. A good agreement between theory and experiment was found in [1] and [4]. Using a complete MESFET model [3], the intermodulation distortion sensitivity to source reflection coefficient was related to the MESFET's stability. A second-order product in the low frequency feedback has been used in [2] to reduce the third-order intermodulation distortion.

This paper presents some results showing how the source and load impedances affect GaAs MESFET third-order intermodulation distortion (IMD) level.

II NONLINEAR ANALYSIS

The nonlinear transistor model is obtained by the replacing the specific linear elements of the linear model with nonlinear ones. The MESFET chip is modeled by a lumped-element equivalent circuit in which there are five sources of nonlinearities: gate-to-source capacitance, drain-to-gate capacitance, voltage-controlled current source in drain, output conductivity and drain-to-source capacitance. The impact of nonlinear feedback capacitance, drain-to-source capacitance and output conductivity to the overall nonlinearity is small compared to the nonlinear dependence of the drain current on gate bias and gate-source capacitance. In small signal operating conditions, the nonlinear drain current source is controlled by two voltages: $i_D(v_G,v_D)$. This current source can be represented by a two-dimensional Taylor series [4]. The small-signal incremental drain current is:

$$i_d(v_g,v_d)=i_D(v_G,v_D)-I_D(V_{G0},V_{D0})=$$

$$=\frac{\partial i_D}{\partial v_G}v_g+\frac{\partial i_D}{\partial v_D}v_d+\frac{1}{2}\left[\frac{\partial^2 i_D}{\partial v_G^2}v_g^2+2\frac{\partial^2 i_D}{\partial v_G\partial v_D}v_g v_d+\frac{\partial^2 i_D}{\partial v_D^2}v_d^2\right]+$$

$$+\frac{1}{6}\left[\frac{\partial^3 i_D}{\partial v_G^3}v_g^3+3\frac{\partial^3 i_D}{\partial v_G\partial v_D^2}v_g v_d^2+3\frac{\partial^3 i_D}{\partial v_G^2\partial v_D}v_g^2 v_d+\frac{\partial^3 i_D}{\partial v_D^3}v_d^3\right]+\ldots$$

where V_{G0} and V_{D0} are bias voltages and v_g and v_d are incremental gate and drain voltages, respectively. The small-signal drain current (input excitation is less then -30 dBm) can be modeled by two separate nonlinear controlled current sources. The capacitance C_{gs} is modeled as an ideal Schottky-barrier capacitance. At the operating frequency of 2 GHz, the transistor AT10650-5 is a conditionally stable element. Additional 1 nH source inductance is used to extend the allowable load impedance range.

The passive matching circuit consists of a 50 Ω transmission line of variable electrical length, and a variable characteristic impedance quarter-wave transformer [1]. These variables can produce any desired impedances at the FET terminals (Fig.1).

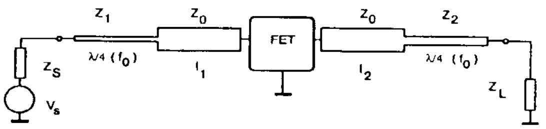

Fig.1. The GaAs MESFET amplifier topology

The matching circuit output impedance at the second harmonic frequency is always 50 Ω. Therefore the second-order distortion component has always the same effect on the third-order IMD. Additional elements in the matching circuit (shaded) produce pure reactive component at 2ω that is controlled by the transmission line length (Fig.2).

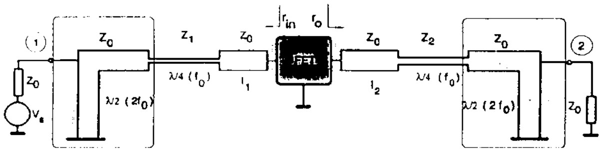

Fig.2. The GaAs MESFET amplifier with second harmonic circuits

A relatively small frequency difference (1 MHz) of the excitation signal components, allows the following approximations:

$$Z(\omega_1+\omega_2) \approx Z(2\omega_1) \approx Z(2\omega_2)$$

Figs.3 and 4 show constant I/C curves in source (Z_S) and load (Z_L) impedance planes.

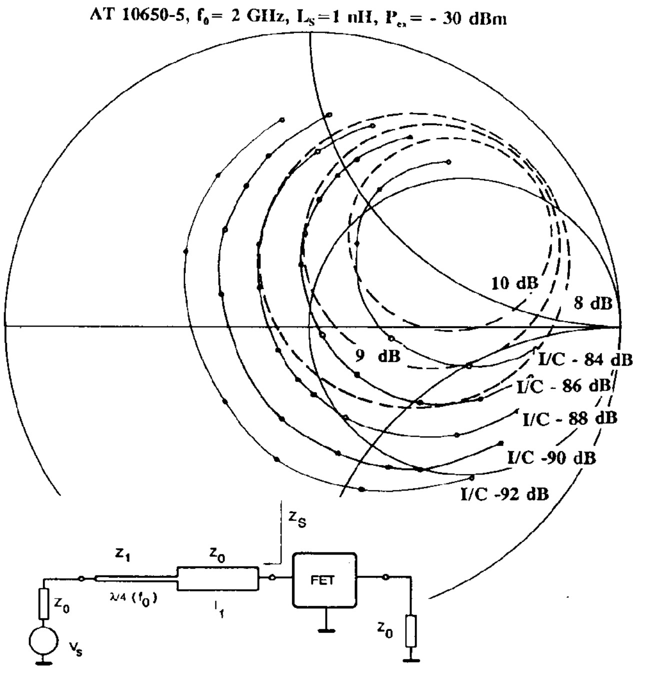

Fig.3. The loci of the constant I/C in the source impedance plane with the constant gain circles

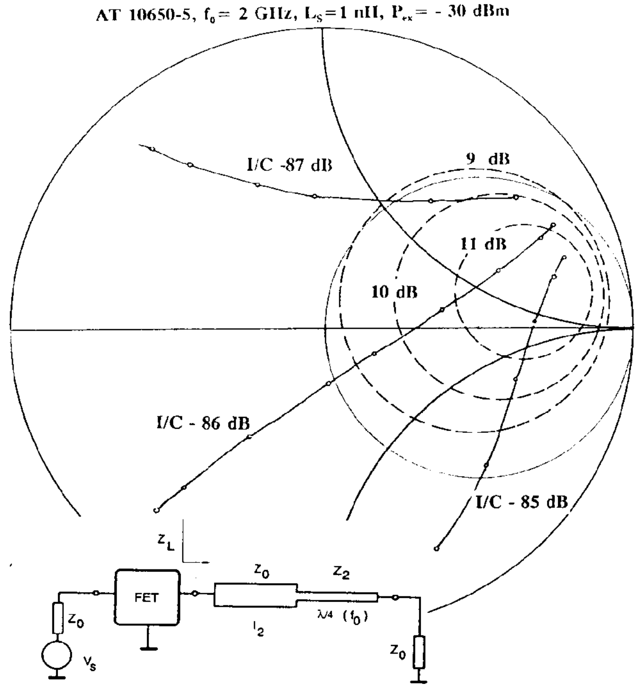

Fig.4. The loci of the constant C/I in the load impedance plane with the constant gain circles

I/C ratio was expressed as the ratio between the fundamental and the $2f_2$-f_1 ($2f_1$-f_2) components power levels. Constant I/C curves were calculated with the 50 Ω termination on the MESFET opposite port. In the load impedance plane, these curves have the characteristic form (Fig.4) relative to constant power gain circles. Thus, different load impedances can produce different I/C values of constant power gain. The constant I/C source impedance curves partly have the similar form as the circles of constant power gain. These features demonstrate that IMD suffers small changes when constant gain is achieved with different source impedances. This was not the case with the output impedance plane. In the first step the MESFET amplifier was optimized on the basis of maximum power gain to inspect the third-order IMD optimization process. After this first step, the amplifier parameters were:

G_T[dB]	r_{in}	r_o	I/C[dB]
17	0.79∠39°	0.68∠26°	-78.5

Tab.1. The amplifier parameters after the ports impedance optimization for maximum IMD improvement

Where :G_T is transducer power gain, r_{in} and r_o source and load reflection coefficient and I/C intermodulation to carrier ratio. The transducer power gain, input and output return losses are shown on the Fig.5. With optimal $Z_S(\omega)$ and $Z_L(\omega)$, IMD improvement of 5.5 dB were achieved with 1.0 dB gain drop. As the third-order nonlinear transfer function $H_3(\omega_1,\omega_1,-\omega_2)$ depends on $H_2(\omega_1,-\omega_2)$, an attempt has been made to improve the third-order IMD by controlling the matching circuit parameters at 2ω ($2\omega \approx 2\omega_1 \approx 2\omega_2$) (Fig.6). This effect exists in the input and

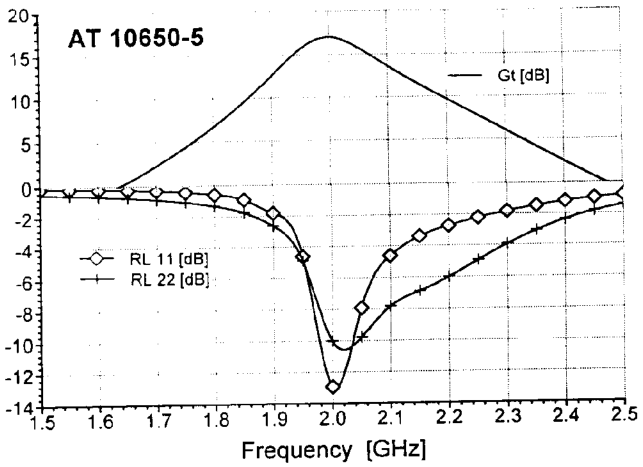

Fig.5. The GaAs MESFET amplifier parameters after the first optimization step

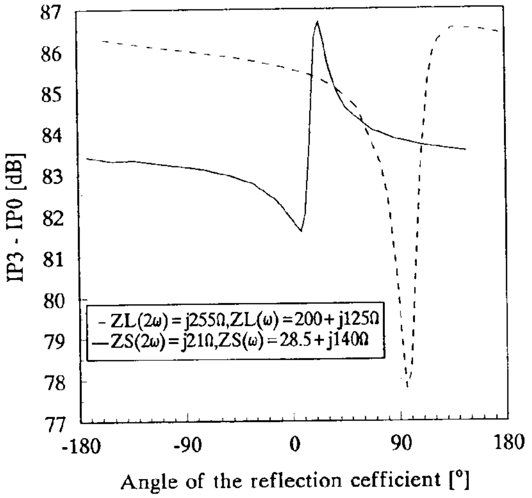

Fig.6. Intermodulation component $2f_2$-f_1 change with $Z_S(2\omega)$ and $Z_L(2\omega)$ terminations

output matching circuits as well, because of the external and internal feedback and C_{gs} nonlinearities. To investigate the input and output circuit of the second harmonic impedance effect on IMD, the I/C variations were analyzed for specific load (source) terminations when the opposite port was terminated with 50 Ω. Using the described topology, the changes in the I/C were found for pure reactive second harmonic terminations. This effect is even more significant if the opposite port is terminated with the optimal second harmonic impedance (Fig.6). Proper terminations of input and output matching networks can significantly suppress or enhance the third-order IMD.

There are many similarities between image recovery mixers [5] and the proposed method but the final results are quite different. The third-order IMD optimization process results in minimal gain reduction and the I/C overall improvement. The optimized amplifier final parameters were:

G_T[dB]	r_{in}	r_o	I/C[dB]
16	0.89∠37.7°	0.69∠13.7°	-86.5

Tab.2. The amplifier parameters after the final optimization for maximum IMD improvement

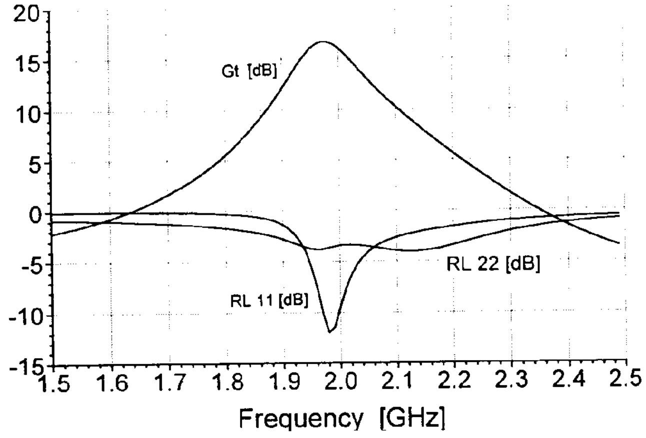

Fig.7. Amplifier final parameters

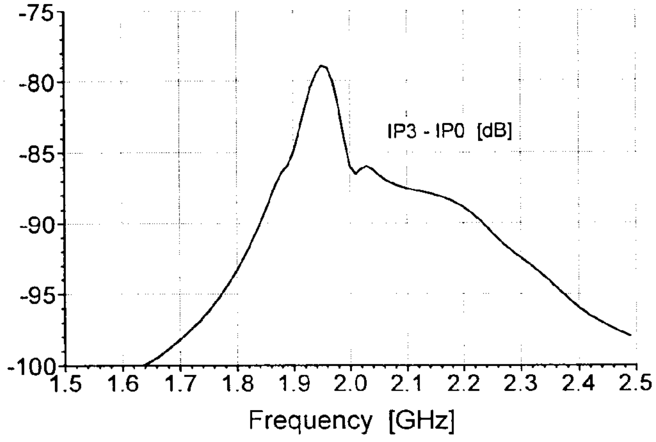

Fig.8. IP_3-IP_0 variations by final amplifier

The transducer power gain, input and output return losses are shown on the Fig.7. and IP_3-IP_0 on the Fig.8. (ΔG_T= 1.0 dB, ΔI/C=8.5 dB). The results have been verified for this specific transistor model with an additional series feedback.

III CONCLUSION

The goal was to find the optimal load and source impedances that produce minimal third-order intermodulation distortion. The optimization of $Z_S(\omega)$ and $Z_L(\omega)$ results in some I/C improvements. Much better results were obtained by controlling the input and output terminating impedances at the second harmonic frequency. The results could be of practical interest due to simple modifications of passive matching circuits.

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