Linearity Improvement for Power MESFET Devices Using Source Inductive Feedback and Input Impedance Mismatch

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Abstract — **Linearity can be improved drastically by sacrificing power gain with the same output power. GaAs MESFET devices with source-via-hole ground and with source-bond-wire ground are used to investigate the effect of source inductive feedback and input impedance mismatch on the effect of linearity. The output matching for all the devices are tuned for the maximum power condition. At 2.4 GHz, the device without source-bond-wire ground and input impedance mismatched has the highest linearity, OIP_3=50 dBm, gain=13.5 dB gain and P_{1dB}=29 dBm while the device with source-via-hole ground and input impedance matched has the lowest linearity OIP_3=40 dBm, 18.3 dB gain and P_{1dB}=29 dBm.**

Index Terms **—power amplifier, MESFETs, linearity, GaAs, and intermodulation.**

I. INTRODUCTION

A power amplifier is the indispensable element in a wireless transmitter. It provides sufficient gain and output power at the final stage of the transmitter. All the modern high data rates wireless communication systems have strong linearity requirement. The linearity of the power amplifier dominates the linearity of the whole transmitter. Thus, the linearity of a wireless transmitter relies especially on the linearity of the power amplifier. Linearity optimization comes from many factors such as device structure design, bias point selection, input impedance, output impedance, feedback and harmonic termination [1][2][3][4]. This paper describes the effects of source grounding and input impedance matching in order to obtain the optimized linearity of a GaAs MESFET power device. A MESFET device with source inductive degeneration is shown in Fig. 1. The formula for input impedance is also illustrated in Fig. 1. Z_1 is the gate-to-source capacitance and Z_2 is the source degeneration inductance. The original input impedance Z_1 is increased by a factor of $1+g_mZ_2$ as expected from the feedback point of view. Feedback can reduce the nonlinear at the cost of lower gain. Because Z_1 is capacitive, an inductive feedback by Z_2 creates a real input resistance and thus lowers the overall gain. In addition, input matching also affects the linearity. Our results demonstrate that the linearity of a power MESFET device can be improved from the source bond-wire inductive degeneration and input impedance mismatch. The input impedance mismatch of a power device will not cause any problem because most of the power amplifiers are two-stage (driver stage and power stage) power amplifiers. Thus, a power amplifier can have mismatch in the inter-stage matching for linearity but still keeps input impedance matching for the drive stage.

$$Z_{in} = Z_1\left(1+g_mZ_2\right)+Z_2$$

$$where\ \ Z_1 = \frac{1}{sC_{gs}} \qquad Z_2 = sL$$

$$Z_{in} = sL + \frac{1}{sC_{gs}} + \frac{g_m}{C_{gs}}L$$

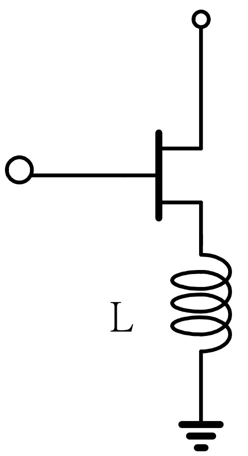

Fig. 1. The schematic of a MESFET device with source inductive degeneration.

II. DEVICE DC AND RF CHARACTERISTICS

A narrow-recessed MESFET device with doping density of $1x10^{17}/cm^3$ is used in this study. The gate length is 0.7 μm and total gate width is 2 mm. The device has g_m of 200 mS, Idss of 440 mA, pinch-off voltage of –2.5 V and gate-to-drain breakdown voltage of 20 V. The I-V curve is shown in Fig. 2. S parameters measurements were performed for the 2 mm MESFET devices in chip form. The maximum available gain and current gain obtained from the measured S parameters are shown in Fig. 3 for MESFET devices with via-hole ground and with source-bond-wire ground. Both devices have almost the same current gain while the maximum available gain is higher for the via-hole-ground device as shown in Fig. 3. The source degeneration inductance behaves as a series resistor when looking into the gate. The effective series resistance lowers the power gain but does not affect the current gain.

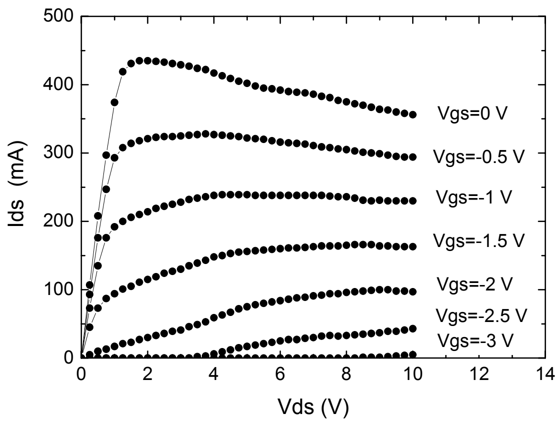

Fig. 2. I-V curves for a GaAs MESFET with doping density of $1x10^{17}/cm^3$.

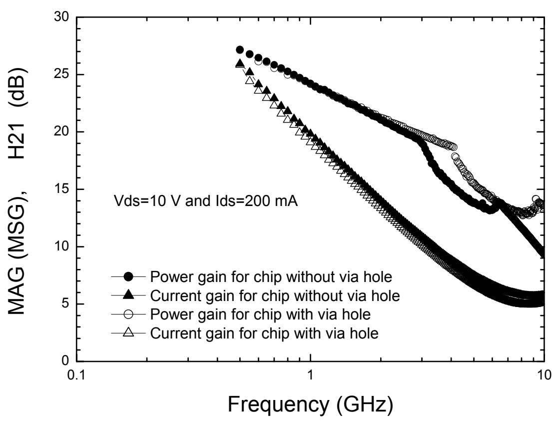

Fig. 3. Maximum available gain (maximum stable gain) and current gain for the 2 mm MESFET chips with source-via-hole ground or source-bond-wire ground.

III. POWER PERFORMANCE

Both devices are packaged by the same ceramic packages for the power performance evaluation. Mechanical tuners are used to characterize the device rf performance. For the power performance evaluation, the device output impedance is tuned for the maximum output power. The gain, output power and PAE (power-added efficiency) as a function of the input available power are measured at the given bias point. All the measurements at this paper are performed at 2.4 GHz. It turns out that the device biased at Ids=200 mA and Vds=10 V has the best linear power performance. The bias point of Ids=200 mA and Vds=10 V corresponds to the bias point equally away from all waveform clipping mechanisms such as knee voltage, pinch-off voltage, breakdown voltage and maximum rf drain current [5]. Those mechanisms clip output current or voltage waveforms of a MESFET at large signal swings, cause gain compression and power saturation.

The one-tone power performance for the via-hole-ground device when the output impedance is tuned for maximum output power is shown in Fig. 4. The results for input impedances tuned for the maximum small signal gain and deliberately mismatched are also shown in Fig. 4. The source-via-hole-ground device with input matched impedance has 18.3 dB gain, 29 dBm P_{1dB} and 40% PAE at P_{1dB}. The source-via-hole-ground device with input mismatched impedance has 15.4 dB gain, 29 dBm P_{1dB} and 40% PAE at P_{1dB}. The input impedance mismatch affects device power gain only and the device is unilateral at 2.4 GHz.

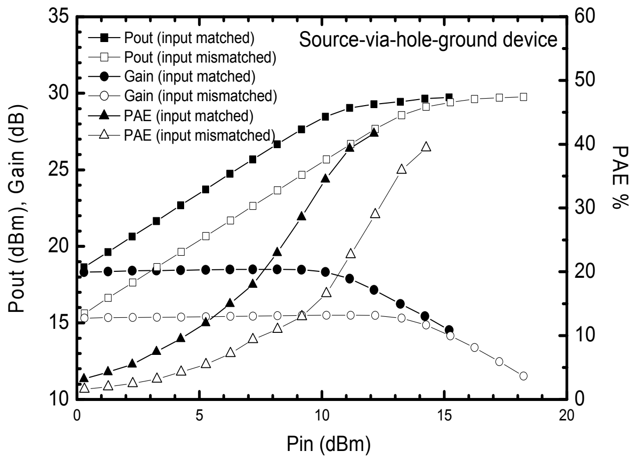

Fig. 4. One-tone power performance for source-via-hole-ground GaAs MESFET devices.

The linearity of a power amplifier can be evaluated by two-tone inter-modulation measurements. When two sinusoidal frequencies are applied to the nonlinear device, the output signal contains the fundamental tones (P_{f1} and P_{f2}) and inter-modulation components (P_{2f1-f2} and P_{2f2-f1}). Linearity of a power amplifier can be described in two ways. One is the third order inter-modulation IM_3, the difference between P_{f1} and P_{2f1-f2}. Normally IM_3 is specified at a certain P_{f1}. The other is OIP_3. OIP_3 is determined from the intercept point where the extrapolated P_{f1} is equal to the extrapolated P_{2f1-f2}. The two-tone power performance for the via-hole-ground device when the output impedance is tuned for maximum output power is shown in Fig. 5. The OIP_3 is unique for a given bias point and is calculated as the summation of P_{f1} and $IM_3/2$. This formula for OIP_3 is only true in the small signal region. Thus, only OIP_3 calculated in the small signal region is shown in Fig. 5. The source-via-hole-ground device with input matched impedance has 40 dBm OIP_3 and the source-via-hole-ground device with input mismatched impedance has 45 dBm OIP_3. The 2.9 dB gain reduction by mismatch increases the OIP_3 by 5 dB.

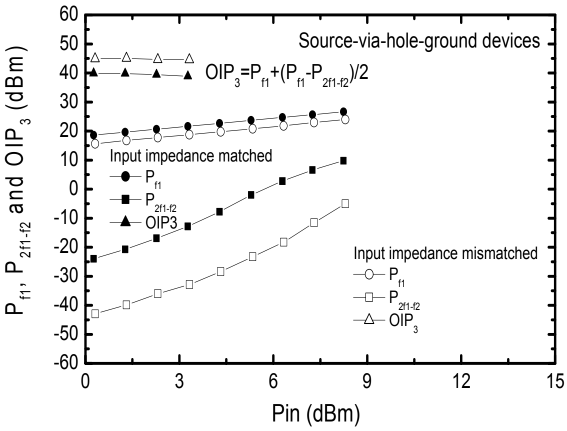

Fig. 5. Two-tone power performance for source-via-hole-ground GaAs MESFET devices.

The one-tone power performance for the wire-bond-ground device is shown in Fig. 6. The output impedance is tuned for maximum output power again. The source-wire-bond-ground device with input matched impedance has 16.2 dB gain, 29 dBm P_{1dB} and 40% PAE at P_{1dB}. The source bond wire causes 2 dB gain reduction as explained in Fig. 1. The source-wire-bond-ground device with input mismatched impedance has 13.5 dB gain, 29 dBm P_{1dB} and 40% PAE at P_{1dB}. The two-tone power performance for the wire-bond-ground device is shown in Fig. 7. The source-wire-bond-ground device with input matched impedance has 45 dBm OIP_3 and the source- wire-bond-ground device with input mismatched impedance has 50 dBm OIP_3. The 2.7 dB gain reduction by mismatch increases the OIP_3 by 5 dB.

All for cases have almost the same power added efficiency at P_{1dB} because all of them have enough power gain. IM_3 at a given output power is also an important figure of merit for linearity. Thus, IM_3 versus power output per tone for all the four cases are shown in Fig. 8. The results clearly indicate that the improvement for linearity occurs for 6 dB back-off from P_{1dB}.

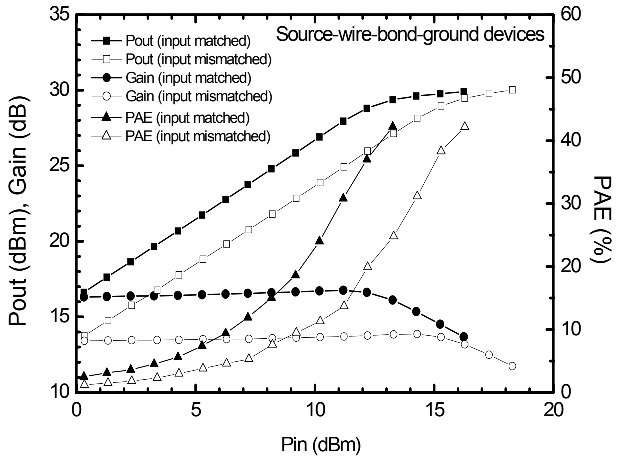

Fig. 6. One-tone power performance for wire-bond-ground GaAs MESFET devices.

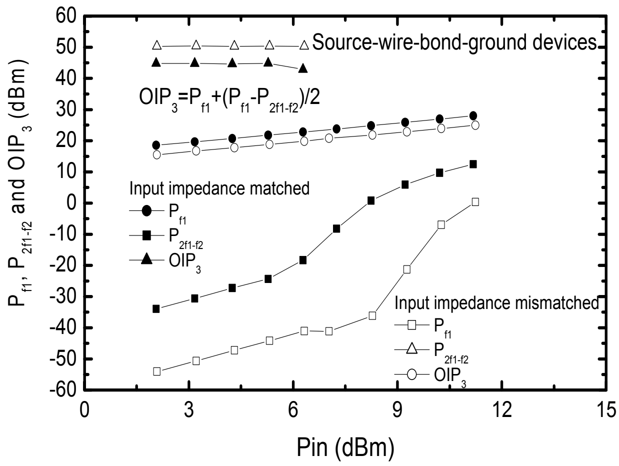

Fig. 7. Two-tone power performance for wire-bond-ground GaAs MESFET devices.

IV. CONCLUSION

Power gain can be reduced to improve linearity with the same output power for GaAs MESFET devices. At 2.4 GHz, the device without source-bond-wire ground and input impedance mismatched has the highest linearity, OIP_3=50 dBm and P_{1dB}=29 dBm. The difference between OIP_3 and P_{1dB} is 21 dB. On the other hand, the device with source-via-hole ground and input impedance matched has the lowest linearity OIP_3=40 dBm and P_{1dB}=29 dBm. The difference between OIP_3 and P_{1dB} is 11 dB. The output impedance for output matching does not change for the linearity improvement. The effect of source inductive feedback and input impedance mismatch can improve the linearity by 10 dB with the same output power and power added efficiency.

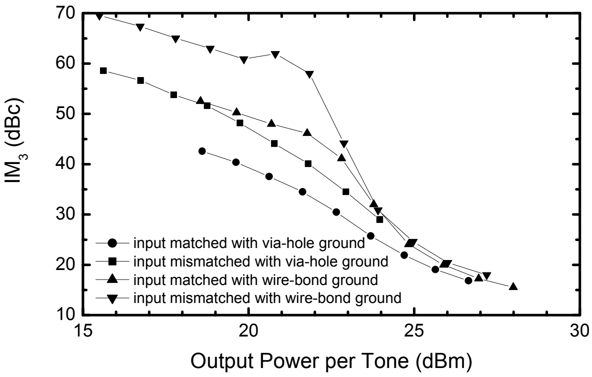

Fig. 8. Two-tone IM_3 power performance for via-hole-ground and wire-bond-ground GaAs MESFET devices.

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