A NEW GAAS POWER-MESFET WITH LARGE UNIT GATE WIDTH

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ABSTRACT

A new GaAs-power-FET is proposed which uses an additional transmission line feeder parallel to the gate. With a suitable termination at the end of this transmission line and a unit gate width of 2mm the fabricated device shows excellent power handling capabilities and an increased output resistance at 4 GHz. It is demonstrated that this approach leads to higher output power and easier matching of GaAs-power-FET.

INTRODUCTION

The maximum achievable output power of a GaAs-power-MESFET is aproximately given by:

$$P_{max} \sim 1/f^2$$

One reason for this is the limitation of the unit gate width by the gate conductor losses at increasing frequency. Therefore we use a transmission line parallel to the gate with feeders which are connected each 200 µm to the active region of the gate electrode. Because the distance between the feeders is short compared with the wavelength the additional transmission line results in an increased cross-section of the gate. The source pads are grounded by via-holes.
This approach yields compared with the conventional "T"-shaped gate structure (1,2,3) a significant reduction of the losses on the gate electrode and allows a gate width up to 2mm at 4 GHz.
Small- and large-signal measurements of this device which are presented here show that the output power is increasing proportionally to the elongation of the gate.
Simultaneously, the input resistance, normalized to the gate width, is increased. This avoids matching problems. It is shown that a suitable termination of the additional transmission line is essential.

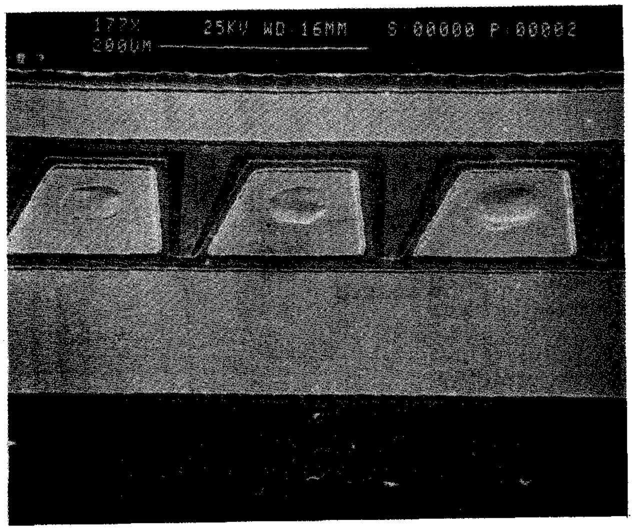

Fig .1a: SEM micrograph of the improved GaAs-power-MESFET.

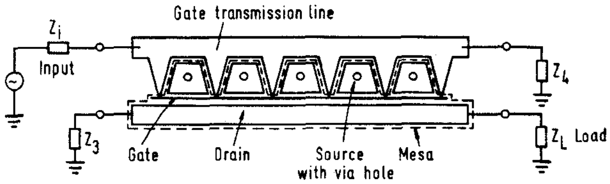

Fig .1b: Schematic configuration and measurement setup.

DEVICE STRUCTURE

The structure of an improved one finger GaAs-power-FET is shown in fig.1. The gate length was chosen to be 2 µm in order to achieve high measurement accuracies. Although the measurements are performed at relatively low frequencies of 4-8 GHz, the

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results presented here are particulary relevant for mm-wave applications because this approach helps to overcome the increased problems at these frequencies. The device allows paralleling without crossovers for a further increase of the total output power.
Power-MESFETs with 2 up to 10 sections were fabricated with a corresponding gate width ranging from 0.4 up to 2 mm.
The devices were structured on 80 µm thick VPE grown GaAs with a plated heat sink. The thermal resistance is further reduced to 20 K/W for a 1 mm wide device by the large number of wet-etched via-holes (4). Conventional Ni Au-Ge Ni ohmic contacts annealed at 465°C were were used. The schottky gate metallisation was Ti Pt Au. Because of the high saturation current of 0.5 A for the 2 mm wide device a thick Au-plating for source, drain and the transmission line parallel to the gate is necessary.

RESULTS

A direct impression of the improvements obtained by the additional transmission line is given in fig. 2. The phase- and attenuation constants of the wave which is travelling along the gate electrode of the 2 mm wide device was measured using a new method (5). For this method the propagation constants, the wave impedances and the coupling constants were computed from measured 4-port scattering parameters. For comparison the corresponding results for a conventional MESFET are presented. It is the same device which was used in (6). Because of the high attenuation of the gate mode of this device the measurement error increases and the results are only useful up to a frequency of 4 GHz.
It can be seen that a great improvement is obtained by the new structure which shows an attenuation of only 3 dB/mm. Simultaneously the phase constant is reduced to $4 \cdot 10^2$/m at 4 GHz, whereas the conventional structure reaches $1.57 \cdot 10^3$/m at this frequency which corresponds to a λ/4-line. Therefore the improved device appears electrically shorter and can be made approximately 3 times wider at 4 GHz than the conventional device.

Fig. 3 shows the advantages of wider gates with respect to the input and output matching. For this purpose the real parts of the input and output impedance for conjugate complex matching are computed on the base of 2-port scattering parameters of the optimized structure with various gate widths. These input resistances are consequently normalized to the gate width and depicted versus the gate width. It can be seen clearly that a power-MESFET with one 2 mm wide gatefinger has about 40 %

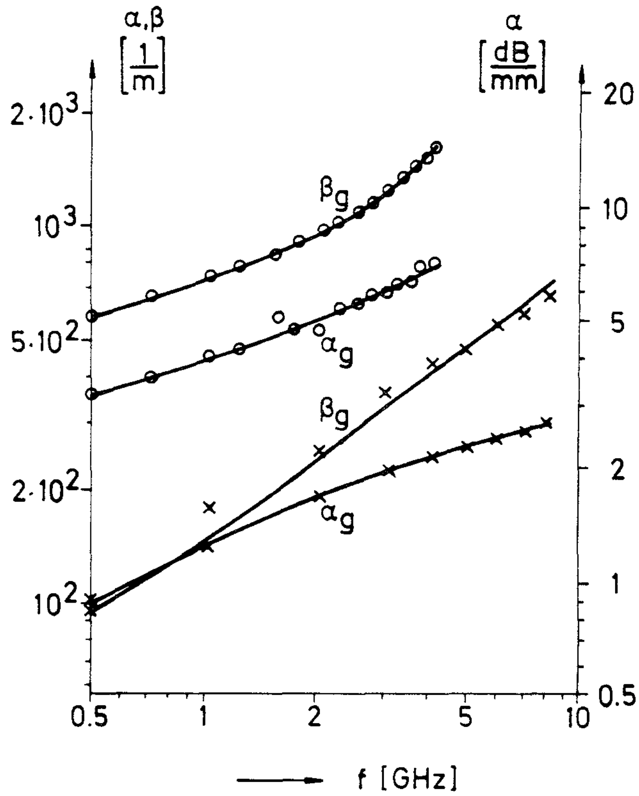

Fig. 2: Propagation constants α + jß versus the frequency f.
o conventional structure (6)
x improved structure
($I_D = I_{Dss}/2$, V_{DS} = 4 V)

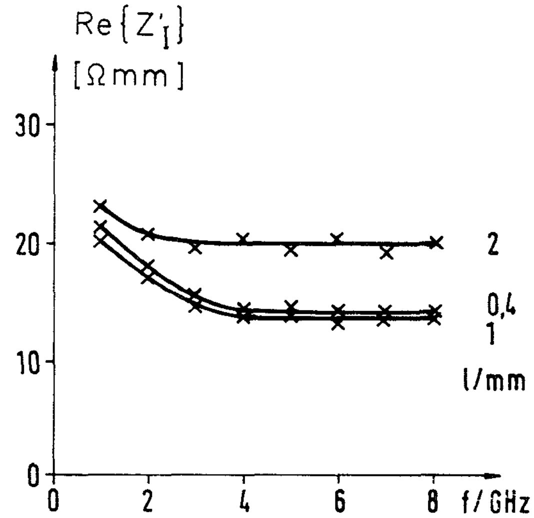

Fig. 3a: Real part of the input impedance Z_I' for matching normalised to the gate width l with l as a parameter versus the frequency . ($I_D = I_{Dss}/2$, V_{DS} = 4 V)

higher input resistance than a FET with two 2 mm wide gates in parallel if the frequency is higher than 3 GHz. The 0.4 and the 1 mm wide devices show nearly identical normalized input impedances. This means that they are both can be regarded as lumped elements.
A corresponding result is obtained for the normalized output resistances for conjugate complex matching. But there the required impedances are quite higher. Therefore the output does not cause serious problems like the input matching. Additionally the output normally is not matched for optimum gain but for maximum output power.

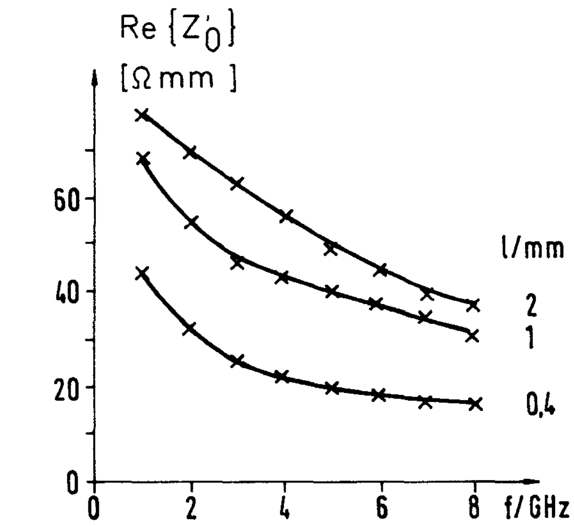

Fig. 3b: Real part of the output impedance Z_O' for matching normalised to the gate width l with l as a parameter versus the frequency f. ($I_D = I_{DSS}/2$, V_{DS} = 4 V)

A summary of the large- and small siganl measurements performed with the 2 mm wide optimized GaAs-power-FET as a function of the lossless termination Z_4 (refer to fig. 1) at the end of the additional transmission line is presented in fig. 4. The operating frequency was 4 GHz. For all these lossless terminations at port 4 the remaining two-port was unconditionable stable. Fig. 4 indicates clearly that the associated gain increases about 4 dB at 4 GHz if the impedance Z_4 is changed from open circuit to j35Ω . The improvement of the maximum output power P_{sat} as well as the power at the 1 dB compression point P_{1dB} is improved by more than 1 dB. These features result in a power added efficiency of 22%. Even 26% efficiency are possible if the input power is slightly changed which is given in fig.4 as the maximum power added efficiency n_{max}. This is a significant improvement compared with the 7% power added efficiency at open circuit at the end of the additional transmission line. The third order intercept point IP does not depend strongly on Z_4.
The high efficiencies obtained demonstrate that wider gates can be used if an additional gate transmission line is introduced and suitably terminated. Similar experiments with a termination at the end of the drain electrode Z_3 (refer to fig. 1) did not result in higher performance in comparison with an open circuit at this port.

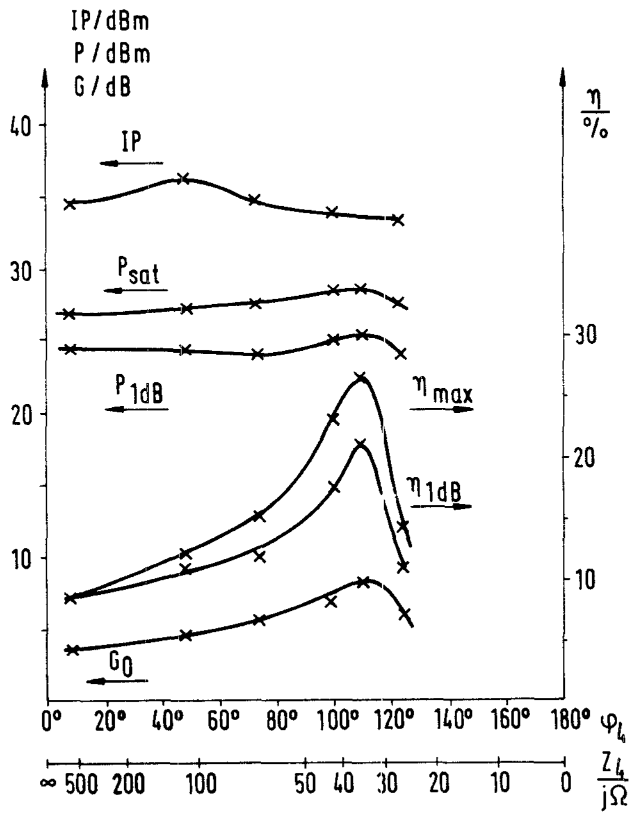

Fig. 4: Saturation power P_{sat} at the 1dB compression point P_{1dB}, maximum power added efficiency n_{max}, n_{1dB}, associated gain G_O and 3rd order intercept point IP versus the angle of the reflection coefficient φ_4 (the impedance Z_4) of the termination at the end of the transmission line. ($I_D = I_{DSS}/2$, V_{DS} = 4 V)

Fig. 5 shows the broadband performance of the device. The maximum available gain MAG for the 2 mm wide device is plotted versus the frequency. The additional transmission line is terminated by a shorted transmission line of the length l_o. This length l_o is chosen to produce the optimum Z_4 of j35Ω at 4 GHz. A broadband improvement of about 4 dB is obtained in comparison with an open circuit at port 4 which is shown in the second row in the figure.

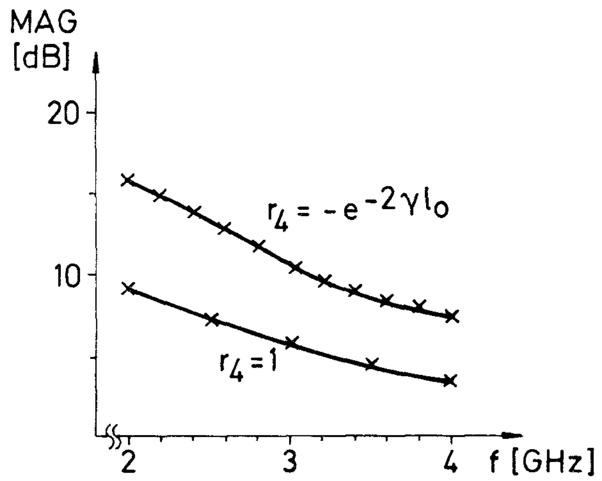

Fig. 5: Maximum available gain of the improved MESFET with the additional transmission line terminated by:
- a shorted transmission line of the length l_o (= j35Ω at 4GHz) ($r_4 = -\exp(2\tau l_o)$)
- an open circuit ($r_4 = 1$)

($I_D = I_{Dss}/2$, $V_{DS} = 4$ V)

CONCLUSION

A new GaAs-power-FET is proposed with an additional transmission line parallel to the gate. The measurements presented here show:

- the additional transmission line reduces the losses of the gate electrode to 3 dB/mm at 8 GHz.
- The unit gate width can be increased up to 2 mm at 4 GHz.
- With an inductive termination at the end of the transmission line this device exhibits good power added efficiency and output power.
- The input resistance of a FET with a 2 mm wide gate is about 40 % higher than that of a FET with 2 gates of 1 mm width in parallel.
- Because of the large number of via-holes an excellent thermal resistance of 20 K/W (1 mm gate width) is obtained

The device is designed for paralleling without crossovers for further increase of the output power. This results in higher output powers than it has been possible so far.

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