36-44 GHz HPA for High Linearity Radio Systems

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Abstract — **A 36-44 GHz HPA was developed for radio applications with complex modulation schemes which require high linearity. The 3-stage HPA achieves a gain of 17 dB and a P-1dB output power of 26.3 dBm. The HPA demonstrates an output IP3 which is 10 dB higher than P-1dB whereas comparable amplifiers have only 6 dB to 8 dB difference between P-1dB and OIP3. The increased linearity permits compact designs with lower dc power consumption due to the reduction of the necessary HPA output power level.**

I. Introduction

Point to point or point to multipoint radio systems have advantages in regions with poor fiber optic infrastructure or in special applications like company internal communication networks. Modern radio systems achieve data rates of 155 Mbit/s which is sufficient to connect office towers with the internet. Complex modulation schemes like 16 QAM are used to achieve high data rates. The distortion caused by the high power amplifier (HPA) in the transmit path is essential for the bit error rate of the radio link. Typically the HPA is used 6 dB to 10 dB back off from the P-1dB output power to achieve the necessary level of third order intermodulation distortion (OIP3). It is a significant advantage if the linearity specification can be fulfilled with a HPA which requires a lower back off from the P-1dB point. Lower P-1dB output power levels result in smaller chip sizes less dc power consumption and reduced cost.

A comparison of power amplifiers in the 36-44 GHz frequency range is depicted in Table 1. The values were found in the data sheets. The differences between OIP3 and P-1dB are estimated for an OIP3 value of approximately 21 dBm total output power. The OIP3 values are typically 6 dB to 8 dB higher than the measured P-1dB output power levels. The developed highly linear 36-44 GHz HPA achieves an OIP3 value which is 10 dB higher than P-1dB over a broad frequency range from 36 to 44 GHz. This attractive feature results in a linearity characteristic which is comparable to the linearity of a HPA with significantly higher P-1dB output power.

The Triquint TGA1171 has a 3 dB higher P-1dB output power than the HPA 36-44 GHz and achieves the same OIP3 value of 36 dBm. The dc power consumption of the TGA 1171 is 0.5 W lower due to the high efficiency of the 0.25 um PHEMT Triquint process technology. Other competing power amplifiers require significantly higher dc power consumptions and P-1dB output power levels to achieve comparable OIP3 values.

II. HPA 36-44 GHz

The HPA 36-44 GHz is realized on 75 um thick wafers using the HEMTP60 technology. This purely optical process technology achieves a gate length of 0.18 um by optical stepper lithography in combination with a sidewall spacer process. The delta doped double heterojunction pseudomorphic HEMTs with a double recess are fabricated on 6“ wafers. The technology has a maximum f_T of 60 GHz and f_{max} of 120 GHz. The extrinsic transconductance is typically 500 mS/mm and the saturated drain current density 550 mA/mm. The gate to drain breakdown voltage exceeds 9 V. The technology demonstrates an output power density of 500 mW/mm at 30 GHz.

A chip photo of the microstrip amplifier is depicted in Fig. 1. The chip size of the first pass success design is 4.2 mm x 2.8 mm. The chip size was not minimized to avoid significant on chip coupling. It is a 3-stage amplifier with lange couplers at the input and output. PHEMTs with a gate width of 6x60 um were used in the design operating at V_{DS}=4 V and I_{DS}=200 mA/mm. The total output periphery gate width is 2.88 mm using 8 parallel PHEMT cells. The HPA has a gain (Fig. 2) between 17 dB and 19 dB in the frequency range 36-44 GHz for the operating conditions V_{DS}=4 V, I_{DS}=1000 mA. The input and output match are depicted in Fig. 3. The match is better than -12 dB in a broad frequency range due to the lange couplers. The measured P-1dB output power (Fig. 4) is between 26.3 dBm and 27.2 dBm over the whole frequency band. The HPA

Power Amplifier	f [GHz]	Gain [dB]	P-1dB [dBm]	OIP3 [dBm]	OIP3-P-1dB [dB]	P_{DC} [W]	Chip size [mm²]
HPA 36-44 GHz	36-44	17	26	36	10	4	11.7
Triquint TGA 1171	36-40	14	29	36	7	3.5	7.8
Raytheon RMPA 39100	37-40	18	29	35	6	5	13.6
Velocium APH 473	37-40	13	28	37	8.5	5.4	4.5
Velocium APH 474	40-44	13	27	36	8	5.4	4.5

TABLE 1
COMPARISON OF 40 GHZ POWER AMPLIFIERS

achieves a saturated output power around 28 dBm. The difference between the simulated and measured P-1dB is better than 0.4 dB.

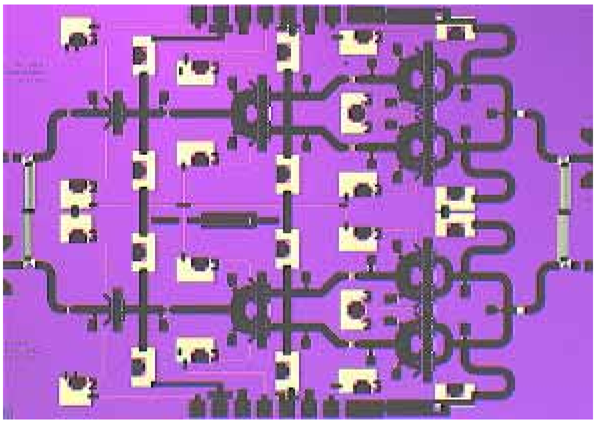

Fig. 1. Chip photo of the HPA 36-44 GHz.

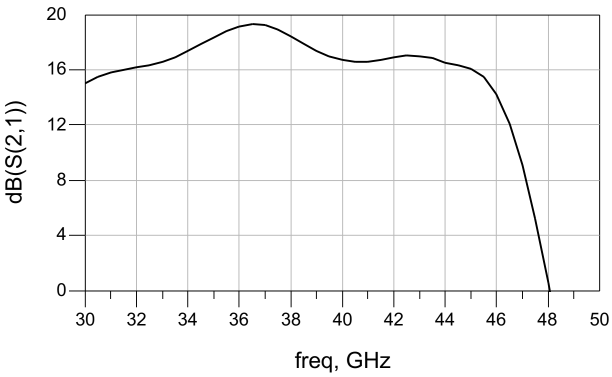

Fig. 2. HPA small signal gain.

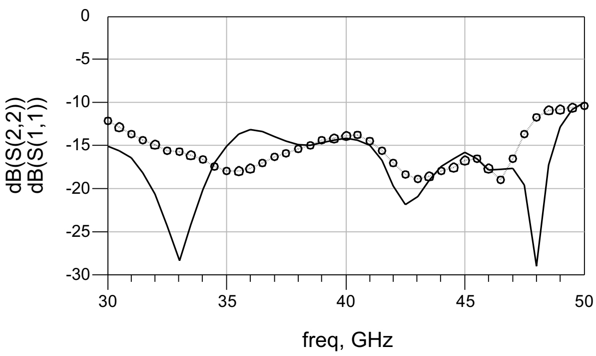

Fig. 3. HPA input match (solid line) and output match (dotted line).

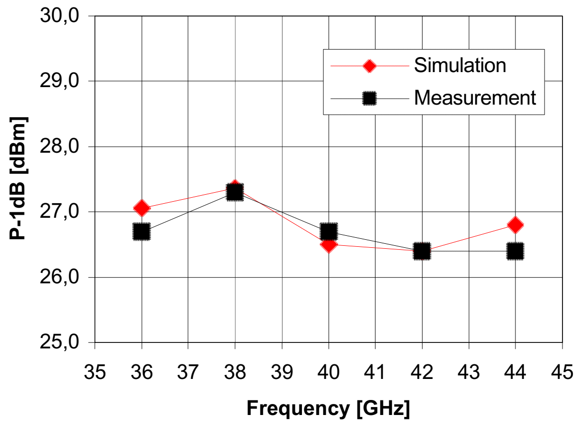

Fig. 4. HPA P-1dB output power.

The measured OIP3 for low output power levels in the order of 10 dBm is depicted in Fig. 5. The OIP3 is higher than 36 dBm in the frequency range from 36-41 GHz and drops to 34.7 dBm at 44 GHz. The simulated OIP3 is less than 1.5 dB higher than measured. More important than the IP3 calculated for very low output power levels is the IP3 for HPA output power levels which are really used in the radio. Fig. 6 shows the measured and simulated OIP3 for two carriers with 13 dBm output power each and Fig. 7 for 18 dBm output power in each carrier. The measured OIP3 is above 36.4 dBm in each cases. The simulated OIP3 agrees very well with the measurement for 16 dBm total output power. The deviation between measurement and simulation is better than 2.1 dB for 21 dBm total output power. The difference between the measured P-1dB and OIP3 of the HPA is 10 dB. This is 2 dB higher than for comparable 40 GHz HPAs. Fig. 8 shows the carrier to 3rd order intermodulation distortion for 16 dBm and 21 dBm total output power. The difference between the total output power and the intermodulation products is 46 dBc for 16 dBm power and 38 dBc for 21 dBm power level.

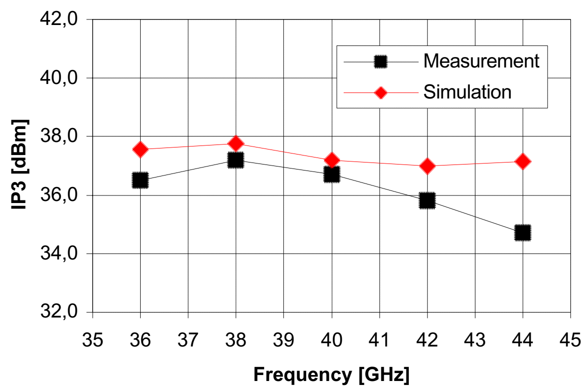

Fig. 5. HPA OIP3 calculated from small signal region.

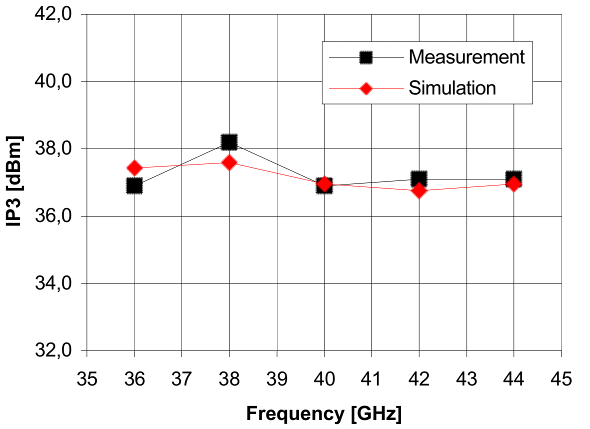

Fig. 6. HPA OIP3 calculated for 16 dBm total output power.

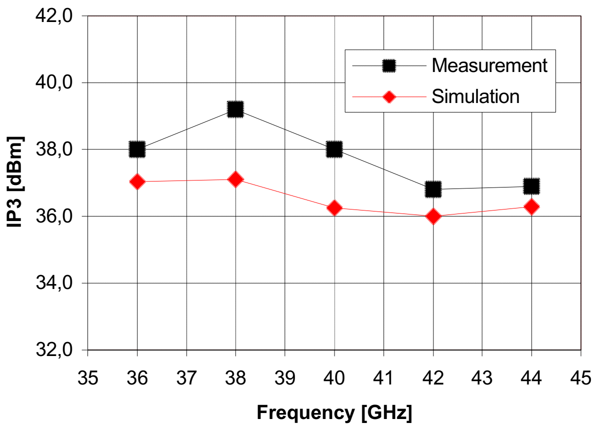

Fig. 7. HPA OIP3 calculated for 21 dBm total output power.

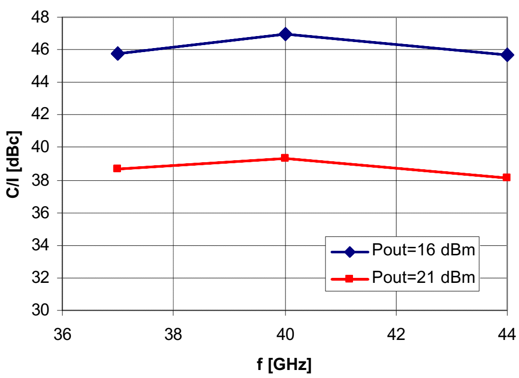

Fig. 8. HPA carrier to 3rd order intermodulation distortion.

The reasons for the very linear HPA characteristic are in the design approach and in the characteristic of the PHEMT cells. The gate width ratio between the first, second and third stage is 2:1 which assures that the last stage compresses first. PHEMT cells with 6x60 um gate width are connected in parallel in the 2nd and 3rd amplifier stages. The individual 6x60 um PHEMT cell has a gain of 7 dB at 40 GHz and achieves an output power density above 300 mW/mm. It was verified by 38 GHz load pull measurements that the gain and output power of a 6x60 um PHEMT scales linear for PHEMTs with smaller gate widths. The scaling is degraded for PHEMTs with larger gate widths like 8x60 um or 10x80 um. This indicates that 6x60 um gate width is the optimum choice at 38 GHz.

Essential for linear operation are the nonlinearities which are created in the PHEMT cells during the period of the voltage and current swing. The HEMTP60 technology has a flat bias dependence of f_T on drain current which is shown in Fig. 9 for various drain voltages. The current gain transit frequency f_T is 50 GHz under nominal operating conditions V_{DS}=4 V and I_{DS}=200 mA/mm. The extreme instantaneous operating conditions are low voltage / high current as well as high voltage / low current. The f_T of the transistor cell changes not much for different operating conditions. 45 GHz f_T is achieved for V_{DS}=1 V, I_{DS}=350 mA/mm and 40 GHz f_T for V_{DS}=5 V, I_{DS}=100 mA/mm.

A large signal model based on the current equation published in [1] and the charge equation of [2] was extracted from dc and S-parameter measurements. The output match of the last amplifier stage was designed with the goal that the P-1dB output power of the HPA was maximized using harmonic balance simulations.

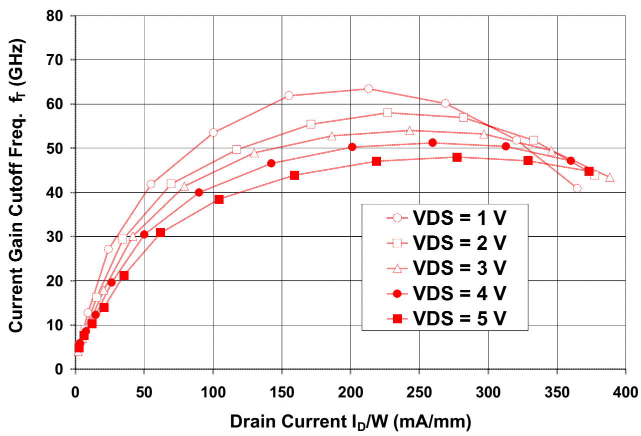

Fig. 9. Measured f_T versus I_{DS} for different drain voltages.

III. Comparison With The TGA 1171

The Triquint TGA 1171 (Fig. 10) is a balanced 2-stage amplifier with 14 dB nominal gain and 29 dBm P-1dB output power in the 36-40 GHz frequency range. The chip size is 2.86 mm x 2.74 mm. The amplifier is fabricated using Triquints proven 0.25 um process technology. Four 400 um PHEMTs drive eight 400 um PHEMTs at the operating conditions V_{DS}=6-7 V, I_{DS}=500 mA.

The measured P-1dB output power as well as the OIP3 for 16 dBm and 21 dBm output power levels are depicted in Fig. 11. The amplifier demonstrates a P-1dB of more than 29 dBm and P_{SAT} exceeds 30 dBm. The optimum OIP3 is achieved around 38 GHz. The measured OIP3 is in this case 6 dB higher than P-1dB for 16 dBm total output power and 7 dB higher for 21 dBm total output power.

The TGA 1171 achieves a P-1dB of 29 dBm wheras the HPA 36-44 GHz demonstrates a P-1dB of 27.4 dBm at 38 GHz for comparable dc power consumptions. The higher efficiency of the Triquint 0.25 um process technology is also a consequence of the different PHEMT device concepts. This process technology uses significantly higher drain source operating voltages in combination with less drain current compared to the HEMTP60 technology. This makes more compact PHEMT cell layouts feasible for a defined power level.

The difference between P-1dB and OIP3 is approximately 2 dB below the values of the HEMTP60 amplifier. The absolute OIP3 value of 36 dBm referenced to the dc power consumption is similar for both process technologies.

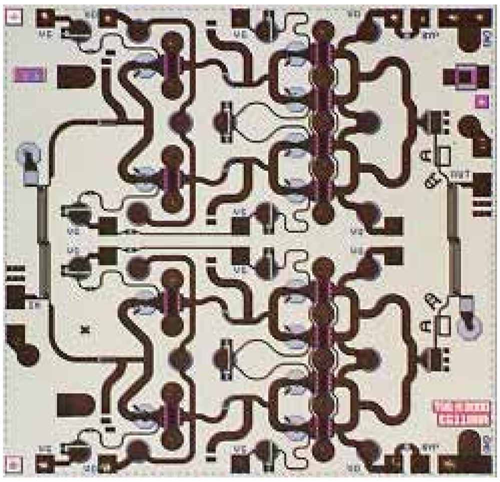

Fig. 10. Chip photo of the TGA1171.

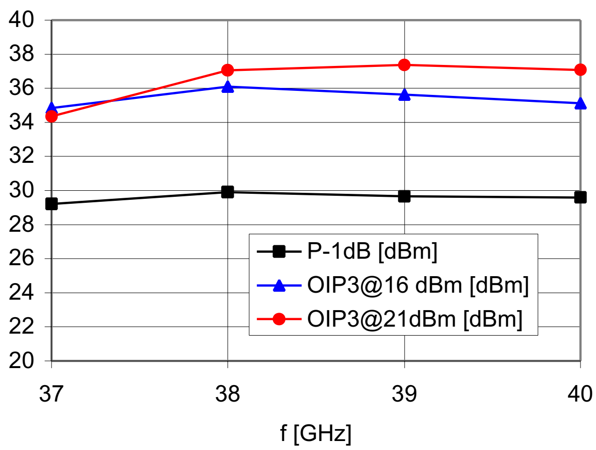

Fig. 11. Measured P-1dB and output IP3 for 16 dBm and 21 dBm total output power.

IV. Conclusion

A 36-44 GHz HPA is developed for communication systems which require high linearity. The amplifier demonstrates 17 dB small signal gain, a P-1dB output power of more than 26 dBm and an output IP3 of 36 dBm. The difference between P-1dB and OIP3 is 10 dB which is 2 dB up to 4 dB better than comparable amplifiers. The linearity is based on the characteristics of the PHEMT cells. The HEMTP60 process technology has a flat characteristic of f_T on the operating conditions. This has the effect that the PHEMT cell gain is approximately constant during the instantaneous gate and drain voltage swing of a time period which reduces the generation of nonlinearities. The simulated P-1dB and OIP3 values are in good agreement with measurements.

The improved linearity characteristic makes it feasible to develop amplifiers with a specified OIP3 value which require lower P-1dB output power levels. Reducing the required P-1dB output power permits more compact HPA designs with reduced dc power consumption.

Acknowledgement

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References

[1] I. Angelov, H. Zirath, N. Rorsmann, "A new empirical nonlinear model for HEMT and MESFET devices," *IEEE Transactions on Microwave Theory and Techniques*, vol. 40, no. 12, pp. 2258-2266, December 1992.

[2] M. Pirola, G. Ghione, J. M. Dortu, J. E. Müller, "An improved P-HEMT large-signal model for medium-power Ka-band amplifiers," in *Proceedings of GAAS Conference*, Torino, Italy, September 1994.