W-Band Cascode Amplifier Modules for Passive Imaging Applications

Axel Tessmann, William H. Haydl, Markus Neumann, and Jürgen Rüdiger

***Abstract*—W-band amplifier modules with high gain and large bandwidth have been developed for passive imaging applications. With three cascaded waveguide modules, an average small-signal gain of 60 dB and a ± 3 dB bandwidth of 15 GHz was achieved centered around 94 GHz. The assembled three-stage amplifier monolithic microwave integrated circuits are realized in coplanar technology for compact size and low cost. Cascode devices, based on a 0.15 μm AlGaAs/InGaAs/GaAs pseudomorphic high electron mobility transistor technology, allow for individual gain control of the stages by varying the second gate voltage.**

***Index Terms*—Cascode, coplanar waveguide, millimeter wave, monolithic microwave integrated circuits (MMIC), passive imaging.**

I. INTRODUCTION

MILLIMETER-wave amplifier modules with large bandwidth, high gain, and medium output power are key components for active and passive imaging systems in commercial and defence applications [1], [2]. Distributed amplifiers are known to provide flat gain over an extremely large bandwidth. For these, InP dual-gate high electron mobility transistors (HEMT's) are the preferred technology, due to their superior gain performance per stage [3]. High gain and large bandwidth were recently reported for a six-stage common-source InP HEMT G-band amplifier having about 20 dB gain [4]. Other methods to improve the bandwidth and flatness of amplifiers involve negative feedback principles [5], [6].

In contrast to the techniques mentioned above, we have investigated the method of stagger tuning, applied to several amplifier stages in order to effect the gain and bandwidth characteristics of multistage amplifiers. Additionally, cascode HEMT amplifier stages were used, which provide individual gain control by varying the voltage on the second gate [7]. This results in high gain and a flat gain response for the entire amplifier circuit, while still maintaining good matching and reasonable noise figures. The amplifier monolithic microwave integrated circuits (MMIC's) were packaged in WR-10 waveguide mounts and used as a 60-dB amplifier module for passive imaging applications.

II. TECHNOLOGY

For the fabrication of the active devices, we used a molecular-beam epitaxy grown double-doped AlGaAs/InGaAs/GaAs PM-HEMT technology on Si 3-in wafers. The 0.15 μm mushroom gates were written with e-beam, and the recess was dry etched. The devices typically had an f_t of 100 GHz and an $f_{\max}$ of 180 GHz. A current density $I_{\rm sat}$ of 1000 mA/mm was achieved with 25% indium in the channel. The extrinsic transconductance was 800 mS/mm. The cascode configuration used in the presented MMIC's consists of common-source and common-gate HEMT's, separated by a short section of high-impedance coplanar transmission line. This transmission line, which acts as an inductor, improves the matching of the HEMT's and simplifies the stabilization of the cascode device [8]. The small-signal equivalent circuit parameters of the common-source and common-gate HEMT's were extracted separately, using S-parameter measurements up to 120 GHz. The metallization thickness of the coplanar lines is 3 μm, and the ground-to-ground spacing is 50 μm. For the simulation of the passive components, we are using in-house models that were extracted by means of experimental test structures [9].

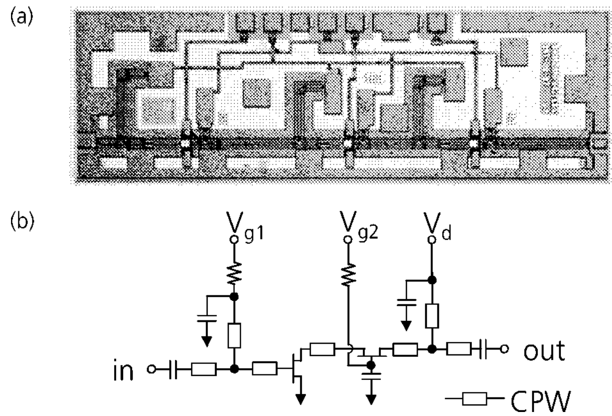

Fig. 1. (a) Photograph of the coplanar three-stage cascode amplifier and (b) schematic diagram of a single cascode stage.

III. CIRCUIT DESIGN, PACKAGING AND EXPERIMENTAL RESULTS

A photograph of the three-stage amplifier is shown in Fig. 1(a). The compact chip size of 1 $\times$ 3 mm^2 was possible by employing the cascode HEMT devices in combination with coplanar technology. The gate width of the HEMT's is 2 $\times$ 40 μm each. Fig. 1(b) illustrates the schematic diagram of a single cascode stage. The conventional reactive matching technique was used in the design of the circuit. The three cascode stages were optimized at different frequencies, maintaining an overall flat gain and low input and output reflection within the bandwidth of operation. Fine tuning of the gain response can

Manuscript received January 21, 2000; revised March 24, 2000. This work was supported by the German Ministry of Defense.

The authors are with the Fraunhofer Institute for Applied Solid State Physics, Freiburg D-79108 Germany (e-mail: tessmann@iaf.fhg.de).

Publisher Item Identifier S 1051-8207(00)04880-7.

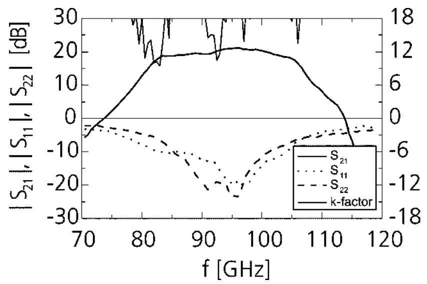

Fig. 2. Measured gain, return loss, and k-factor of the three-stage cascode amplifier.

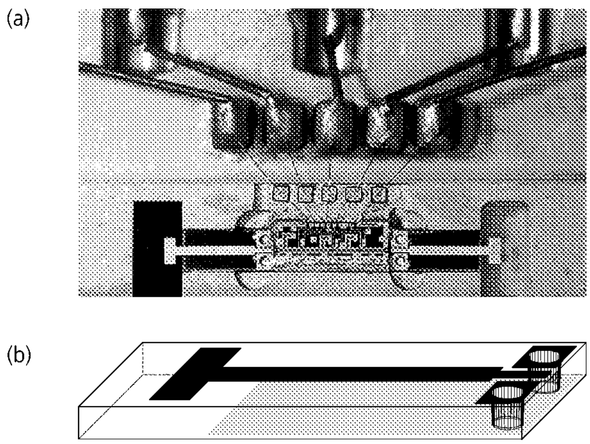

Fig. 3. (a) Inside view of the W-band cascode amplifier waveguide module and (b) detailed drawing of the CPW to waveguide transition.

be achieved by adjusting the second gate voltage of each stage. Therefore, the three HEMT's in common-gate configuration have an individual bias supply. The radio-frequency (RF) performance of the MMIC is shown in Fig. 2. A constant small-signal gain (S_{21}) of more than 18 dB was measured on-wafer between 85 and 105 GHz with good input (S_{11}) and output (S_{22}) reflection. The maximum gain is 21 dB at 96 GHz. Typical supply voltages are -0.1 V at the gate of the common-source HEMT (gate), 1.8 V at the gate of the common-gate HEMT (gate 2), and 3 V at the drain. The circuit was designed for maximum gain and bandwidth, resulting in a noise figure of about 10 dB between 85 and 105 GHz. The measured output power of the amplifier circuit was 10 dBm at 94 GHz. To ensure an unconditionally stable circuit behavior, each stage was carefully analyzed for possible oscillations and matched to 50 Ω. To prevent the excitation of parasitic modes in the substrate, the chip was thinned to 100 μm and mounted on microwave absorbing material [10].

The broadband cascode amplifier MMIC was packaged in a gold-plated WR-10 waveguide mount as shown in Fig. 3(a). All ground planes of the amplifier chip were connected with the module by conductive epoxy to ensure a uniform potential. The bond-wires for the bias and RF interconnections were chosen as short as possible, using wedge-bonded 17-μm gold wires. The transition from the coplanar output of the MMIC to the waveguide of the module was realized with a microstrip line on 127-μm-thick quartz substrates. A detailed drawing of the coplanar waveguide (CPW) to waveguide transition is shown in Fig. 3(b). For the simulation and optimization of the transitions, the Hewlett-Packard full-wave EM analysis software HFSS was used. To prevent low-frequency oscillations, we integrated 120-pF chip capacitors, 10 nF surface-mounted device (SMD) ceramic capacitors, and filters in the bias connections. The overall module size was 32 × 23 × 18 mm^3.

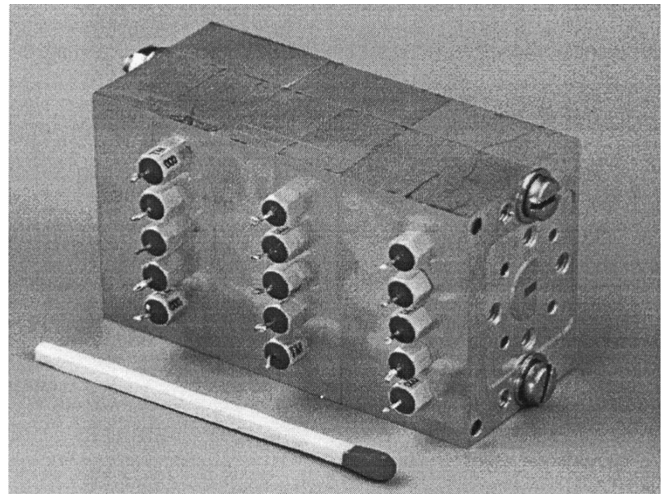

Fig. 4. Photograph of three cascaded W-band cascode amplifier modules.

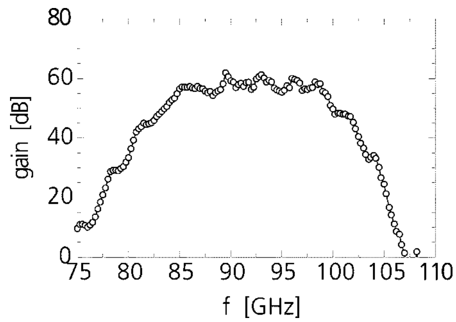

Fig. 5. Measured gain of three cascaded W-band cascode amplifier modules.

Fig. 4 shows a photograph of three W-band cascode amplifier waveguide modules connected in series. The cascaded W-band amplifiers achieved an average gain of 60± 3 dB in the frequency range from 85 to 100 GHz, as shown in Fig. 5. The noise figure of the cascaded modules is better than 12 dB within this frequency band. The necessary low noise figure of the imaging system is obtained by the use of an InP-based preamplifier.

IV. SUMMARY

High-gain W-band cascode amplifier modules with a ±3 dB bandwidth of 15 GHz around 94 GHz have been successfully developed. The achieved small-signal gain was 20 dB over this frequency range for a single module and 60 dB for three cascaded modules. Cascode HEMT's were used to maintain a flat amplifier gain characteristic by adjusting the gain of each stage.

ACKNOWLEDGMENT

The authors would like to thank their colleagues from the technology department for the fabrication of the coplanar devices, B. Matthes for wafer thinning, H. Massler for measurements, K. Köhler for epitaxial material preparation, and G. Weimann for support.

REFERENCES

[1] B. Kane, S. Weinreb, E. Fischer, and N. Byer, "High-sensitivity W-band MMIC radiometer modules," in *1995 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symp. Dig.*, May 1995, pp. 59–62.

[2] D. C. W. Lo, L. Yurjiri, G. S. Dow, T. N. Ton, M. Mussetto, and B. R. Allen, "A W-band direct-detection radiometric imaging array," in *1994 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symp. Dig.*, May 1994, pp. 41–44.

[3] B. Agarwal, A. E. Schmitz, J. J. Brown, M. Le, M. Lui, and M. J. W. Rodwell, "A 1–157 GHz InP HEMT travelling-wave amplifier," in *1998 IEEE Radio Frequency Integrated Circuits (RFIC) Symp. Dig.*, June 1998, pp. 21–23.

[4] S. Weinreb, T. Gaier, R. Lai, M. Barsky, Y. C. Leong, and L. Samoska, "High-gain 150–215 GHz MMIC amplifier with integral waveguide transitions," *1999 IEEE Microwave Guided Wave Lett.*, vol. 9, pp. 282–284, July 1999.

[5] S. Nam, S. Miya, M. Ozaki, and I. D. Robertson, "A comparison of topologies for single-ended millimeter-wave monolithic amplifier design," in *1998 IEEE MTT-S Int. Microwave Symp. Dig.*, June 1998, pp. 677–680.

[6] D. Mensa, Q. Lee, J. Guthrie, S. Jaganathan, and M. J. W. Rodwell, "Baseband amplifiers in transferred-substrate HBT technology," in *1998 IEEE Gallium Arsenide Integrated Circuit Symp. Dig.*, Nov. 1998, pp. 33–36.

[7] A. Tessmann, W. H. Haydl, T. Krems, M. Neumann, H. Massler, L. Verweyen, A. Hülsmann, and M. Schlechtweg, "A compact W-band variable gain amplifier MMIC with wide control range using dual-gate HEMTs," in *1998 IEEE MTT-S Int. Microwave Symp. Dig.*, June 1998, pp. 685–688.

[8] A. Tessmann, W. H. Haydl, A. Hülsmann, and M. Schlechtweg, "High gain cascode MMIC's in coplanar technology at W-band frequencies," *1998 IEEE Microwave Guided Wave Lett.*, vol. 8, pp. 430–431, Dec. 1998.

[9] W. H. Haydl, A. Tessmann, K. Züfle, H. Massler, T. Krems, L. Verweyen, and J. Schneider, "Models of coplanar lines and elements over the frequency range 0–120 GHz," in *Proc. 26th Eur. Microwave Conf.*, Sept. 1996, pp. 996–1000.

[10] T. Krems, A. Tessmann, W. H. Haydl, C. Schmelz, and P. Heide, "Avoiding cross talk and feedback effects in packaging coplanar MM-wave circuits," in *1998 IEEE MTT-S Int. Microwave Symp. Dig.*, June 1998, pp. 1091–1094.