COMPACT MONOLITHIC COPLANAR 94 GHZ FRONT ENDS

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Abstract

Fully integrated W-band 94 GHz heterodyne receivers in coplanar 0.15 µm AlGaAs/InGaAs /GaAs PM-HEMT technology are described. The MMICs consist of a multistage low noise RF amplifier, a mixer, and an LO buffer amplifier. Balanced diode and single ended resistive HEMT mixers were investigated. A conversion gain of 13 dB and a DSB noise figure of 6.5 dB were obtained with a very compact 1 x 4 mm^2 front end MMIC, employing cascode amplifiers and a balanced rat race diode mixer. The chip size is substantially less than that of any receiver chip published to date.

Introduction

The coplanar technology [1] is increasingly being explored for microwave and millimeter wave MMICs. Its potential lies in reduced chip cost. The IAF has a long tradition in coplanar design of microwave and millimeter wave circuits [2-4]. The development of coplanar systems is however still slowed by the incomplete design data base for coplanar components, especially at W-band frequencies. We have extracted broadband models for coplanar elements such as transmission lines, air bridges and corners, based on experimental test structures [5] . These models are extremely simple and highly accurate. With this in house data base, a number of millimeter wave circuits for front ends have been developed, using a 0.15 µm AlGaAs/InGaAs /GaAs PM-HEMT technology [6-7].
In the past, a number of millimeter wave front ends have been reported [8-10]. Here, we describe 94 GHz front ends which differ from those reported significantly, because we utilize coplanar technology, and make extensive use of chip area saving cascode amplifiers.

Device Technology

A 0.15 µm AlGaAs/InGas//GaAs PM-HEMT technology was used, which produced devices with a typical g_m of 0.8 S/mm, a maximum current density of 0.5 A/mm, an intrinsic f_t of 140 GHz, an f_{max} of 180 GHz, and a threshold of 0.1 Volt. The gates were written by e-beam, and the recess was dry etched. Diodes are HEMTs with source and drain connected. Both common source single gate and dual gate cascode HEMTs were used. The cascode HEMT, which can be considered to be a series connection of a common source single gate HEMT and a common gate single gate HEMT, sharing the same chip area, has the advantage of being small in size. It requires however a higher drain voltage, and an additional second gate supply. Typical values for our cascode HEMTs are 4 V on the drain, 2.3 V on gate 2, and 0.3 V on gate 1. Cascode amplifiers thus provide about twice the gain as single gate amplifiers, for the same chip area. Noise figure and power performance are similar. The layout of a typical cascode HEMT embedded in a 50 µm coplanar (ground to ground) environment is shown in Fig. 1.

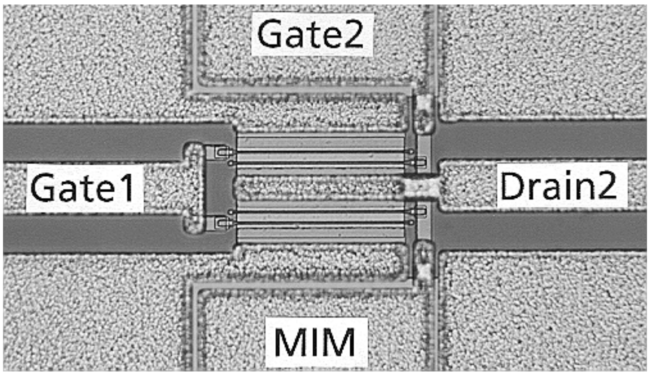

Fig. 1: Cascode dual gate HEMT in 50 Ω coplanar line with 50 µm ground to ground spacing.

Coplanar Technology

Complex multifunction millimeter wave circuits require precise models, not only for the active, but also for the passive components. We have developed an experimental method which provides equivalent circuit models of high accuracy for application over the 10-120 GHz frequency range [5]. The method consists of generating test structures, incorporating a sufficient number of the coplanar elements to be studied, and

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fitting an equivalent circuit to the data. Figure 2 illustrates this for the case of an air bridge over the center conductor. Here a large number of air bridges and short sections of 50 Ω coplanar lines, with 50 µm ground to ground spacing, are connected in series. From S-parameter measurements and analysis with a circuit simulator (Hewlett Packard MDS), we determined an equivalent circuit. A single air bridge can be described as a transmission line with the parameters Z_o=33 Ω and ε_{reff}=8.8, compared to Z_o=50 Ω and ε_{reff}=6.3 for the plain transmission line. The fundamental properties of the coplanar lines were obtained from EM simulations, using the Hewlett Packard HFFS simulator.

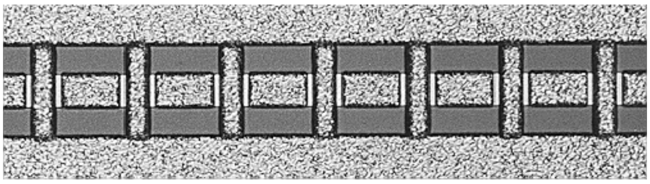

Fig. 2: Test structure of air bridges over 50 Ω coplanar line with 50 µm ground to ground spacing.

Circuits

Using the area saving cascode HEMT, multistage amplifiers were developed. A 2-stage cascode amplifier (which can be viewed as an equivalent 4-stage single gate amplifier) is illustrated in Fig. 3, occupying an area of 1x1.5 mm^2. Its S-parameter performance is shown in Fig. 4. Cascode amplifiers are more difficult to stabilize, since the S_{22} of the cascode HEMT is >1 at frequencies above about 50-70 GHz. Typical gains of 2-stage cascode amplifiers were 15-20 dB at 94 GHz, with a DBS (double side band) noise figure of 5.5-6.5 dB. The saturated output power of the amplifier is 10 dBm, with the P_{-1dB} point at +7 dBm.

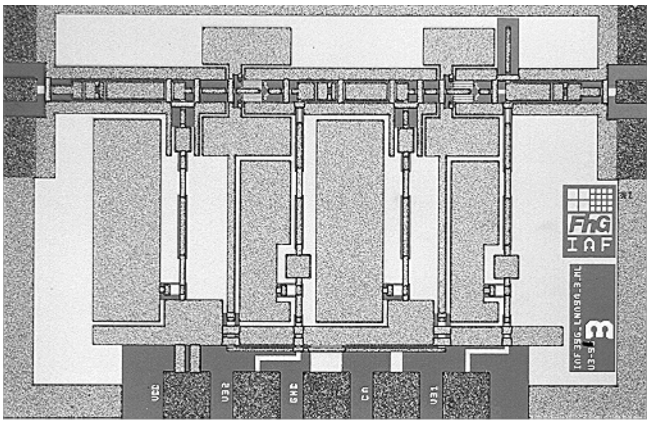

Fig. 3: Two-stage coplanar cascode amplifier. The chip size is 1x1.5 mm^2.

A single stage version of this cascode amplifier, providing 10 mW of output power to the mixer, was used in the LO path.

Various HEMT and diode mixers, such as balanced diode, gate, and resistive, were designed at 94 GHz in coplanar technology. The design was performed with in house nonlinear HEMT and diode models, using the Hewlett Packard MDS circuit simulator. The coplanar couplers are described in more detail in [8]. Experimental results of the conversion loss of a balanced diode rat race mixer and a single ended resistive HEMT mixer are shown in Fig. 6. The resistive mixer is expected to perform as well as the diode mixer for an optimized HEMT layer structure.

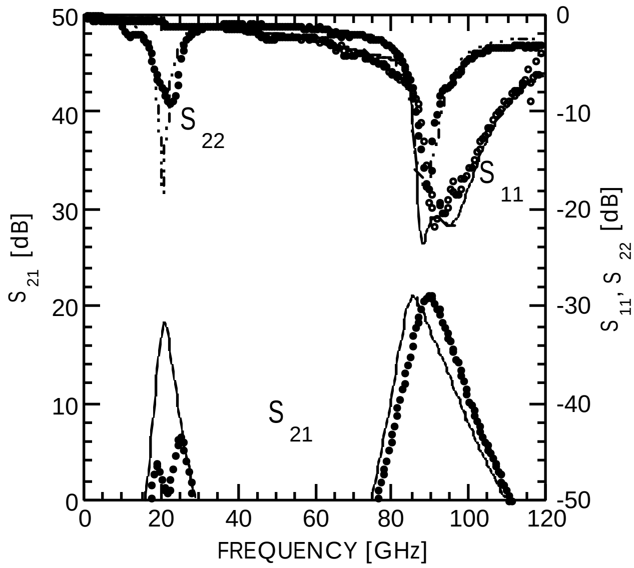

Fig. 4: S-parameters of two-stage coplanar cascode amplifier.

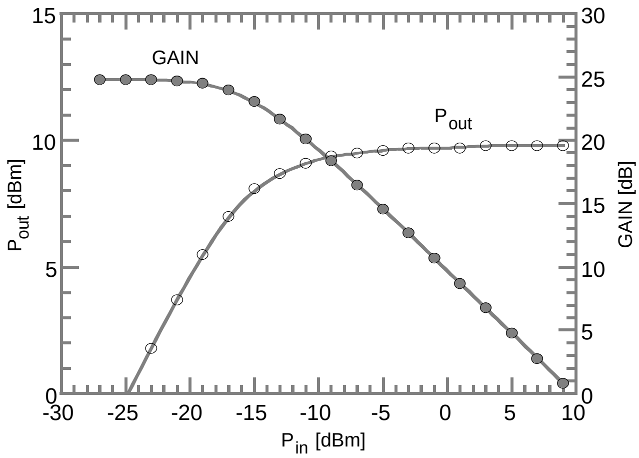

Fig. 5: Output- versus input power of two-stage coplanar cascode amplifier.

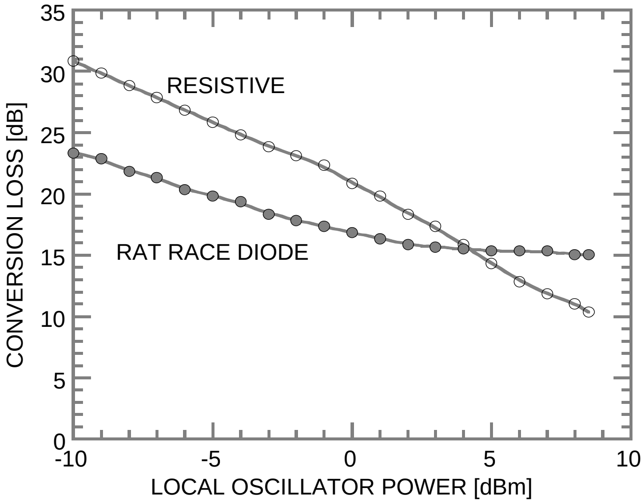

Fig. 6: Performance of balanced diode and single ended resistive HEMT mixers.

Front Ends

A number of front ends [9-11], combining different versions of mixers as well as RF and LO amplifiers, were developed. With the goal of small size and thus low cost in mind, cascode amplifiers were used in the two front ends shown in Figs. 7 and 8. The two front ends shown differ only in the type of mixer used. The two-stage cascode amplifiers, described above, with 20 dB gain and 6 dB noise figure were used in the RF path, and a single-stage version with 10 dB gain in the LO path. Two versions, differing in the tpe of mixer incorporated, are shown in Fig. 7 and 8, and have a size of 1x4 mm^2.

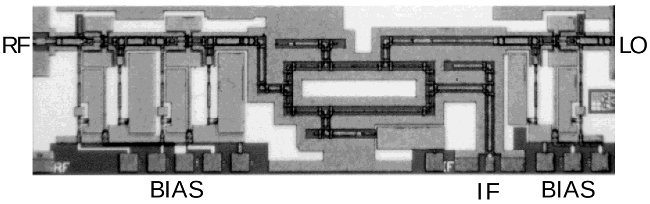

Fig. 7: Coplanar heterodyne front end with two-stage cascode RF amplifier, balanced diode mixer , and one-stage cascode LO amplifier.

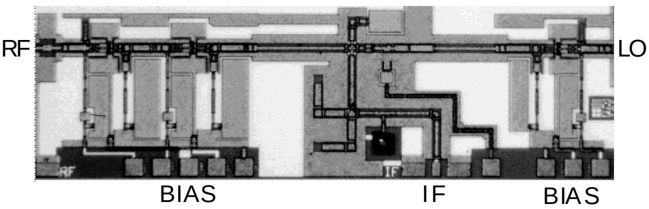

Fig. 8: Coplanar 94 GHz heterodyne front end with two-stage cascode RF amplifier, single ended resistive HEMT mixer, and one-stage cascode LO amplifier.

A single chip, dual channel front end, with RF inputs from two antennas and one from the LO, is shown in Fig. 9. It is made up of two receivers, as shown in Fig. 7, and an additional 3 dB Wilkinson power divider in the LO path. The total chip size is 2x4 mm^2.

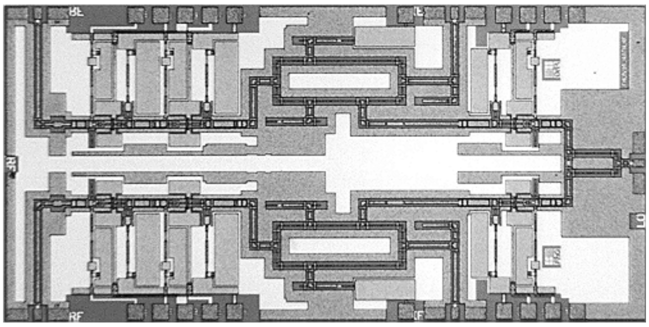

Fig. 9: Dual channel coplanar heterodyne front end with balanced diode mixer and 3 dB power divider in the LO path.

The electrical performance, measured on wafer, of the dual channel front end MMIC is shown in Fig. 10, where the conversion gain and the DBS noise figure of the two channels are plotted as a function of the LO input power at the Wilkinson divider.

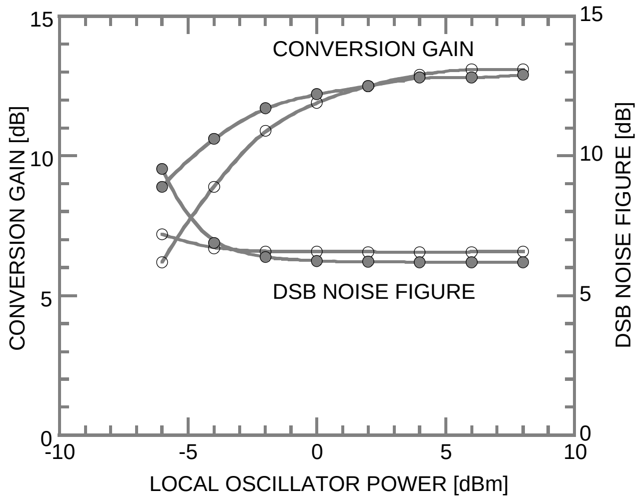

Fig. 10: Performance of the individual channels of the dual channel coplanar heterodyne front end MMIC.

The packaged receiver is shown in Fig. 10. Quartz coplanar to microstrip transitions and microstrip lines were used to couple the chip to the W-band waveguides. Commercial low noise IF amplifiers were incorporated in the package. The wire bonds from the MMIC to the quartz lines were coplanar bonds as described in [12,13], having a length of less than 150 µm, with an estimated loss of about 1 dB per bond

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at 94 GHz. The finished module had a conversion gain of more than 30 dB and a noise figure of 7.5 dB.

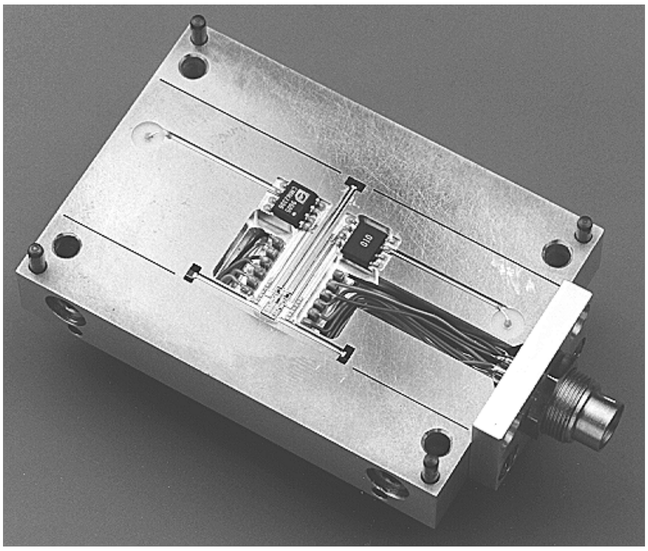

Fig. 11: Assembled dual channel front end.

Conclusion

Using 0.15 µm PM-HEMT and coplanar technologies, we have demonstrated the feasibility of single and dual channel 94 GHz heterodyne front ends. Through the use of cascode amplifiers, the chip size was considerably reduced.

Acknowledgement

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References:

[1] R. Majidi-Ahy, M. Riaziat, C. Nishimoto, M. Glenn, S. Silverman, S. Weng, Y. C. Pao, G. Zdasiuk, S. Bandy, Z. Tan, " 5-100 GHz InP CPW MMIC 7-section amplifier," IEEE Microwave and Millimeter Wave circuits Symposium Digest, p. 31-34, 1990.

[2] W. H. Haydl, W. Heinrich, R. Bosch, M. Schlechtweg, P. Tasker, J. Braunstein, "Design data for millimeter wave coplanar circuits", 23rd European Microwave Conference, pp. 223-228, Sept. 1993.

[3] M. Schlechtweg, W. H. Haydl, A. Bangert, J. Braunstein, P. J. Tasker, L. Verweyen, H. Massler, W. Bronner, A. Hülsmann, K. Köhler, "Coplanar Millimeter-wave IC's for W-band applications using 0.15 µm pseudomorphic MODFET's ", IEEE Journal of Solid-State Circuits, pp. 1426-1434, Oct. 1996.

[4] M. Schlechtweg, W. H. Haydl, J. Braunstein, P. J. Tasker, A. Bangert, W. Reinert, L. Verweyen, H. Massler, J. Seibel, K. H. Züfle, W. Bronner, T. Fink, A. Hülsmann, P. Hofmann, G. Kaufel, K. Köhler, B. Raynor, J. Schneider "110 GHz amplifiers based on compact coplanar W-band receiver technology ", 1995 IEEE GaAs IC Symposium, pp. 214-217, Oct./Nov. 1995.

[5] W. H. Haydl, A. Tessmann, K. Züfle, H. Massler, T. Krems, L. Verweyen, J. Schneider, "Models of coplanar lines and elements over the frequency range 0-120 GHz", 26th European Microwave Conference Proceedings, pp. 996-1000, Sept. 1996.

[6] A. Bangert, M. Schlechtweg, M. Lang, W. Haydl, W. Bronner, T. Fink, K. Köhler, B. Raynor, "W-band MMIC VCO with a large tuning range using a pseudomorphic HFET", IEEE 1996 MTT-S Digest, pp. 525-528, June 1996.

[7] M. Schlechtweg, W. Reinert, A. Bangert, J. Braunstein, P. J. Tasker, R. Bosch, W. H. Haydl, W. Bronner, A. Hülsmann, K. Köhler, J. Seibel, R. Yu, M. Rodwell, "High performance MMICs in coplanar waveguide technology for commercial V-band and W-band applications ", IEEE 1994 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, pp. 81-84.

[8] L. Verweyen, W. H. Haydl, A. Tessmann, H. Massler, T. Krems, J. Schneider, "Coplanar branch-line and rat-race couplers for W-band applications", 26th European Microwave Conference Proceedings, pp. 602-606, Sept. 1996.

[9] K. W. Chang, G. S. Dow, H. Wang, T. H. Chen, K. Tan, B. Allen, J. Berenz, J. Wehling, R. Lin, "A W-band single-chip transceiver for FMCW radar," IEEE 1993 Microwave and Millemeter-Wave Monolithic Circuits Symposium, pp. 41-44, June 1993.

[10] D. C. W. Lo, K. W. Chang, R. Lin, E. W. Lin, H. Wang, M. Biedenbender, G. S. Dow, B. R. Allen,"A single-chip W-band transceiver with front-end switching receiver for FMCW radar applications", IEEE 1995 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, pp. 225-228, May 1995.

[11] M. Camiade, C. Dourlens, V. Serru, P. Savary, .J. C. Blanc, "Highly integrated and compact W-band front-end for radiometry applications", IEEE 1995 GaAs IC Symposium Digest., pp.230-233,1995.

[12] T. Krems, W. H. Haydl, L. Verweyen, M. Schlechtweg, H. Massler, J. Rüdiger, "Coplanar bond wire interconnections for millimeter wave applications", IEEE Electronic Performance of Electronic Packaging (EPEP '95) Digest, pp. 178-180, Oct. 1995.

[13] T. Krems, W. H. Haydl, H. Massler, J. Rüdiger, "Millimeter-wave performance of chip interconnections using wire bonding and flip chip", IEEE MTT-S Digest, pp. 247-250, June 1996.