A Monolithic Integrated HEMT Frontend in CPW Technology from 10 - 50 GHz for Measurement Systems or Broadband Receivers

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Abstract

In this paper the design, performance and fabrication of a broadband frontend is shown. The frontend consists of a broadband matrix distributed amplifier with a gain of about 10 dB and a noise figure of 6.5 dB, a four stages distributed amplifier with 5 dB gain and an output power of 12 dBm, and a distributed mixer with a conversion gain of 0 dB with a LO-power of 0 dBm including the LO buffer amplifier. The active devices are 0.2 µm recessed gate AlGaAs-HEMTs and the coplanar waveguide is used as the propagation medium. The devices have been simulated by using own models for the active device and the passive coplanar elements. For the mixer design a nonlinear HEMT model was used. The total size of the frontend is 6 mm x 6 mm including bias networks and block capacitors.

Introduction

The need of very broadband devices for measurement systems and other broadband applications up to the mm-wave range forced us to develop different circuits that can be used in a very broadband frontend. A distributed buffer amplifier, a matrix distributed amplifier and a broadband mixer including a broadband combiner feeding the LO and RF signals to the mixer have been developed. The devices are connected by wire bonding. Fig. 1 shows the block diagram and Fig. 2 a photograph of the frontend. The coplanar waveguide technology (CPW) is used as the propagation medium in the frontend because of its low dispersion, low radiation loss and easier ground plane access. For the circuit design the CPWs were modeled by ideal lossy transmission lines and the propagation constant and the loss factor were estimated from measurements of 30 Ω, 50 Ω and 70 Ω CPW transmission lines [1]. The passive components used in the amplifier design, like inductors, capacitors and resistors, have been simulated with equivalent circuit elements, which were also extracted from measurements. A simple equivalent circuit model has been chosen for the coplanar T-junctions [2].

The wafers were processed at the Fraunhofer Institute for Applied Solid State Physics (IAF) in Freiburg, Germany. To verify the simulation results on-wafer measurements have been performed.

Active Device

The active devices are enhancement AlGaAs/GaAs HEMTs. The gates have a length of 0.2 µm. The transit frequency of a 2 x 25 µm wide HEMT is 63 GHz with a g_{max} of 6.3 dB at 60 GHz. The circuit is passivated with 0.2 µm SiN. Spiral induc-

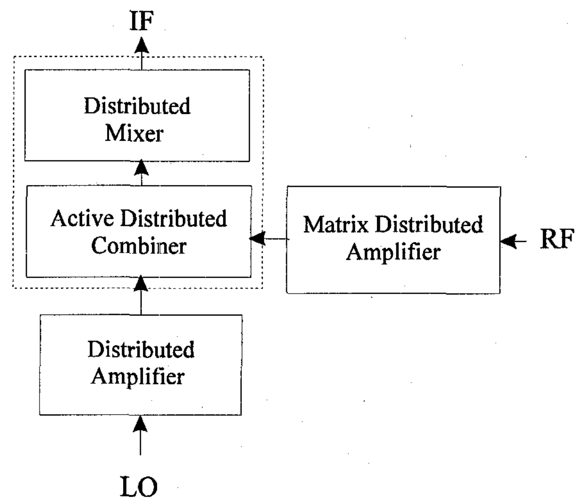

Fig. 1: Block diagram of the 10-50 GHz frontend.

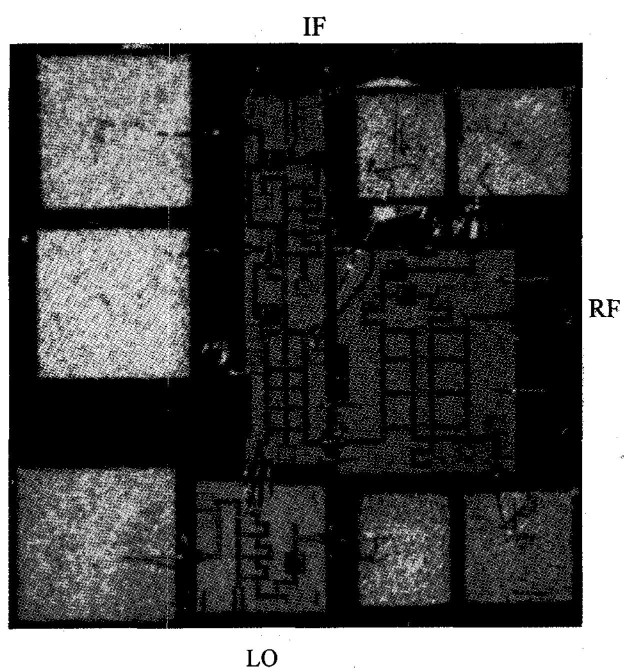

Fig. 2: Photograph of the 10-50 GHz frontend.

tors, MIM capacitors and thin film NiCr resistors are used. For the linear simulation a small-signal equivalent HEMT model, scalable to the gate width was used [3],[4]. The equivalent circuit elements of the HEMT devices have been extracted by "hot" and "cold" S-parameter on-wafer measurements. Additionally a nonlinear HEMT model was used to simulate the nonlinear circuit [5],[6].

Circuit Design

Distributed Amplifier

A four section distributed amplifier [7] was designed for a buffer/driver amplifier for the LO-port of the distributed mixer described later.

The distributed amplifier has been simulated with the program LIBRA™ from EESOF Inc, in which user defined models for the HEMT device (small and large signal) and the passive components were implemented. The tradeoff between high gain-bandwidth product and small chip size resulted in a four section distributed amplifier design. The gate and drain bias networks are integrated on the MMIC.

Fig. 3 shows an average gain of 5.5 dB up to 50 GHz and an input return loss of less than 10 dB. An output return loss of less than 10 dB is also shown in Fig. 3. The agreement between simulation and measurement is very well.

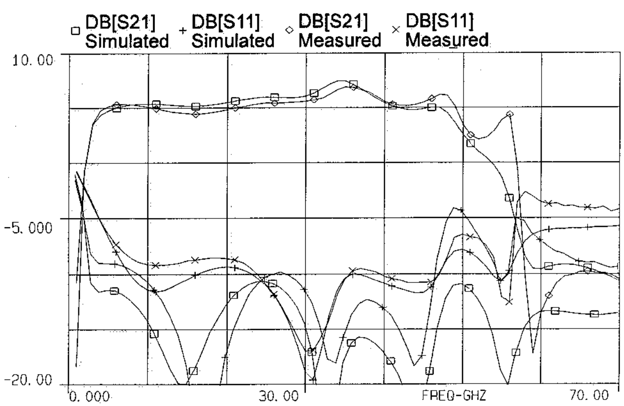

Fig. 3: Measured and simulated S-parameters of the buffer amplifier.

Output power measurements have been done and were compared to the simulations with our nonlinear HEMT model. Fig. 4 shows the harmonics of the distributed amplifier. In the linear region the higher harmonics are more than 20 dB below the fundamental frequency.

Matrix Distributed Amplifier

A matrix distributed amplifier has been fabricated with a noise figure of about 6.5 dB and a gain of more than 10 dB. The operating frequency range of this amplifier is 2 to 52 GHz and the input/output return loss is less than -12 dB. The reverse isolation is greater than 20 dB up to 52 GHz.

The advantages of the matrix distributed amplifier over a cascaded distributed amplifier are better return losses, higher gain and smaller chip size [8].

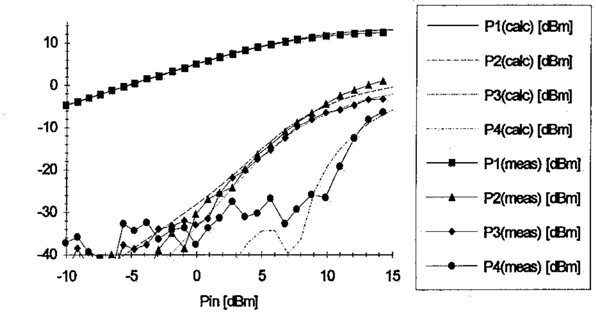

Fig. 4: Harmonics of the distributed amplifier at an input frequency of 10 GHz.

The amplifier was designed as a 2 stage 4 section device to get a high gain bandwidth product and a small chip size of only 2 mm x 2.5 mm [9]. Fig. 5 shows the measured and the calculated S-parameters of the matrix amplifier. The noise figure is presented in Fig. 6 and the output power and the harmonics in Fig.7 [10].

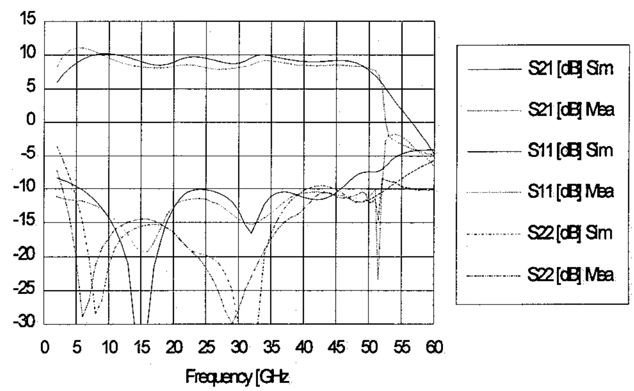

Fig. 5: Measured and simulated s-parameters of the matrix distributed amplifier.

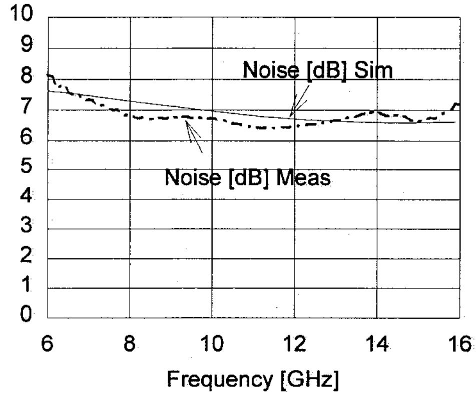

Fig.6: Noise figure of the matrix distributed amplifier

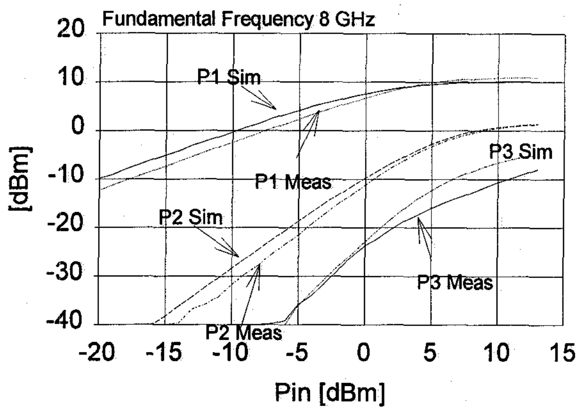

Fig. 7: Harmonics of the matrix distributed amplifier.

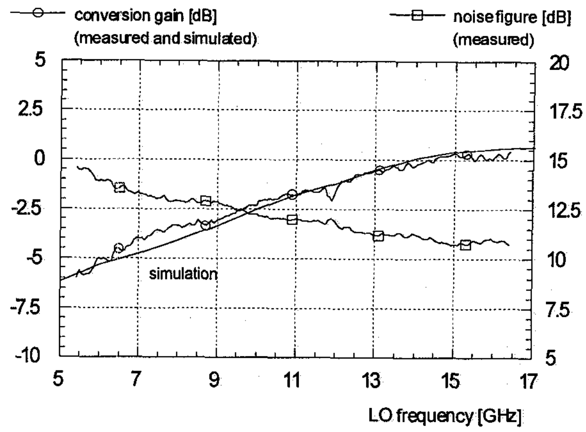

Fig. 9: Measured noise figure and gain of the distributed mixer.

Distributed Mixer

The design of the distributed mixer is based on a distributed amplifier circuit [11]. The RF and LO signals are injected together into the gate line. The IF signal passes a low-pass filter at the output on the drain line. The HEMT devices are biased near pinch-off. For ideal mixer operation the phase constants of the transmission lines have to fulfill the equation

$$\beta_{gate}(f_{LO}) - \beta_{gate}(f_{RF}) = \beta_{drain}(f_{IF}) \quad (1)$$

to maximize the conversion gain. This can be accomplished in a wide RF frequency range due to the very low dispersion of the CPWs. The lumped inductors are realized by high-impedance transmission lines.

An active combiner has been chosen for the RF and LO signals, because of having gain, improved isolation and lower noise figure as compared to passive combiners.

The active combiner and the distributed mixer have been integrated on a single chip. The mixer with different LO and RF input ports has been designed including bias networks with joined drain bias and gate bias for both the combiner and the mixer part. Fig. 8 shows the conversion gain, Fig. 9 the noise figure of the distributed mixer for a constant IF-frequency of 4.5 GHz.

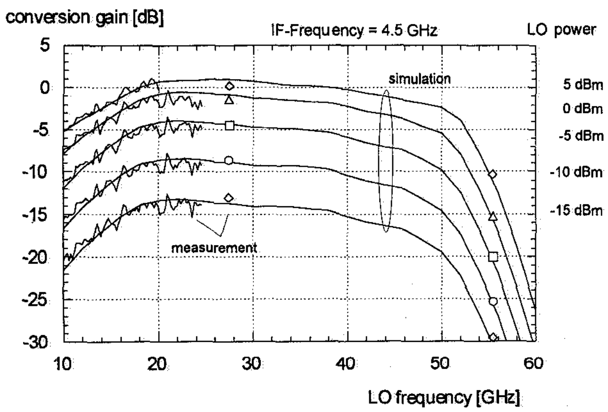

Fig. 8: Conversion gain of the distributed mixer.

Broadband Frontend

To build the frontend, the chips were mounted on a gold plated substrate and connected by wire bonding, Fig. 2. The bias lines were connected via single layer capacitors to decouple the DC-sources from the RF-devices. The frontend has been measured with a CASCADE prober and a HP7000 spectrum analyzer. Fig. 10 shows the comparison between the measured and the simulated conversion gain of the frontend including all bias networks. The conversion gain of the frontend is more than 8 dB and the mixer is usable up to 50 GHz with a conversion gain of more than 0 dB. Due to the noise figure of the input matrix amplifier of 6.5 dB the noise figure of the frontend should be less than 7 dB. The dimensions are 6 mm x 6 mm^2 including the bias networks and the block capacitors.

Conclusions

A very broadband frontend in coplanar waveguide technology for measurement systems or other broadband applications has been developed. The different devices have been fabricated by using 0.2 µm AlGaAs-HEMT with a total gatewidth of 50 µm. A buffer amplifier with 5 dB gain and 12 dBm maximum output power, a matrix distributed amplifier with more than 10 dB gain and a noise figure less than 6.5 dB and a distributed mixer with 0 dB conversion gain and a noise figure of less than 12 dB have been fabricated. The devices were connected with bond wires and biased via additional capacitors.

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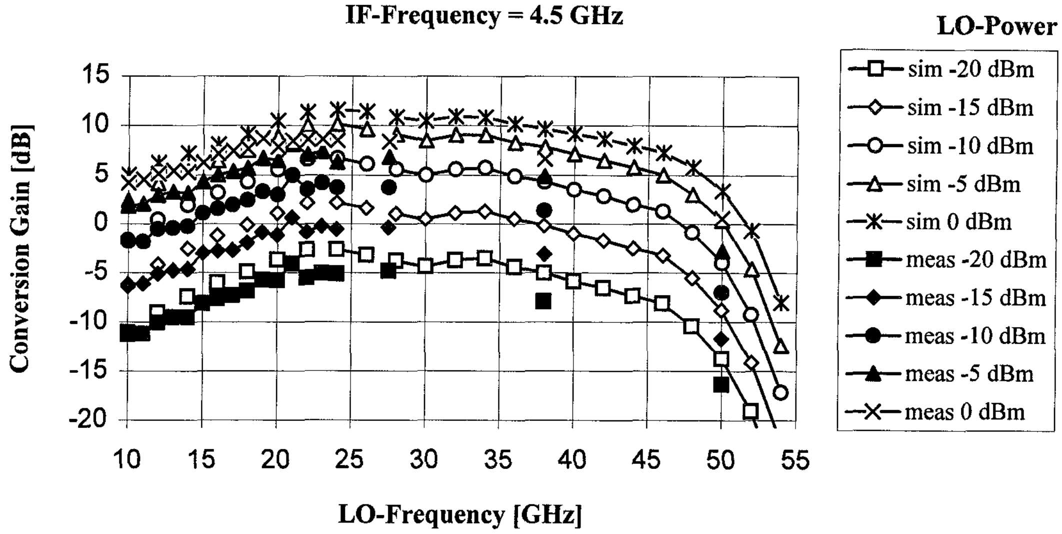

Fig. 10: Conversion gain of the broadband frontend.

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