# $K_a$- AND V-BAND MMIC COMPONENTS FOR PERSONAL COMMUNICATION NETWORKS

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*Summary:* The "wireless revolution" has created a number of new opportunities not only at lower microwave communication frequencies at 0.9GHz and 1.8GHz, but also at millimeterwave frequencies. The 38± 2GHz frequency range has emerged as an internationally accepted frequency band for typical radio applications with a promising market for transmit and receive modules in the next years. Another frequency allocation has been granted for mobile broadband communication networks in the 62GHz to 66GHz band aiming to extend the scope of the broadband integrated services digital networks (B-ISDN). This system is envisaged to give mobile users access to future broadband services like speech, data, and video. In order to produce radio-frontends for these communication systems, low cost, reliable, high performance components in monolithic form are a basic necessity. This paper describes GaAs technologies developed at Daimler-Benz which can serve the needs and requirements of wireless millimeterwave communication systems at $K_a$- and V-band frequencies. Based on different available technologies (HBT, Schottky diodes, MESFET, PM-HFET) oscillators, low-noise amplifiers, medium power amplifiers, variable-gain amplifiers, single-gate mixers, dual-gate mixers, and diode mixers have been fabricated and will be described.

## INTRODUCTION

For mm-wave communication systems volume applications arise at 38GHz for the interconnection of cells for personal communication networks (PCNs) and around 60GHz for short range mobile vehicle to beacon communication [1-3]. Millimeter-wave radio links for point-to-point communication in PCNs, particularly for intercom of base stations for mobile phone telephone systems, are already being installed [4]. Based on advanced III/V semiconductor devices and integration technologies components are becoming available which establish the basis for the use of millimeterwave systems in first volume applications. Key factors to seize the new opportunities are technical performance and especially cost, the latter one essentially determining the access to volume markets.

This paper demonstrates the potential of the technologies now available at Daimler-Benz for the realization of specific monolithic components for $K_a$- and V-band PCNs. The performance of a whole set of MMICs (Monolithic Millimeter-wave Integrated Circuits) for both 38GHz and 60GHz applications will be described in detail.

## TECHNOLOGIES FOR $K_A$-BAND AND V-BAND MMICS

For frequencies up to 40GHz a well established 0.25µm MESFET process is available. In addition 0.25µm HFET-technology, especially the pseudomorphic (PM) HFET, is excellently suited at $K_a$-band and even higher frequencies. Although standard HFET technology with quarter micron gates has proved to be applicable even at 60GHz [5], the pseudomorphic material based on a single-side planar doped AlGaAs/GaInAs/GaAs hetero-junction structure has succeeded to be the first choice especially above 40GHz due to its high sheet carrier concentration which is about twice as high when compared to standard AlGaAs/GaAs devices [6]. High power density, high cutoff frequencies, state-of-the-art low noise performance and a low dependence of the noise figure on the drain-source current make PMHFETs excellently suited for the realization of various circuit functions [7-9]. To achieve higher gain at mm-wave frequencies especially at 60GHz and above the gate length of PMHFETs has been reduced further. To



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maintain low gate resistance a T-shaped gate cross section is chosen, for high reproducibility and homogeneity an etch stop layer for the gate recess step has been developed by Daimler-Benz and Thomson CSF within the CLASSIC program sponsored by the European Community [10]. The layer sequence which is used is an optimized delta doped single heterojunction structure grown by MBE. The characteristic DC-, RF-, and noise data for MESFETs and HFETs (gate width is 120μm) are summarized in Table 1. Heterojunction bipolar transistors are known to have low baseband noise when compared to MESFET or HFET devices. Therefore the HBT is an excellent candidate as active element in low phase noise mm-wave oscillators. The main high frequency characteristics of an HBT with an emitter area of $40\mu m^2$ are given also in Table 1.

## $K_a$- AND V-BAND MMICs

Based on the developed processes the circuits necessary for T/R-modules have been designed, fabricated and tested. All designs have been carried out at the microwave design center at Daimler-Benz Aerospace in Ulm. Commercially available software packages as well as in-house developed software has been used for linear, non-linear, and electromagnetic simulation. For the active devices linear, noise, and large-signal models are available.

***$K_a$*-band oscillators:** Oscillators have been designed by using a source feedback configuration for high frequency stability. To obtain low phase noise dielectric resonator stabilized oscillators (DROs) have been realized as well as voltage controlled oscillators (VCOs) with a varactor diode placed between the transistor base and ground for tuning. Monolithic $K_a$-band DROs based on PMHFET material have shown output powers of 11dBm and a phase noise as low as -97dBc/Hz at 100kHz off carrier [11]. The temperature dependence of output power and frequency is as low as -0.02dB/°C and -60kHz/°C, respectively.

A monolithic 38GHz frequency source consisting of a varactor tuned oscillator and a buffer amplifier has been fabricated in MESFET technology on one chip [12]. The adjustable tuning range of the source is more than 1GHz, two independent varactors allow good frequency linearity and compensation of temperature drift. The oscillator-amplifier chain delivers more than 18dBm of output power over the entire tuning range.

***$K_a$*-band amplifiers:** In the transmitting and receiving parts of communication systems amplifiers occur for low-noise or medium power amplification or as gain control blocks. Gain controllable amplifiers can be easily realized by using a dual-gate transistor which has a high dynamic amplification range [13]. The gain then can be adjusted by applying a control voltage at the second gate. At $K_a$-band a gain dynamic of 25dB can be realized without changing the input and output VSWR drastically (maximum gain 18dB from 32-38GHz).

Low-noise amplifiers (LNAs) have been fabricated for a frequency range from 32GHz to 40GHz. A 3-stage LNA has a gain of more than 18dB and a noise figure of 3dB. Output power levels of 100mW and above have been achieved from a two-stage balanced amplifier with Lange couplers at the input and output ports. The gain of this medium power amplifier is 8dB with return loss values of less than -15dB over the whole $K_a$-band (26-40GHz). The output power at 1dB gain compression is higher than 20dB.

***$K_a$*-band mixers:** For $K_a$-band PCN applications different mixer types are available, all of them based on PMHFET material: Schottky diodes, single gate, or dual-gate HFETs are used as the active mixing device. The mixers can be used for upconversion as well as for mixing a RF signal to a desired IF-frequency.

By using PMHFET Schottky diodes in a single balanced mixer configuration the conversion loss at 38GHz is less than 5.5dB for a local oscillator power of 10dBm. Conversion gain can be achieved by using PMHFETs as the mixing element. A single ended gate mixer exhibits a conversion gain of 3-5dB in the 32-38GHz band ($P_{LO}$ = 7dBm) [14]. Dual-gate PMHFET mixers in a single ended configuration show a conversion gain of 4dB at 38GHz. Due to a noise figure of about 10dB the PMHFET mixers are used in combination with a low-noise amplifier in the receiver part of a radio system.

***V-band oscillators:*** Dielectrically stabilized PMHFET oscillators have been fabricated as a LO source in V-band systems. A monolithic DRO in a standard series feedback configuration with the active device in common source operation has been designed, delivering an RF output power of 2.3dBm at 62GHz. The phase noise is -78dBc/Hz at 100kHz off carrier. Fig. 1 shows a chip photograph of the oscillator MMIC. To drive the mixers at optimum conversion gain the DRO output power is amplified by using buffer amplifiers.

***V-band amplifiers:*** For application in the mobile broadband system LO- and RF-buffer amplifiers, low-noise amplifiers, and medium power amplifiers have been developed within the CLASSIC program. A two-stage buffer amplifier for 57GHz (BW = 2GHz) has a gain of 6.5dB and shows an output power of 11.5dBm at 1dB compression. A three-stage amplifier for 62-66GHz operation delivers an output power of 11dBm at a RF gain of at least 8.3dB. Input and output return loss is better than 10dB in each case. For low-noise amplification a four-stage chip has been designed (Fig. 2). At 62GHz a gain of 19dB with excellent noise behaviour (NF <3.5dB) has been obtained.

***V-band mixers:*** Quarter micron Schottky diodes have been used as the mixing element in single- and double-balanced up- and down-converters [15,16]. Fig. 3 shows a single sideband upconverter, which is composed of two balanced upconverters.To achieve the necessary bandwidth and the isolation between ports two Lange couplers are used at the IF and RF ports. The LO signal is applied through a Wilkinson divider. According to the MBS specifications the IF signal between 5.2GHz and 9.2GHz is upconverted into the 62-66GHz band.

## CONCLUSION

To meet the requirements for communication systems at 38GHz or 60GHz a set of monolithic integrated circuits has been fabricated at Daimler-Benz. State-of-the-art results have been achieved. Transmit and receive modules for application in 38GHz PCNs are under development at Daimler-Benz Aerospace. Detailed results on a realized demonstrator for high data rate mobile broadband communication networks are also submitted for presentation at the IEEE MTT-S Symposium [17].

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| Device | $g_{m\,max}$ [mS/mm] | $I_{ds\,max}$ [mA/mm] | $f_T$ [GHz] | $f_{max}$ [GHz] | $F_{min}$ [dB] | $G_{ass}$ [dB] |
|---|---|---|---|---|---|---|
| 0.25µm MESFET | 300 | 250 | 40 | 80 | 1.2 @12GHz | 8 @12GHz |
| InGaP/GaAs HBT | - | - | ≥50 | ≥90 | - | - |
| 0.25µm PMHFET | 600 | 650 | 40-100 | 100-130 | ≤0.8 @18GHz | 12 @18GHz |
| 0.15µm PMHFET | 700 | 700 | 100 | ≥200 | 1.8 @60GHz | 6 @60GHz |

Table 1: Characteristic DC-, RF-, and noise data for millimeter-wave devices.

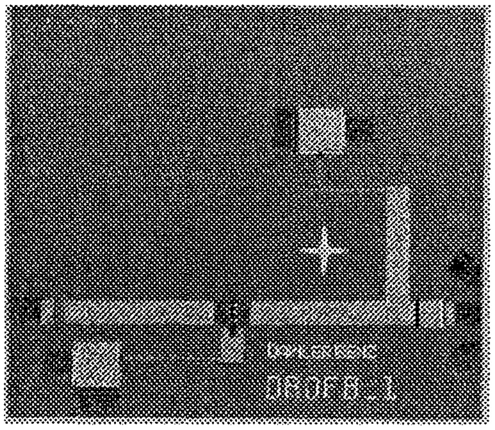

Fig. 1: Chip photograph of a dielectrically resonator stabilized oscillator for V-band (chip-size: 1.9 x 2.2mm$^2$).

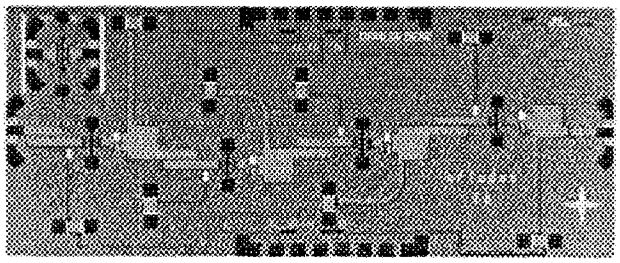

Fig. 2: Low-noise V-band amplifier chip (chip-size: 4.2 x 1.8mm$^2$).

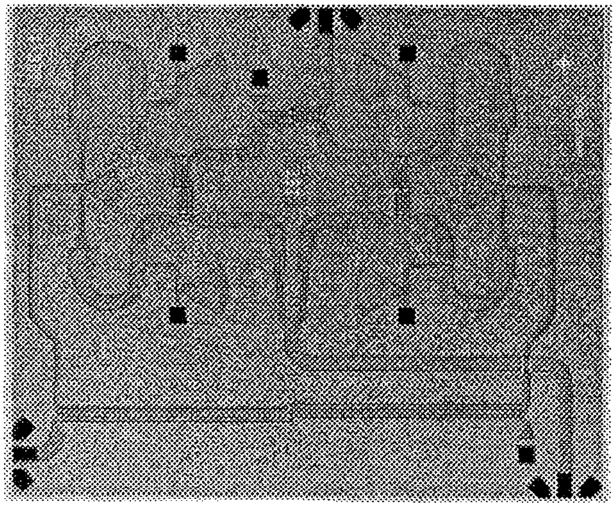

Fig. 3: Schottky diode single sideband upconverter ($f_{IF}$=5.2-9.2GHz, $f_{RF}$=62-66GHz, chip-size: 4.7 x 3.9mm$^2$).