An 18–22-GHz Down-Converter Based on GaAs/AlGaAs HBT-Schottky Diode Integrated Technology

K. W. Kobayashi, *Member, IEEE,* L. T. Tran, A. K. Oki, M. Lammert, T. R. Block, and D. C. Streit, *Member, IEEE*

***Abstract*— Here we report on a K-band AlGaAs/GaAs HBT-Schottky diode down-converter which represents the highest complexity monolithic integrated GaAs HBT-Schottky MMIC so far demonstrated at K-band frequencies. The MMIC integrates a double-balanced Schottky diode mixer with an 18–22 GHz two-stage K-band radio frequency (RF) amplifier, a 6–10 GHz two-stage X-band IF amplifier, and a 12-GHz local oscillator (LO) heterojunction bipolar transistor (HBT) buffer amplifier. The Schottky diodes are constructed from the existing GaAs HBT base and collector vertical epitaxy layers and can be easily fabricated with only one additional mask processing step. The double-balanced Schottky mixer provides high IP3 and high 2-2 spur suppression over a broad band while consuming little dc power. The HBT-Schottky integrated down-converter MMIC achieves $>$16-dB conversion gain over an RF input band from 18–22 GHz and a corresponding IP3 $>$10 dBm with only $+$3 dBm of LO drive. The total chip is 3.85 $\times$ 3.75 mm^2 and can be self-biased through a single 5.5-V supply while consuming 545 mW of dc power. The use of GaAs HBT vertical-Schottky-diode technology has inherent performance advantages for frequency conversion MMIC's.**

I. Introduction

THE high-frequency operation, high IP3 performance, and low dc bias characteristics of Schottky-diode mixers make them attractive for high-performance frequency conversion applications and have been preferred over active mixer approaches where cost and size is not an issue. The earlier development of GaAs MESFET- and HEMT-based MMIC technologies has lead to the use of the planar gate-source/drain Schottky diode to provide monolithically integrated Schottky mixers in MMIC receiver applications.

Parasitic resistances and capacitances of the field-effect transistor (FET) planar Schottky-diode structure, however, have limited the Schottky cutoff frequency well below 500 GHz [1]. With an HBT MBE technology, low parasitic HBT vertical Schottky diodes can be constructed from existing HBT MBE layers, which can obtain cutoff frequencies of 1 THz. This low parasitic HBT vertical Schottky diode can result in improved mixer performance. For example, an experimental comparison of an X-band double–double balanced mixer fabricated with both GaAs HEMT planar Schottky diodes and GaAs-HBT vertical Schottky diodes concluded that the HBT vertical Schottky diodes could achieve comparable or better conversion gain and IP3 performance *while requiring 3 dB less LO drive* [1]. Techniques for reducing the parasitics of the FET planar Schottky using a buried implantation [2] or integrating a separate vertical MBE diode structure using selective MBE [3] both require a more complex fabrication process and/or material growth. Moreover, it has been recently revealed that the vertical MBE HBT-Schottky diode also results in a lower mixer noise figure at IF frequencies compared to a planar HEMT Schottky-diode implementation [4]. This is thought to be related to the lower $1/f$ noise expected from the vertical Schottky diode due to the absence of surface recombination effects commonly encountered in planar FET technologies. The lower $1/f$ noise corner of the vertical HBT-Schottky diodes will allow conversion down to baseband and eliminate the need for an additional frequency converter which would increase the complexity and dc power of the system.

In this letter, we describe the performance of a GaAs HBT down-converter MMIC that integrates vertical Schottky diodes constructed of the existing vertical GaAs HBT epitaxy structure. While a GaAs HBT-Schottky X-band down-converter has been recently reported [5], the present work describes a K-band down-converter that relies on a new 1-μm GaAs HBT process with enhanced f_T's and $f_{\max}$'s of 43 and 65 GHz, respectively, in order to provide the required device gain to accommodate the higher K-band HBT RF amplifier designs. Moreover, this work represents the highest complexity GaAs HBT-Schottky down-converter demonstrated at K-band using an integrated GaAs HBT-Schottky IC technology.

II. Merged GaAs 1-μm SABM HBT and Schottky-Diode Technology

The down-converter was fabricated using a 1-μm emitter width self-aligned base ohmic metal (SABM) HBT-device process. The HBT MBE profile is similar to that described for our 2-μm SABM GaAs HBT process [5], except for the use of a thinner base structure in order to obtain higher device gain to support the K-band HBT RF amplifier design. The resulting fabricated 1-μm GaAs HBT's with the thin base material obtain a typical f_T and $f_{\max}$ of 43 and 65 GHz, respectively.

Utilizing the same HBT MBE profile, low parasitic vertical Schottky diodes are also fabricated (see Fig. 1). The Schottky-diode structure is made by wet-chemical etching the emitter and base material away to get to the n$^-$ collector material.

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The authors are with TRW Electronics Systems and Technology Division, Redondo Beach, CA 90278 USA.

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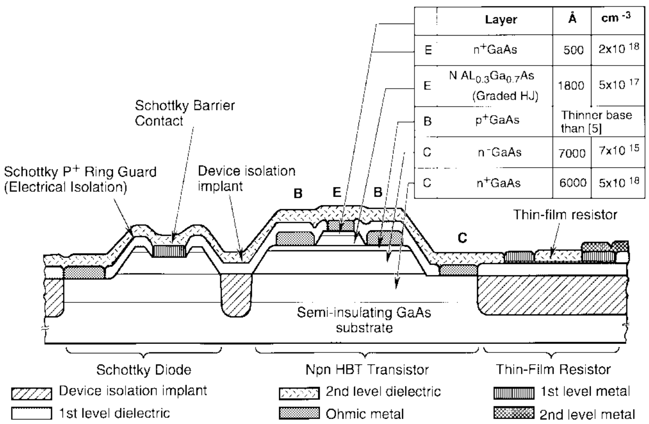
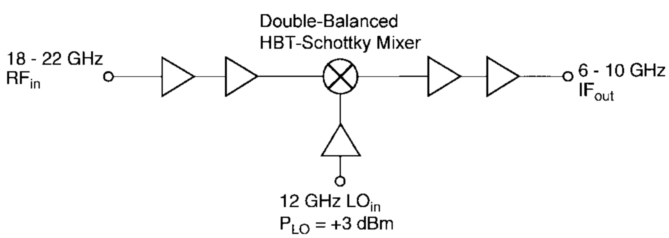


Fig. 1. GaAs HBT-Schottky-diode device MBE profile.



	Nom. Gain Budget			Total
Conv. Gain (dB)	8	-10	20	18
NF (dB)	6.5	10	4.5	9.4
IP3 (dBm)	10	10	13	12

Fig. 2. Schematic and gain budget of the HBT-Schottky integrated down-converter.

A p^+ guard-ring made from the base material is left which surrounds the Schottky diode. This p^+ guard-ring electrically isolates the Schottky diode and reduces the reverse-bias leakage current. The etch continues into the n^- collector region. The Schottky contact is made by evaporating Ti/Pt/Au. The resulting Schottky diodes have ideality factors of nearly 1.0 and a cutoff frequency as high as 1 THz.

III. K-Band GaAs HBT-Schottky Down-Converter Design and Results

Fig. 2 gives the block diagram and gain budget of the HBT-Schottky down-converter. The MMIC down-converter integrates an 18–22-GHz two-stage HBT RF amplifier, a double-balanced GaAs Schottky-diode mixer, a 12-GHz HBT LO amplifier, and a 6–10-GHz two-stage HBT IF amplifier. The double-balanced Schottky mixer consists of four $10 \times 10\,\mu m^2$ Schottky diodes, and broad-band microstrip and lumped-element 180° baluns for the radio frequency (RF) and IF ports, respectively. The conversion gain of the mixer is dependent on the level of local oscillator (LO) power being presented to the diodes. A 12-GHz 10-dB gain LO buffer amplifier is used to reduce the LO port input power requirement to around +3 dBm. A two-stage K-band RF feedback amplifier is required to provide 8–10 dB of gain over the broad 18–22-GHz band to buffer the mixer RF input port. The IF port is followed by a 6–10-GHz two-stage HBT feedback amplifier. Also shown is the gain budget, which gives the nominal gain, NF, and IP3 of each of the individual down-converter components in the RF path. The overall HBT-Schottky-integrated down-converter nominally achieves >18-dB conversion gain, an IP3 = 12 dBm, and a DSB NF of ≈9.5 dB. A preceding K-band HEMT MMIC LNA at the RF input port of the down-converter MMIC could be used to reduce the noise figure and increase the sensitivity of the converter MMIC. Also, a low phase noise HBT VCO/Oscillator can be monolithically integrated with the HBT-Schottky converter MMIC to provide a low phase noise HBT converter MMIC.

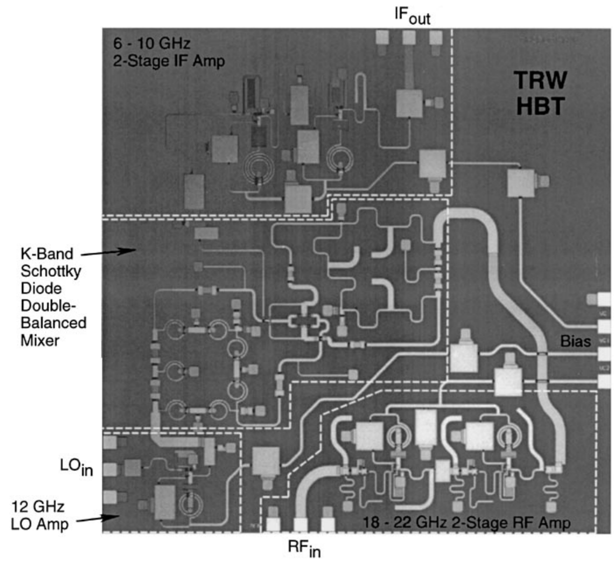


Fig. 3. Microphotograph of the down-converter MMIC.

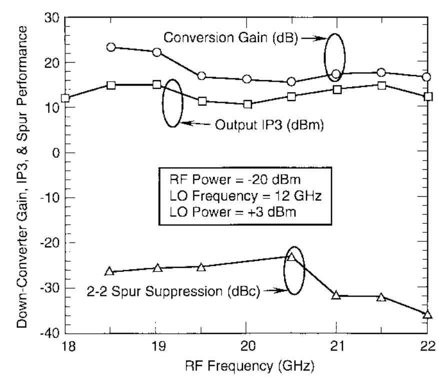


Fig. 4. K-band GaAs HBT-Schottky down-converter MMIC performance.

Fig. 3 gives a microphotograph of the compact GaAs HBT-Schottky integrated down-converter MMIC. The MMIC is self-biased through a 5.5-V supply and consumes 545 mW of dc power. The compact down-converter MMIC is $3.85 \times 3.75\ mm^2$.

The MMIC was fully RF characterized on-wafer for conversion gain, isolation, and spur performance and is given in Fig. 4. The conversion gain is greater than 16 dB across the 18–22-GHz rf input band. The corresponding IP3 is greater than 10 dBm across the same band, with a maximum IP3 of

15 dBm. This IP3 is obtained with a low LO drive of $+3$ dBm. Because of the nearly octave IF frequency band performance of the mixer and amplifiers, 2-2 spur suppression performance is of special interest. Fig. 4 illustrates the 2-2 spur suppression, which is better than 24 dBc across the full 6–10-GHz IF band.

IV. Conclusion

An AlGaAs/GaAs HBT-Schottky diode integrated down-converter was demonstrated at K-band. The MMIC represents the highest complexity HBT-Schottky diode integrated down-converter MMIC so far demonstrated. The Schottky diodes can achieve terahertz frequency performance and are constructed from the existing GaAs HBT base and collector vertical epitaxy layers. The HBT-Schottky down-converter MMIC obtained greater than 16-dB conversion gain over an RF input band from 18–22 GHz and a corresponding IP3 as high as 15 dBm with only $+3$ dBm of LO drive. GaAs HBT vertical-Schottky-diode integrated technology can support the monolithic integration of low phase noise HBT VCO's, high linearity Schottky mixers, and wide-band HBT amplifiers and possess inherent device performance advantages such as low $1/f$ noise, which is attractive for these frequency conversion MMIC functions.

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