A K-Band Subharmonic Down-Converter in a GaAs Metamorphic HEMT Process

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***Abstract* — In this paper, we present the first implementation of a K-band subharmonic down-converter fabricated in a 0.18-μm GaAs Metamorphic High Electron Mobility Transistor (MHEMT) process. The low noise and high gain characteristics of the MHEMTs at K-band allow for the integration of a single-stage amplifier with a subharmonic mixer resulting in low-power broadband performance. The subharmonic mixer exhibits a conversion loss of 13 dB and IIP3 of +8 dBm from 23 to 30 GHz. With the addition of the amplifier, the down-converter exhibits a conversion loss of 3 dB, noise figure of 5 dB, and IIP3 of -5 dBm from 26 to 30 GHz. The single-stage amplifier exhibits InP-like performance with gain of 11 dB, NF of 1.5 dB, and dc power consumption of 15 mW.**

I. INTRODUCTION

The increasing demand for existing millimeter-wave wireless systems, such as Local Multi-point Distribution Systems (LMDS) and emerging applications such as Wireless Local Area Networks (WLAN), has given rise to the development of low-power and high-performance millimeter-wave transceivers. Most commercial millimeter-wave transceivers have utilized GaAs based HEMT and pseudomorphic HEMT processes for their reasonable performance and cost of fabrication. Until recently the only alternative for higher performance was the more expensive InP-based processes. However, due to the high cost of InP substrates and fabrication, InP-based technology had been limited to high-end applications and specialized commercial and military markets. To address this cost limitation, many researchers have pursued the development of metamorphic HEMT (MHEMT) technology, in which high indium material is grown on a GaAs substrate [1,2]. Devices fabricated in the MHEMT process exhibit superior InP-like frequency and noise performance while providing the inherent cost advantage of fabrication on a large-diameter, high-volume GaAs substrate.

In this paper, we present the first implementation of a K-band subharmonic down-converter fabricated in a 0.18-μm GaAs Metamorphic High Electron Mobility Transistor (MHEMT) process. Low noise and high gain of the MHEMT devices at the K-band allow for the integration of a single-stage front-end amplifier with a subharmonic mixer for low-power and broadband performance suitable for LMDS and WLAN applications.

II. CIRCUIT DESIGN

Two Monolithic Microwave Integrated Circuits (MMICs), a subharmonic mixer and a subharmonic down-converter, have been designed and fabricated for K-band applications between 23 to 30 GHz.

A. Subharmonic Mixer

A subharmonic mixer topology was chosen to allow for the use of a lower LO frequency that not only relaxes the constraints of the LO source but also alleviates the concern for LO to RF isolation.

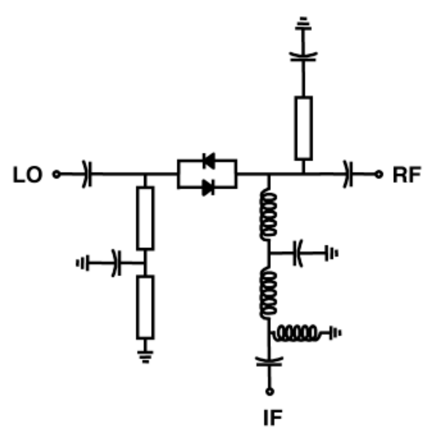


Fig. 1. Circuit schematic of the mixer MMIC.

As shown in Fig. 1, the antiparallel diode pair is used to generate simultaneous doubling and frequency conversion in the mixer [3]. Each diode is implemented by shorting the source and drain of a 4x12.5 μm MHEMT. The diodes have been connected in an antiparallel configuration and terminated by two transmission line stubs that were designed to be quarter-wavelength long at the LO frequency. The transmission lines were designed using a quasi-lumped transmission line technique in order to reduce the physical length while maintaining the quarter wave electrical length [4]. The stub at the LO port was designed to act as an open quarter-wavelength line so that it exhibits high impedance at the LO and low impedance at the RF frequency. The stub at the RF port was designed in the opposite manner to act as a shorted quarter-wavelength so that it exhibits low impedance at the LO and high impedance at the RF frequency. The IF signal is tapped from the RF side through a low-pass filter that allows for rejection of RF and LO signals. The IF port is matched using a high-pass LC network for an IF frequency range of 0.7 to 1.3 GHz.

B. Subharmonic Down-Converter

As shown in Fig. 2, the down-converter is composed of a single-stage amplifier followed by a modified version of the subharmonic mixer described earlier. By taking advantage of the low noise and high gain of a 100-µm periphery MHEMT, a single-stage amplifier with noise figure (NF) of 1.5 dB and gain of 11 dB at 26 GHz is implemented without the use of additional input noise matching. The MHEMT is biased at a drain voltage of 1.5 V and a drain current of 10 mA. Source degeneration is used to stabilize the amplifier and simple input matching is used to improve return loss. The amplifier is mated with the mixer with minor modifications, including the addition of a blocking capacitor to isolate the diodes from the dc bias of the amplifier.

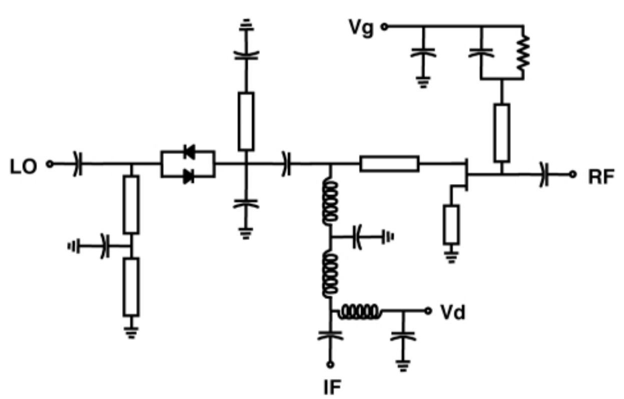
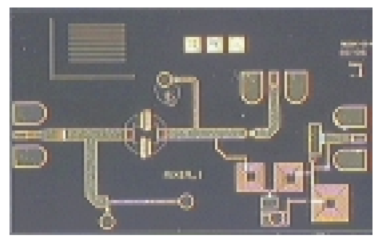


Fig. 2. Circuit schematic of the down-converter MMIC.

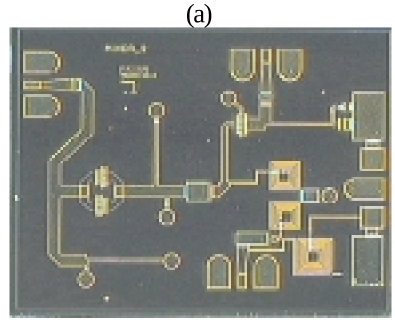
As shown in Fig. 2, the drain bias of the amplifier is fed through the IF matching network and the gate bias is applied through the RF input matching stub of the amplifier.

III. MEASUREMENTS

Figure 3 shows the photographs of the fabricated MMICs. Die size of the mixer and down-converter are 2.4x1.1 mm^2 and 2.3x1.7 mm^2, respectively. The chips were evaluated using on-wafer coplanar RF probes for a RF input frequency range of 23 to 30 GHz, which corresponds to a LO frequency of 10.5 to 14.5 GHz with an IF frequency of 1 GHz. Single- and two-tone measurements were performed to characterize the conversion characteristic and linearity. Figure 4 shows the conversion loss, LO to IF isolation, and 3rd-order input intercept point (IIP3) of the subharmonic mixer.



(a)



(b)

Fig. 3. Photographs of (a) the subharmonic mixer and (b) down-converter MMICs.

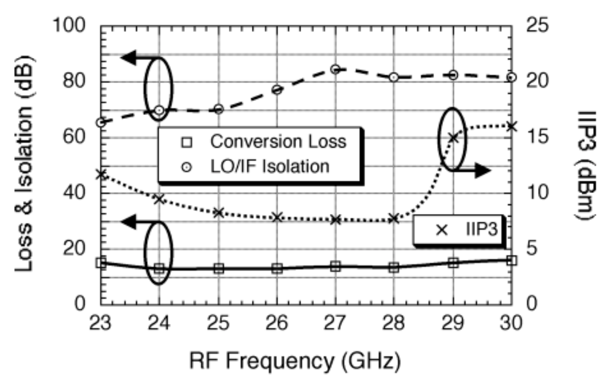


Fig. 4. Performance of the subharmonic mixer with LO power range of 8 to 12 dBm..

Our measurements show a conversion loss of 14 dB, IF return loss of 15 dB, LO to IF of 65 dB, and out-of-band

LO to RF isolation of better than 15 dB. In addition, a 650 MHz conversion bandwidth was observed, proving the mixer to be very suitable for high bandwidth wireless systems.

For the testing of the down-converter, an additional signal-ground-signal dc probe is used to provide the dc bias for the amplifier. The dc probe incorporates 0.1-µF capacitors that help improve RF grounding and prevent low frequency oscillations. Figure 5 shows the conversion loss and IIP3 of the subharmonic down-converter. Figure 6 shows the input reflection of the IF and RF ports. Noise figure of the down-converter is measured to be below 5 dB from 26 to 30 GHz, showing more than 9 dB of improvement over the stand-alone mixer results.

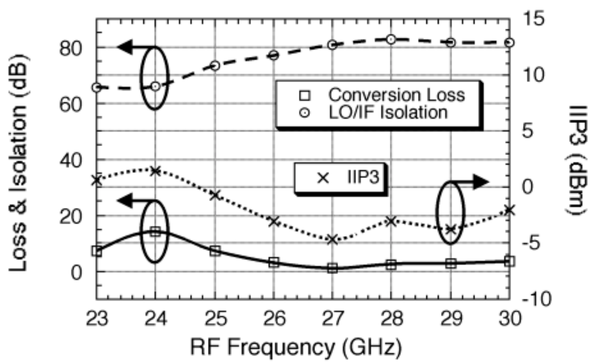


Fig. 5. Performance of the down-converter with LO power of 6 to 11 dBm.

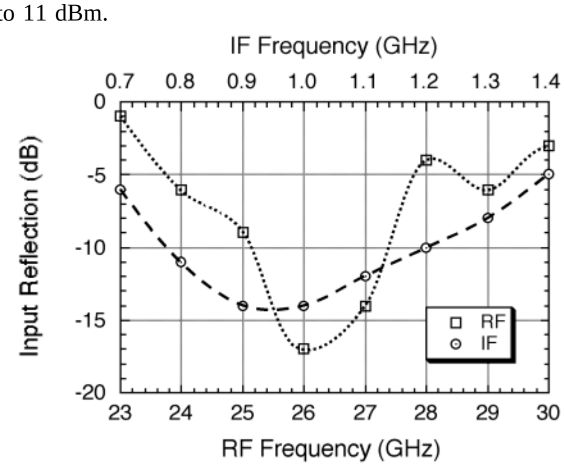


Fig. 6. IF and RF input reflection of the down-converter.

IV. Conclusion

We have presented the first implementation of a K-band down-converter fabricated in a 0.18-µm GaAs Metamorphic High Electron Mobility Transistor (MHEMT) process. Low noise and high gain characteristics of the MHEMT devices are utilized to integrate a single-stage amplifier with a subharmonic mixer for low-power broadband performance suitable for LMDS and WLAN applications. The subharmonic mixer exhibits a conversion loss of 13 dB, IIP3 of +8 dBm from 23 to 30 GHz. With the addition of the amplifier, the down-converter exhibits a conversion loss of 3 dB, NF of 5 dB, and IIP3 of -5 dBm from 26 to 30 GHz. The single-stage amplifier exhibits InP-like performance with gain of 11 dB and NF of 1.5 dB, and dc power consumption of 15 mW. The overall conversion loss and noise figure of the down-converter can be further reduced by increasing the gain of the amplifier with additional gain stages.

Acknowledgement

The authors wish to acknowledge Raytheon RF Components and Yamacraw Design Center for their support of this work.

References

[1] C. S. Whelan, W. F. Hoke, R.A. McTaggart, M. Lardizabal, P. S. Lyman, P. F. Marsh, T. E. Kazior, "Low noise In0.32AlGa0.68AsIn0.43Ga0.57As metamorphic HEMT on GaAs substrate with 850 mW/mm output power density," IEEE Electron Device Letters , vol. 21, no. 1, pp. 5-8, Jan. 2000.

[2] D. -W. Tu, S. Wang, J. S. M. Liu, K. C. Hwang, W. Kong, P. C. Chao, K. Nichols "High-performance double-recessed InAlAs/InGaAs power metamorphic HEMT on GaAs substrate," IEEE Microwave and Guided Wave Letters, vol. 9, no. 11, pp. 458 –460, Nov. 1999.

[3] M. Cohn, J. E. Degenford, and B. A. Newman, "Harmonic mixing with an antiparallel diode pair," IEEE Transactions on Microwave Theory and Technique, vol. 23, no. 8, 1975.

[4] T. Hirota, A. Minakawa, and M. Muragchi, “Reduced-size branch-line and rat-race hybrids for uniplanar MMIC’s,” *IEEE Transactions on Microwave Theory and Technique*, vol. 38, no. 3, pp. 270-275, 1990.