A K-Band Monolithic CPW Upconverter Utilizing a Source Mixing Concept

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Abstract

This paper concerns with the design consideration and performance of a CPW upconverter MMIC for K-band wireless system applications. The upconverter consists of an FET as a "3-port" mixing element, IF, LO, and RF matching networks, and an output filter. Including a 3dB pass-band insertion loss of the filter, the upconverter exhibits a maximum conversion gain of -6dB with a port-to-port isolation better than 20dB.

Introduction

Development of low-cost small-size low-power fully monolithic transceiver modules with 1-2GHz IF frequencies, for facilitating a high-speed transmission of data, voice, and video, in a wireless system, has been urged [1]-[4]. In a transceiver module, mixers are key-elements for frequency conversion, and require rigorous design methods to achieve an optimum operation.

Conventional FET mixers employ either a "gate mixing" [5]-[6] or a "drain injection" [7]-[8] topology to produce a desired frequency component, by applying the LO signal to the gate terminal or drain terminal of the device, respectively. In such a structure, since LO signal shares the same port with IF (or RF) signal, independent port matching for each signal is impossible, and to achieve a sufficiently high isolation between LO signal and IF (or RF) signal, usually hybrid circuits such as Lange couplers, power dividers as well as balun circuits and several anti-phase input signals are required [9]-[12] which totally increase the mixer circuit complexity.

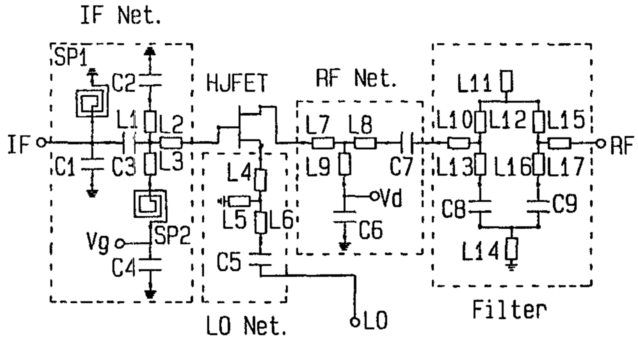

Fig. 1. Upconverter equivalent circuit.

Introducing a "source mixing" concept, and treating an FET as a "3-port device", the present paper describes a simple FET mixer for microwave and millimeterwave frequency converter applications.

Circuit Design

An equivalent circuit for the CPW K-band upconverter is shown in Fig. 1. The upconverter incorporates a heterojunction FET (HJFET) as a mixing element. IF signal with a frequency of f_{IF} is applied to the gate terminal through the IF matching network, and LO signal with a frequency of f_{LO} is applied to the source terminal through the LO matching network. On the other hand, a resultant upper sideband RF signal having a frequency of $f_{LO} + f_{IF}$ is extracted from the drain terminal, after passing through the RF matching network and the output filter. Use is made of spiral inductors in the IF matching network for resonant type filtering

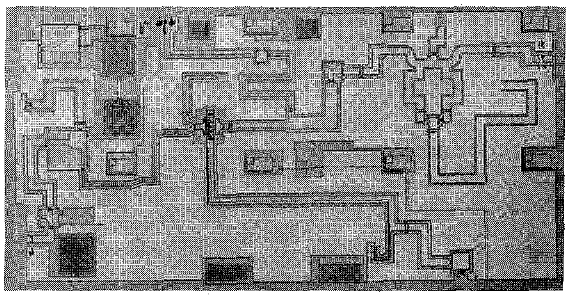

Fig. 2. Upconverter chip photograph.

and IF frequency matching. The output filter consists of two T-type networks connected in parallel for suppressing the lower sideband frequency ($f_{LO} - f_{IF}$) and LO frequency (f_{LO}), but passing upper sideband frequency ($f_{LO} + f_{IF}$). The LO matching network is essentially responsible to provide an unconditionally stable operation for the upconverter, both in the presence and absence of an LO signal. The short-circuited transmission line $L5$ in the LO matching network facilitates transistor's gate and drain dc biasing.

This structure utilizes the inherent isolation characteristics of the FET terminals under the pinch-off condition to separate the IF, LO, and RF signals without necessity of any hybrid circuit.

Applying non-linear parameters of a discrete $0.15\mu m \times 200\mu m$ AlGaAs/InGaAs HJFET, a 3-port non-linear harmonic balance circuit analysis was carried out to optimize all matching networks as well as the output filter, for port-matching, conversion gain, and rejection of undesirable frequencies. In the analysis, the gate was biased at the pinch-off voltage to realize the maximum mixing effect and minimum power consumption.

Fabrication Process and Device Characteristics

The K-band upconverter IC was fabricated on a 3-inch undoped SI GaAs substrate. Employing a Si step-doped AlGaAs layer structure, the HJFET was fabricated using an MOCVD growth technology. A CPW structure was used for transmission lines, and an MIM structure was applied for fabricating resonant capacitors in IF matching network, dc blocking capacitors and bypass capacitors. Details of the fabrication process have been reported elsewhere[13]-[14]. The HJFET used in the upconverter IC has a gate length of $0.15\mu m$ and a total gate width of $200\mu m$ ($25\mu m \times 8$ fingers). The device has a typical transconductance of 380mS/mm, a pinch-off voltage of -1.4V, and a breakdown voltage of 11V. Measured minimum noise figure for the device is 1.1dB at 24GHz with an associated gain of 9.5dB.

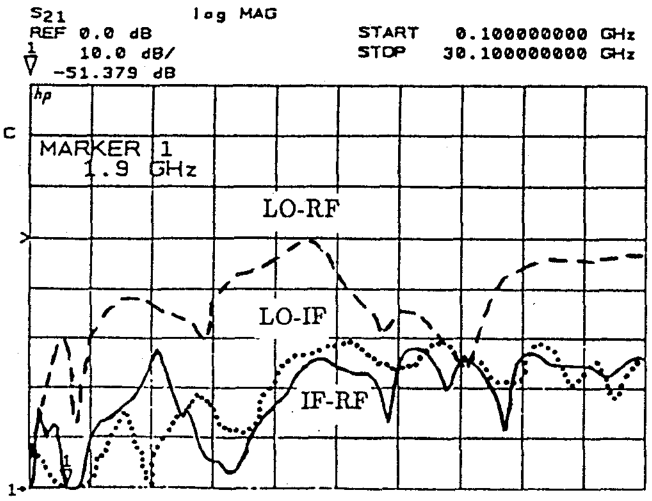

Fig. 3. Upconverter isolation characteristics.

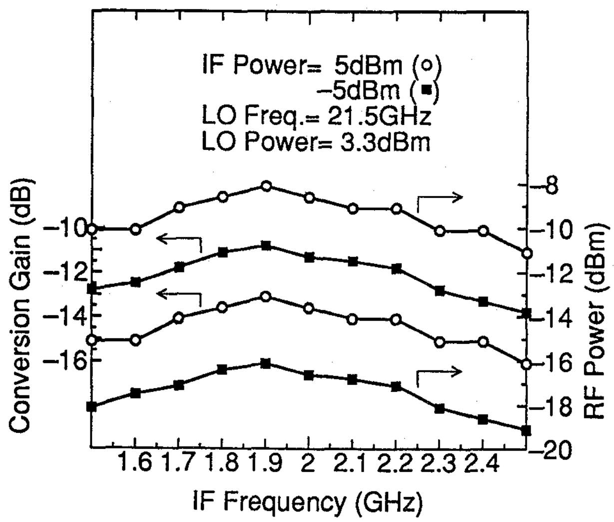

Fig. 4. Conversion gain and output power versus IF frequency.

Performance

Fig. 2 shows the chip photograph for the complete K-band CPW upconverter IC. Chip size is $4mm \times$

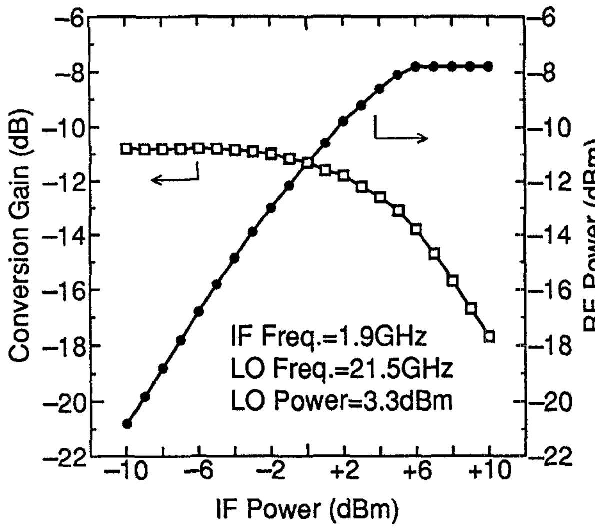

Fig. 5. Conversion gain and output power versus IF power.

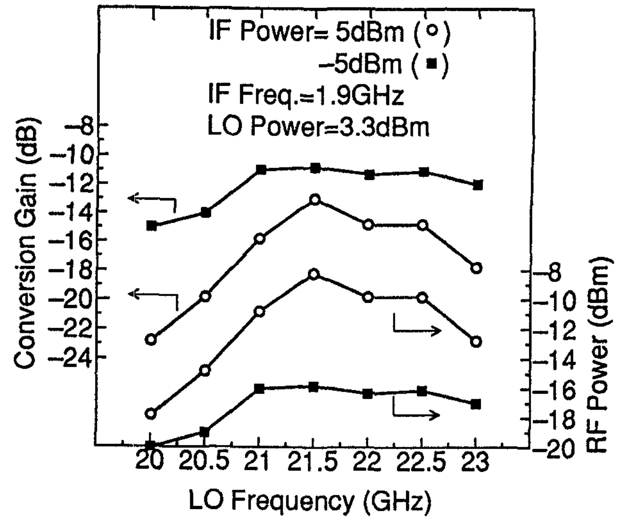

Fig. 6. Conversion gain and output power versus LO frequency.

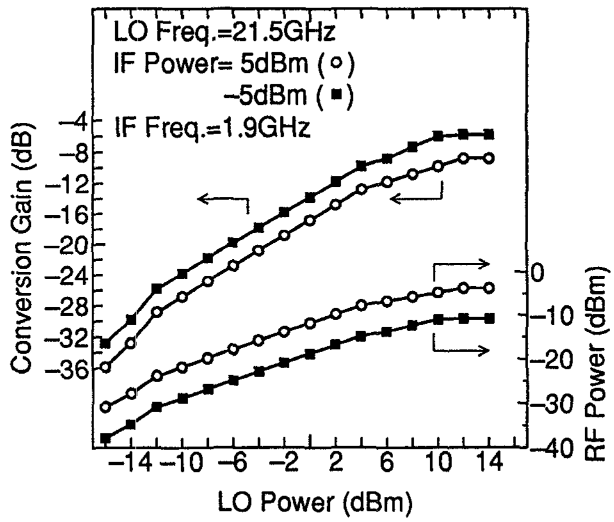

Fig. 7. Conversion gain and output power versus LO power.

2*mm*. On-wafer Cascade Microtech probes were utilized to evaluate the chip performance. The FET gate bias was -1.4V, corresponding to the pinch-off voltage, and the drain bias was 0.8V.

Fig. 3 shows small signal LO to IF, LO to RF, and IF to RF port isolation for the upconverter. LO suppression at IF and RF ports is, respectively, better than 22dB and 20dB, and IF suppression at RF port is better than 35dB. On the other hand, measured pass-band and rejection-band insertion loss for the output filter were 3dB and 18dB, respectively. Fig. 4 depicts conversion gain as well as RF output power variation versus IF frequency for an LO power of 3.3dBm, an LO frequency of 21.5GHz, and IF power levels of -5dBm and +5dBm. Fig. 5 represents conversion gain and RF output power against IF power for an LO power of 3.3dB, an LO frequency of 21.5GHz and an IF frequency of 1.9GHz. Conversion gain is constant for IF power levels lower than 2dBm, and reduces with increasing IF power, for which RF output power saturates. Fig. 6 exhibits conversion gain as well as RF output power variation versus LO frequency for an LO power of 3.3dBm, an IF frequency of 1.9GHz, and IF power levels of -5dBm and +5dBm. Fig. 7 represents conversion gain and RF output power against LO power for an LO frequency of 21.5GHz, an IF frequency of 1.9GHz, and IF power levels of -5dBm and +5dBm. The upconverter operates with LO power levels as low as -10dBm, and maximum conversion gain is -6dB which is obtained for an IF power of -5dBm and an LO power of 10dBm. On the other hand, maximum output power is -3dBm which is obtained for an IF power of 5dBm and an LO power higher than 10dBm.

No spurious oscillation was observed, and the upconverter was stable for any input signal and under any bias level condition.

Conclusions

Design consideration and performance of a CPW upconverter MMIC for K-band wireless system applications were described. In the circuit design, the FET was treated as a 3-port device in which the LO signal is applied to the source terminal. Including a 3dB pass-band insertion loss of the filter, the upconverter exhibits a maximum conversion gain of -6dB, and a maximum output power of -3dBm. In the present paper, we described the "source mixing" concept for the case of a K-band upconverter. The same design approach could be applied to realization of microwave / millimeter-wave downconverters, as well.

Acknowledgements

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