Miniaturized Three-Dimensional MMIC K-Band Upconverter

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***Abstract*— A miniaturized K-band balanced upconverter that effectively uses the three-dimensional monolithic microwave integrated circuit (MMIC) structure is presented in this paper. This upconverter consists of two unit mixers with stacked matching circuits and a newly developed Marchand balun. This balun is composed of two broad-side couplers and realizes a great reduction in circuit area. Each component's area is less than 0.13 mm^2, resulting in a total area of only 0.55 mm^2. This three-dimensional MMIC upconverter achieves conversion gains of greater than 1 dB and local oscillator (LO) leakage suppression rates of greater than 30 dB over the 17–18.5-GHz frequency band.**

I. Introduction

A BALANCED upconverter is a key device for transmitters and transceivers that must be implemented as smaller chips with lower cost. The balanced upconverter is constructed by combining two unit mixers and a 180° hybrid or two 90° hybrids [1], [2]. In the chip of conventional upconverters, the passive components dominate the monolithic microwave integrated circuit (MMIC) chip area. Therefore, it is most efficient to reduce the area of the passive components in upconverter chips. Three-dimensional (3-D) MMIC's [3]–[8] are very useful in solving this problem. The 3-D MMIC broad-side coupler reported in [4] is a very compact hybrid component and is easily combined with another broad-side coupler, with very little increase in area, to form the Marchand balun, a replacement for the 180° hybrid.

This letter introduces a miniaturized balanced upconverter that offers a very small MMIC chip. It is realized as a 0.79 mm $\times$ 0.69-mm chip and consists of two unit mixers formed as stacked matching circuits; the Marchand balun is composed of two broad-side couplers. The size of the presented three-dimensional MMIC balanced-mixer is a mere one third that of the minimum-sized planar balanced-mixer MMIC [1].

II. Circuit Design

Fig. 1 shows the circuit structure of the miniaturized balanced upconverter. The cross section of this structure is also shown in Fig. 2. A Marchand balun is designed to reduce the size of the passive components. A pair of gate mixers are directly connected to the balun's output ports. The most significant feature of this upconverter MMIC is that all passive circuits are formed as a three-dimensional structure. The use of 2.5-μm-thick polyimide films results in the very small area of 0.55 mm^2. This is due in part to the narrow-width thin-film microstrip (TFMS) lines and broad-side couplers.

A. Marchand Balun

The Marchand balun consists of two broad-side couplers [4], connected as shown in Fig. 1, with a short intermediate line for chip layout. Each coupler is constructed of two narrow conductors (6 and 9 μm width) stacked on the top and the second-top layers of the polyimide films with an associated ground plane on the wafer's surface. The length of the broad-side couplers is designed to be less than a quarter of the wavelength of the center frequency. This is due to the wideband operation frequency of the Marchand balun. The designed amplitude and phase errors are within 1 dB and 10°, respectively, and the loss is −5 dB (2-dB insertion loss) from 10 to 30 GHz. This frequency range is six times wider than that of the following mixer.

B. Unit Mixer

A gate mixer configuration is employed for the unit mixers to provide a conversion gain of nearly 0 dB. Intermediate frequency (IF) and local oscillator (LO) signals are applied to the field-effect transistor (FET) gate as shown in Fig. 1, and the radio frequency (RF) signals from the FET drains are directly combined with an associated short stub for output impedance matching. The matching circuits and IF/RF feeder lines are designed to be stacked above and below an intermediate ground plane to halve the mixers' area. The lower lines (inverted TFMS lines) are as wide as 14 μm for a characteristic impedance of 30 Ω and lower loss. The upper lines (TFMS lines) are 10-μm wide for a characteristic impedance of 50 Ω. The gate width of each FET is 200 μm.

C. Balanced Upconverter

The total circuit design was performed using a quasi-linear approach [1], which treats the LO and RF ports as the amplifier's input and output; the assumption is that out-of-phase IF inputs switch the mixing FET. This method provides a good insight for achieving the same gain and out-of-phase in the required frequency range. The predicted amplitude and phase errors were within 0.3 dB and 5° from 17 to 20 GHz, respectively, and the quasilinear gain was -4.5 ± 1.5 dB.

III. Measured Results

A microphotograph of a balanced upconverter MMIC is shown in Fig. 3. This MMIC was fabricated using a 0.3-μm

Manuscript received February 27, 1997.

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Publisher Item Identifier S 1051-8207(97)05419-6.

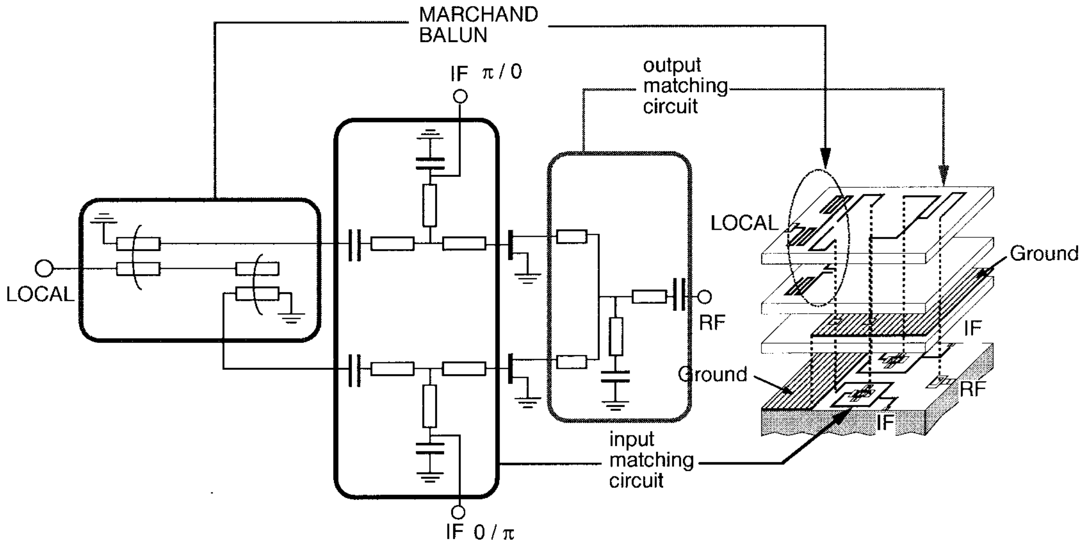

Fig. 1. Structure of the miniaturized balanced upconverter using three-dimensional MMIC technique.

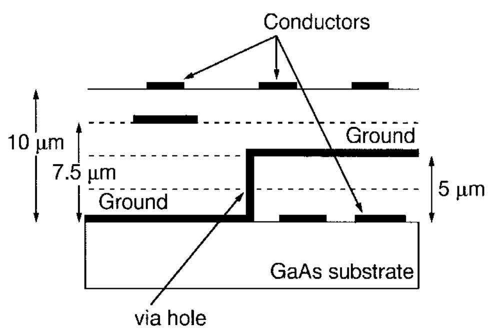

Fig. 2. Cross section of the three-dimensional MMIC.

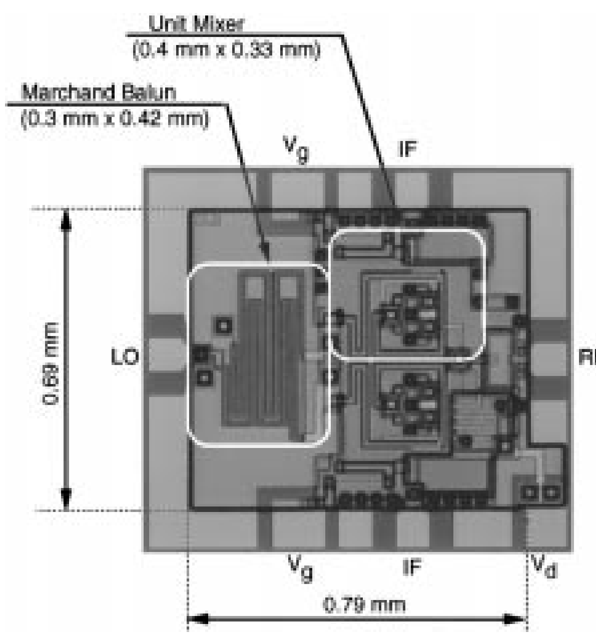

Fig. 3. Photograph of the fabricated balanced upconverter.

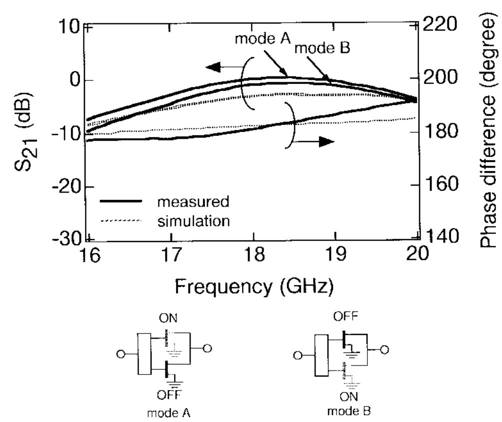

Fig. 4. Measured results of small signal balance characteristics.

gate MESFET IC process and a following 2.5 μm $\times$ 4-layer polyimide process [8], where all miniature transmission lines are meandered and spiraled with narrow line-to-line spacings of less than 30 μm. The line-to-line spacing is wide enough for the maximum 10-μm thickness polyimide substrate. The circuit areas of the Marchand balun and a unit mixer are 0.3 mm $\times$ 0.42 mm and 0.4 mm $\times$ 0.33 mm, respectively. They are nearly the same due to the three-dimensional structure as shown in the microphotograph. The total circuit area is a mere 0.79 mm $\times$ 0.69 mm. The Marchand balun was implemented by combining two 1.5-mm-long broad-side couplers and an intermediate line 0.2-mm long, resulting in a size reduction of 1/6 to the conventional planar 180° hybrid [9].

The quasilinear characteristics of the fabricated upconverter are shown in Fig. 4, where the solid lines and the dotted lines are measured and calculated value, respectively. Mode A indicates that a FET is "on," and the other FET is "off." Mode B indicates the opposite state of mode A. The S_{21} for both states is a small-signal gains. The difference between the small-signal gains for mode A and B is less than 2 dB and, at the same time, the phase difference between both modes is less than 10° over the frequency range 17–20 GHz. The gain flatness is within 3 dB in this frequency range. These results indicate that the developed Marchand balun provides good balance in amplitude and phase for practical mixer impedance values.

Fig. 5 shows the frequency characteristics of the balanced upconverter when a 10-dBm LO and 0-dBm IF signals are supplied, where the IF frequency of 140 MHz was used. The

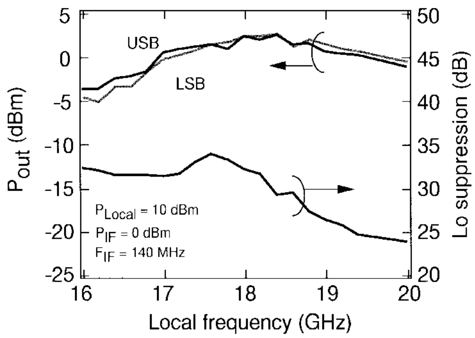

Fig. 5. Performance of the fabricated balanced upconverter.

FET drain bias, V_d, gate bias, V_g, and drain current are 3 V, −0.75 V, and 23 mA, respectively. The output power levels at lower-sideband and upper-sideband frequencies are nearly equal and within 1 ± 1 dBm over the frequency range 17–19.5 GHz. Local signal suppression of greater than 30 dB is achieved from 17 to 18.5 GHz. This result is obtained by using saturated mixing FET's and well-balanced Marchand balun. The output third-order intermodulation intercept point (IP3) measured at 18 GHz is as high as 12 dBm.

IV. Conclusion

A miniaturized K-band balanced upconverter was designed and fabricated by the three-dimensional MMIC technique. Both significantly small size and well-balanced performance were achieved by a newly developed Marchand balun constructed as two miniature broad-side couplers in polyimide layers. Miniaturized unit mixers were constructed using matching circuits in stacked form. The fabricated balanced upconverter exhibited an area of just 0.55 mm^2 and a conversion gain of 1 dB, from 17 to 18.5 GHz, with significant local suppression.

Acknowledgment

The authors would like to thank Dr. Masayoshi Aikawa for his valuable suggestions and encouragement during this work, and they also thank Dr. Kimiyoshi Yamasaki and Dr. Makoto Hirano for their helpful advice on fabrication issues.

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