38/76 GHz PHEMT MMIC Balanced Frequency Doublers in Coplanar Technology

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***Abstract*—Two 38/76 GHz push–push frequency doublers have been realized in a 0.15 μm GaAs PHEMT technology. The circuits are based on different 180° power divider structures: a Lange coupler followed by a 90° transmission line, and a balun. The circuits achieve maximum conversion gains of -4 and -6 dB for 12 and 14 dBm input signals, respectively. The fundamental suppression is approximately 30 dBc in both cases. To our knowledge, these results represent the best performance reported up to date for W-band balanced doublers.**

***Index Terms*—Millimeter wave generation, millimeter wave integrated circuits, MMICs, MODFETs.**

I. INTRODUCTION

FOR 76 GHz automotive radar systems, signal sources with low phase noise are required. Signal generation can be achieved by either W-band oscillators or by multiplication from a lower frequency source. The second approach has the advantage of allowing the use of a superior technology for the oscillator, so that transmitters with improved overall phase noise performance can be realized.

W-band varactor-based monolithic doublers have been presented in [1]. Active frequency multipliers have the advantage of better conversion gain over the diode-based type. Single-ended transistor-based doublers with W-band output frequencies have been reported in [2]–[4]. This topology has the advantage of allowing a compact size. Compared to single-ended designs, a push–push topology offers the potential of a superior odd-harmonic suppression. It consists of a pair of identical PHEMT-stages, driven by signals having 180° phase difference [5]. Due to the phase relation, the fundamental and odd harmonic components are cancelled, while the second harmonic signals are constructively combined. A balanced W-band HEMT doubler was reported in [6]; this circuit achieves a conversion loss of 15–18 dB at 88–96 GHz for an input power of 10 dBm. FET push-push doublers at lower frequencies have been presented in [7]–[10].

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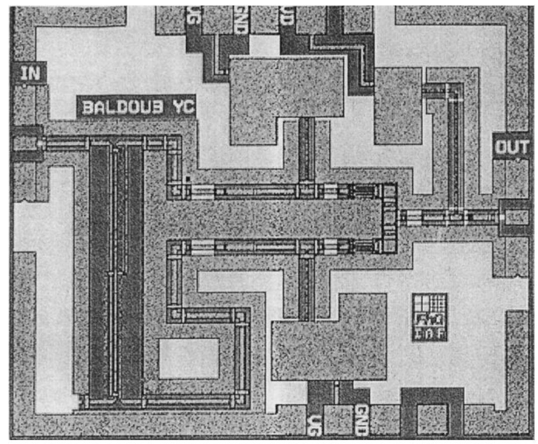

Fig. 1. Photograph of the 38/76 GHz balanced frequency doubler based on a Lange coupler/90° line structure. The chip size is 1.75×1.5 mm^2.

Based on a 0.15 μm GaAs PHEMT process and CPW technology, we present and compare here the achievable performance of push-push frequency doublers at W-band using two different 180° phase shifting structures.

II. CIRCUIT DESIGN

The first circuit discussed (Fig. 1) uses a Lange coupler followed by a 90° transmission line [11], while the second circuit (Fig. 2) is based on a compact balun [12], which provides directly the required 180° phase difference in a wide bandwidth. In the former case, the bandwidth regarding the phase is limited by the transmission line. Fig. 3 shows the transmission characteristics of both structures.

Double δ-doped AlGaAs/InGaAs/GaAs PM-HEMT's with 0.15 μm T-gates and 4×60 μm geometries have been used in the circuits. These devices achieve an extrinsic f_T of 100 GHz, $f_{\max}$ of 180 GHz, an output power density of 600 mW/mm at Ka-band and a breakdown voltage BV_{gd} of 4.5 V. For the simulation of these transistors, a table-based large-signal FET model [13] has been employed. A bias condition near pinch-off has been selected for optimum second harmonic generation.

The input networks of both circuits have been designed to provide the best compromise between large-signal conjugate matching at the fundamental frequency and a purely reactive termination, with a specific phase value (170°), at the second harmonic. This value, obtained by multiharmonic loadpull simulations, corresponds to a minimum output conductance, allowing

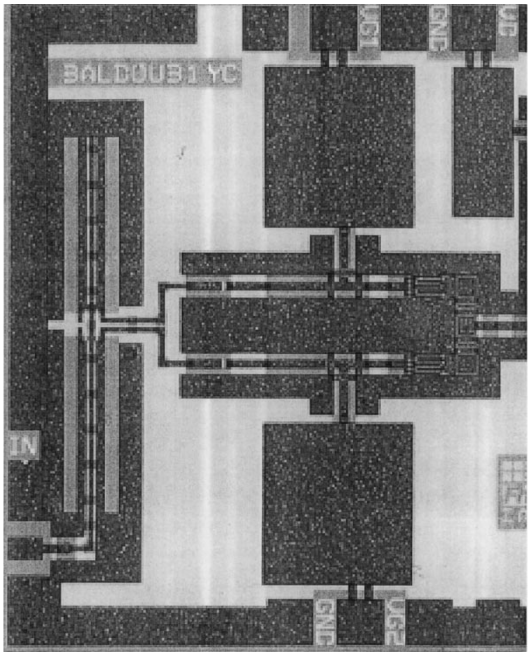

Fig. 2. Photograph of the 38/76 GHz balanced frequency doubler based on a coplanar balun. The chip size is 1.5×1.5 mm^2.

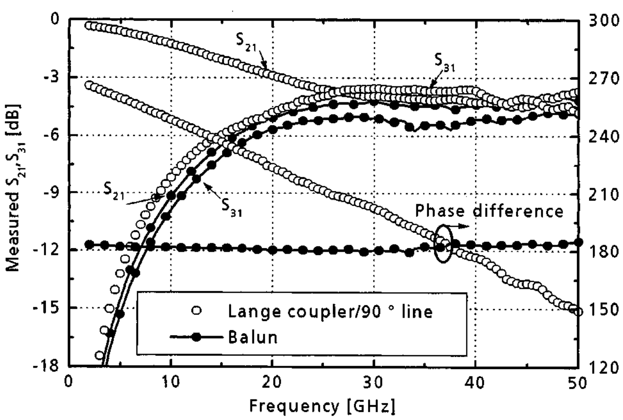

Fig. 3. Measured transmission characteristics of the Lange coupler/90° line structure and the balun.

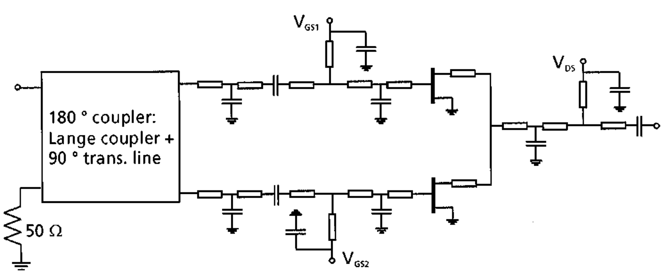

Fig. 4. Circuit schematic of the balanced doubler based on a Lange coupler.

maximum power transfer to the load. To synthesize the input networks, low-pass topologies based on two parallel MIM capacitors have been selected (Fig. 4). Once the optimum terminating impedances are known, the network components can be obtained by linear optimization.

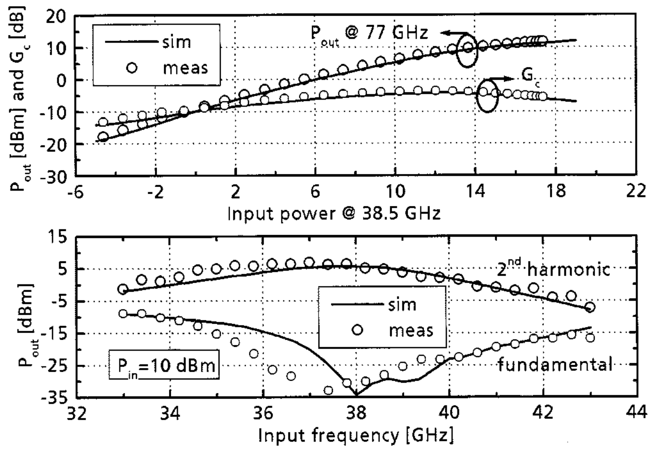

Fig. 5. Performance of the 38/76 GHz doubler based on a Lange coupler as a function of the input power (above) and the frequency (below). $V_{GS1} = -1.1$ V, $V_{GS2} = -0.95$ V, $V_{DS} = 2$ V.

The distance of the output junction to the drain of the transistors has also been optimized in order to maximize the conversion gain of the circuits. The output network after the junction provides large-signal conjugate matching at the second harmonic.

III. Measured MMIC Performance

Both MMIC's have been tested on-wafer using a measurement set-up based on a scalar power meter. Fig. 5 shows the performance of the doubler based on a Lange coupler as a function of the input power and the frequency. The circuit achieves a maximum conversion gain of -4 dB for a 12 dBm input signal. The available input power was not enough to drive the devices into saturation. A maximum output power of 11.5 dBm has been measured, with an associated gain of -5.3 dB. The dc-power consumption values corresponding to input power levels of 10 and 17 dBm are 110 and 225 mW, respectively.

In an ideal push–push doubler, with perfect amplitude symmetry and exactly 180° phase difference between both branches, the fundamental suppression achieves an infinite value. However, in real circuits this suppression is reduced due to residual asymmetries. The sensitivity of balanced doubler performance to asymmetries has been analyzed by using harmonic balance simulations in [14].

The amplitude unbalance of the Lange coupler/90°line structure is approximately 0.5 dB at 38 GHz. In order to compensate it, slightly different gate bias voltages have been applied to both transistors. Fig. 6 shows the measured conversion gain and fundamental suppression of the doubler based on the Lange coupler as a function of the difference between both gate bias voltages ($\Delta V_{GS} = V_{GS2} - V_{GS1}$). The maximum fundamental rejection (35 dBc) is obtained with $\Delta V_{GS} = 0.15$ V. However, the suppression is so sensitive to ΔV_{GS} that it would be impossible to guarantee this maximum value in a reproducible way. On the graph, the fundamental suppression values for ΔV_{GS} in a 50 mV range around the optimum value have been indicated. Considering these 50 mV as the maximum threshold voltage deviation across the wafer, the worst-case fundamental suppression results to be 30 dBc, that is, still more than 10 dB better than the

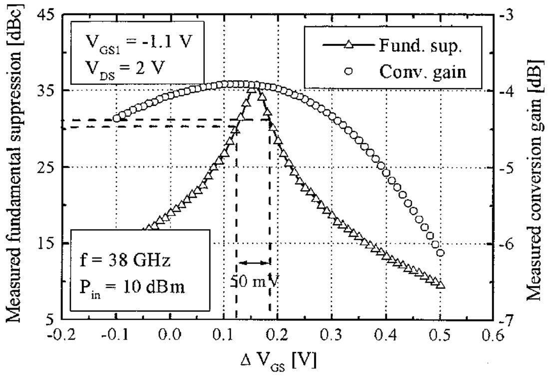

Fig. 6. Measured conversion gain and fundamental suppression of the 38/76 GHz doubler based on a Lange coupler as a function of the difference between gate bias voltages.

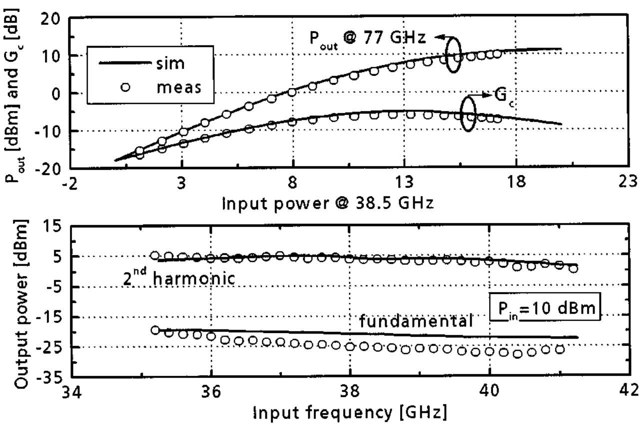

Fig. 7. Performance of the doubler based on the balun as a function of the input power (above) and the frequency (below). $V_{GS1} = V_{GS2} = -1.2$ V, $V_{DS} = 2$ V.

value achieved at the same frequency by using a single-ended topology and the same technology [4].

Fig. 7 shows the performance of the second doubler, based on a balun. The circuit achieves a conversion gain of -6 dB for a 14 dBm input power and a fundamental suppression of 30 dBc. Measurements were possible up to an output power of 10 dBm. The dc-power consumption values for input power levels of 10, 14 and 17 dBm are 86, 182 and 257 mW, respectively. Due to the more broadband characteristics of the balun in relation to the Lange coupler/$90°$ line structure, the doubler based on the former has a wider 3 dB-bandwidth (17% compared to 12%). It is also more compact (1.5×1.5 mm^2 compared to 1.75×1.5 mm^2). However, the latter achieves better conversion gain (-4 dB compared to -6 dB) due to the higher losses of the balun (approximately 1 dB is due to the difference in the transistor transconductance between both runs). Both circuits achieve a saturated output power higher than 10 dBm and therefore could be used, e.g., as the last stage of collision avoidance radar transmitters, avoiding the need of W-band amplifiers.

IV. Conclusion

Two coplanar 38/76 GHz PHEMT balanced frequency doublers based on different $180°$ power divider structures have been realized and compared. The doubler based on a Lange coupler followed by a $90°$ transmission line achieves higher conversion gain (-4 dB) than the doubler based on the balun (-6 dB). However, the latter has wider bandwidth (17% compared to 12%) and is more compact (1.5×1.5 mm^2 compared to 1.75×1.5 mm^2). The fundamental suppression values are 30 dBc. To our knowledge, these results represent the best performance achieved up to now for balanced frequency doublers at W-band.

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