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V-Band Balanced Amplifiers using Monolithic Uniplanar Tandem Couplers

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***Abstract*— V-band balanced amplifiers were monolithically fabricated using the uniplanar tandem couplers and 100-nm GaAs pseudomorphic high electron mobility transistors. Due to the excellent low-loss broadband coupling and high directivity of the tandem couplers, the balanced amplifier showed a very low input return-loss of -44 dB at 60 GHz which is known to be the best performance among the monolithic microwave integrated circuit V-band amplifiers reported to date. Compared to those of the reference single-ended amplifiers, the balanced amplifiers also exhibited comparable high S_{21} gains of 8-14 dB in a frequency range of 55-65 GHz.**

***Index Terms*— V-band, balanced amplifiers, tandem couplers, coplanar waveguide, return-loss.**

I. INTRODUCTION

A balanced structure is widely used for the power combination [1], linearization [2], and stabilization [3] of the amplifiers by improving the wideband matching in wireless communication system. The principal advantage of a balanced structure is that any mismatch reflections from the amplifiers pass back through the couplers and appear in anti-phase and therefore cancel at the RF input (or output) port. Reflected energy is diverted to the terminated coupler ports. For this reason, we can easily stabilize microwave or millimeter-wave transistors using balanced structure without tight matching network technology [4]. Achieving the efficient balanced amplifiers operating at millimeter-wave frequencies critically depends on the performance of the directional couplers with low loss, high directivity, and broadband coupling as well as easy fabrication process. It is difficult to achieve the tight coupling effect of ~3 dB from the coupled line couplers because of critical precision necessary for the fabrication process as well as the degradation of directivity due to the phase velocity mismatch between even and odd modes at the top and the bottom of the transmission line [5, 6]. When we employ a structure comprising the N-section parallel-coupled lines, we can simultaneously achieve a tight coupling and a high directivity even with a low coupling coefficient of the individual coupler. Tandem couplers take this advantage and connect the loose-coupled couplers to form a tightly coupled coupler. In this work, we adopted an air-bridge structure to materialize the coplanar waveguide (CPW)-based tandem coupler as a monolithically fabricated uniplanar structure [7] for the balanced amplifiers operating in a V-band (50-75 GHz) frequency range. For the comparative study, the single-ended amplifier was also fabricated as a reference circuit with the balanced amplifier using the CPW-based tandem coupler structure and 100-nm GaAs pseudomorphic high electron mobility transistor (pHEMT) monolithic microwave integrated circuit (MMIC) technology.

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II. TANDEM COUPLER CONFIGURATION

Figure 1 shows a scanning electron microscopy (SEM) photograph of the fabricated tandem coupler on a 680-μm thick GaAs substrate with air bridge crossovers, where the numbers of 1, 2 and 3 represent a direct port, a coupled port, and an input port, respectively. After Ti and Au were evaporated on the substrate for the ground metal and signal lines, the air bridges were fabricated by using our conventional MMIC process. This type of coupler therefore can be monolithically integrated with the active GaAs MMIC with no additional process step. For the coupler design, the process tolerance first needs to be taken into account; however, this 3-dimenesional structure can be easily realized because of relatively loose coupling requirements of individual couplers. The coupling gap and the line width of ~8 μm could be reliably patterned by our conventional lift-off technology. Besides, we can implement a tandem coupler of which coupling coefficient larger than 3 dB by optimizing the coupling gap of individual couplers. Furthermore, we chose two-section CPW parallel-coupled lines of a 13-μm coupling gap [7]. Each coupler unit was designed to have a coupling of ~8 dB to give a maximum coupling of 3 dB at 60 GHz. For the uniplanar structure at crossover connections, an air bridge structure was used. The air bridge line has a 3-μm height from the underlying metal points and gives more reliable performance than the wire-bonded structures at millimeter-wave frequencies [5].

The measured S-parameters of the couplers are shown in Fig. 2. A maximum coupling of 2.5 dB was obtained at 62 GHz from the coupled port, and average coupling of ~3.5 dB was measured over the entire frequency range of 60±30 GHz with a 0.5 dB power loss. The coupler exhibited a 2 dB bandwidth of 83 % where the power difference between the direct and the coupled ports was maintained within 2 dB. Return-loss and isolation were smaller than -23 and -16 dB, respectively, over the entire our measurement frequency range. The measured phase angle difference between the direct and the coupled ports was varied from 84 to 96° in the same frequency range.

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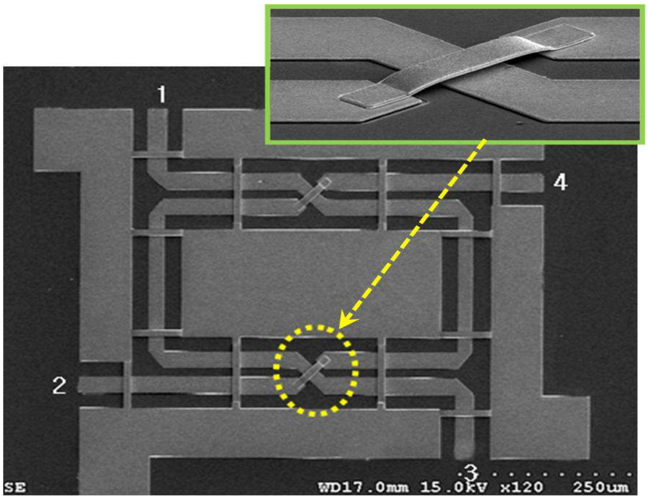

Fig. 1 SEM photograph of the fabricated tandem coupler.

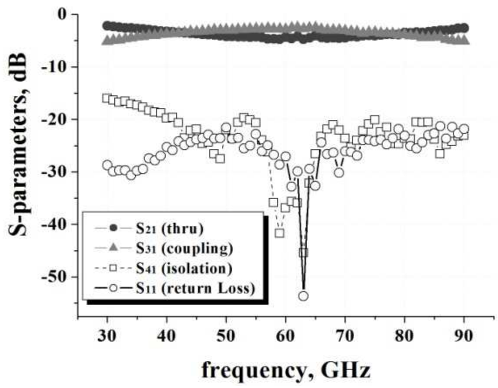

Fig. 2 Measured S-parameters of the fabricated tandem coupler.

III. CHARACTERISTICS OF BALANCED AMPLIFIERS

We used the pHEMT monolithic technology with 100-nm gate length and 2×70 μm gate width for the amplifier design. The fabricated HEMT showed a maximum transconductance of ~340 mS/mm, a maximum oscillation frequency of ~180 GHz, and a cut off frequency of ~113 GHz. In order to obtain the required transducer power gain ($G_T \geq 10$ dB) at 60 GHz, an amplifier with two cells in cascade was designed and optimized through the simulations. In the bias networks, λ/4 75 Ω and 50 Ω impedance transmission lines were adopted. In order to decouple the circuit from the external bias structure, a good RF short circuit was introduced using metal-insulator-metal capacitors at λ/4 line edge. Gate-bias network includes a resistance in series with the λ/4 line to prevent the low-frequency oscillations. We designed class-A single-ended amplifier to obtain a stable output characteristic and good linearity. The input stage utilize a conjugate matching method to maximize the power flowing into the device, and the power matching method was used for the output stage to obtain high 1-dB compression output power. Finally, a balanced amplifier was constructed with two uniplanar tandem couplers and two unit amplifiers as shown in Fig. 3 by using the designed single-ended amplifier as unit amplifier. The 50 Ω Ti resistors were used for the terminations.

The single-ended and balanced amplifiers were fabricated using our standard 100-nm GaAs pHEMT MMIC process with the CPW transmission lines, Ti resistors, and MIM capacitors. The top view of the fabricated balanced amplifier is shown in Fig. 3. The performances of the amplifiers were characterized using an on-wafer probe station and an Agilent 8510C network analyzer with V-band test set. Figure 4 shows the S_{21} gains of 8.5-15 dB in our design frequency range of 55-65 GHz measured from the reference circuit of single-ended amplifier. The frequency ranges for the input and output return-losses smaller than -10 dB were relatively narrow (56-70 GHz for S_{11}, 60-68 GHz for S_{22}) due to the unavoidable wideband reflection mismatch. The balanced amplifier showed comparable S_{21} gains of 8-14 dB in the same frequency range of 55-65 GHz as shown in Fig. 5. On the other hand, the input and output return-losses were smaller than -10 dB over the entire V-band frequency range of 55-75 GHz. At a design target frequency of 60 GHz, the input and output return losses were -44 and -22 dB, respectively. As summarized in Table 1, this is the best performance in terms of input return-loss among the V-band MMIC amplifiers [8-10] reported to date.

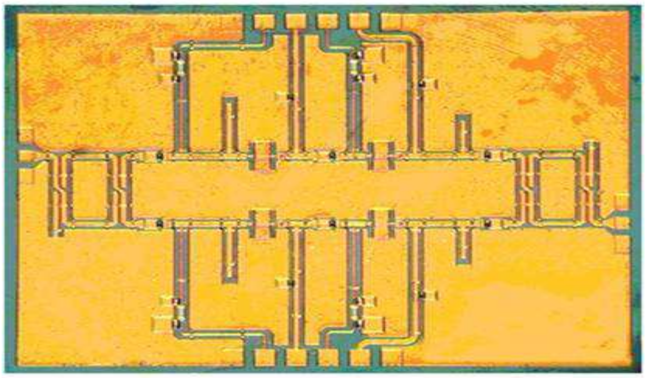

Fig. 3 Top view of the fabricated balanced amplifier (2.8 × 2.2 mm^2) amplifiers.

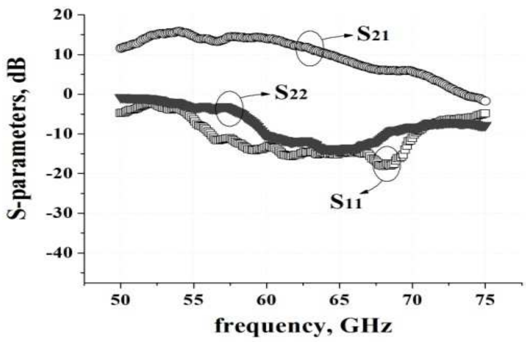

Fig. 4 S-parameter measurements of the single-ended amplifiers.

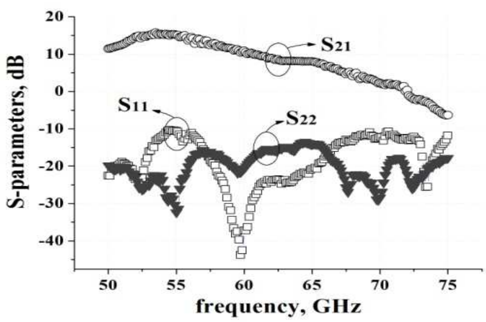

Fig. 5 S-parameter measurements of the balanced amplifiers.

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IV. CONCLUSIONS

The V-band balanced amplifiers of very low return loss were successfully demonstrated by using uniplanar tandem couplers. The fabricated coupler configuration showed broadband coupling, low loss, good isolation, and almost flat quadrature differential phase responses over the entire frequency range of 30-90 GHz. Due to performance of the uniplanar tandem couplers of tight coupling, low loss, and high directivity, the fabricated balanced amplifier showed very low return losses and high stability with comparable small-signal gain with that of the single-ended amplifier.

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