18 – 40 GHz Semi-Monolithic Balanced Cascade Amplifiers Using AlGaAs/InGaAs P-HEMT and GaAs MESFET

Masayuki Kimishima and Tetsuya Ashizuka

TOKIMEC INC.

Aero & Defense Systems Division

2-16 Minamikamata, Ohta-ku, Tokyo 144, JAPAN

ABSTRACT

18 - 40 GHz semi-monolithic balanced cascade amplifiers have been developed by using AlGaAs/InGaAs pseudomorphic HEMT's and GaAs MESFET's. This paper describes the design, fabrication and performance of the modules and exhibits superior advantages of semi-monolithic process technology for millimeter wave applications. It is demonstrated that the P-HEMT amplifier exhibits a gain of 5.7 + 0.4 dB, a noise figure of less than 3.6 dB and the three stage amplifier exhibits a gain of 15.6 + 0.8 dB, a noise figure of less than 4.2 dB, input/output return losses of better than 9.0 dB and an 1 dB compressed power of greater than 11.0 dBm.

INTRODUCTION

In recent years, the requirements for mm-wave have been increasing for a field of study or practical use such as communication systems, measuring instruments and automotive sensing systems. In this background, there are drastic progress in mm-wave semiconductor devices typified by pseudomorphic HEMT devices, which ease to realize various kind of mm-wave amplifiers with MMIC and hybrid circuits[1,2]. Also during the past several years, a number of researchers have reported their works on mm-wave balanced amplifiers characterized by good gain flatness and good input/output return losses over one octave bandwidth[3-5]. To improve performances of the conventional mm-wave balanced amplifiers, we developed novel balanced amplifiers composed by the use of 0.1 X 100 micron AlGaAs/InGaAs pseudomorphic HEMT's and fabricated using a semi-monolithic process technique. This semi-monolithic approach provides many of the manufacturing advantages, the authors already reported this process technique for microwave amplifiers and VCO's[6,7]. In the mm-wave circuits, lower loss and more minute precision are required for its circuit elements than microwave circuits. It means that a semi-monolithic process technique emphasizes its characteristics in mm-wave applications. This paper will present advantages of the improved semi-monolithic approach for mm-wave circuits. Making the best of the circuit flexibility which is one of merits of this

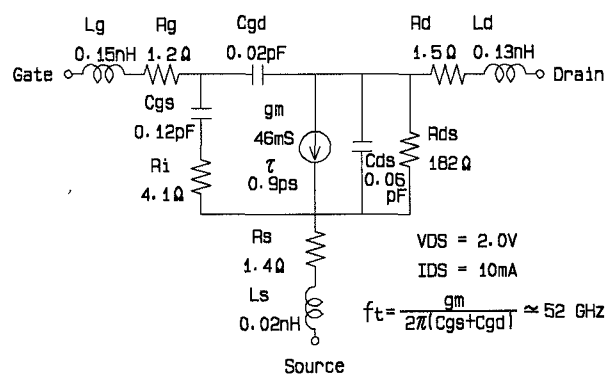

Fig.1 Equivalent circuit of P-HEMT chip

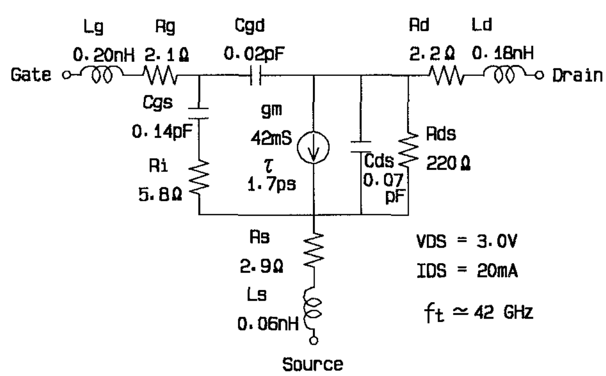

Fig.2 Equivalent circuit of MESFET chip

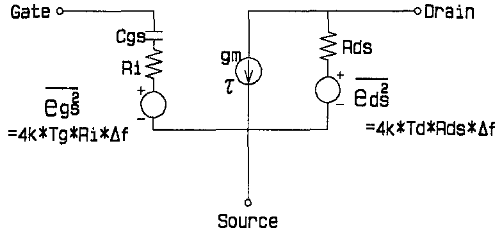

Fig.3 Noise equivalent circuit of an intrinsic chip

process, GaAs MESFET's are also used to fabricate the final power stage for the multi-stage configuration with the same circuit substrate. In addition, the three stage amplifier is composed with combination of P-HEMT amplifiers for the first and the second stage, MESFET amplifier for the third stage.

CIRCUIT DESIGN

Device Performance

To achieve high gain and low noise performance up to 40 GHz, 0.1 X 100 micron T-gate AlGaAs/InGaAs P-HEMT's(TOSHIBA JS8910-AS) are used. On the other hand, 0.25 X 150 micron GaAs MESFET's(CELERITEK CF004-01) are utilized for power stage amplifiers because of the high 1 dB compressed power. Small signal equivalent circuits of P-HEMT and MESFET are shown in Fig.1 and 2. These equivalent circuit elements are derived from careful fit of the measured small signal S-parameters up to 40 GHz. These equivalent circuits include bond-wire inductance to FET chips which are just same as these value with practical amplifiers fabrications. Therefore it can be calculated that these HEMT's and MESFET's have cutoff frequency of 52 GHz and 42 GHz under the actual mounting condition, respectively. As it's very important to deduce noise performance of P-HEMT amplifiers, the noise model shown in Fig.3 is utilized for the P-HEMT[8,9]. Tg and Td in Fig.3 are extracted from measurement NFmin up to 40 GHz and the equivalent circuit shown in Fig.1. On the other hand, the large signal nonlinear model of the MESFET is extracted by the use of commercially available CAD systems in order to anticipate an output power characteristic of the MESFET amplifiers[10].

Amplifier Design

Schematic diagram of the single-ended circuit of the 18 - 40 GHz balanced amplifier is shown in Fig.4. A simplified reflective match network composed of one open stub and one shorted stub is used for both of the input and the output to realize high gain and low noise figure. In addition to these simple network, the split capacitors divided into quarters are used as input/output capacitors. These capacitors can provide help to the accomplishment of a gain flatness over 18 to 40 GHz by tuning these capacitance values. The balanced amplifier consists of two single-ended amplifiers and two interdigitated Lange couplers with four fingers. Design parameters of the Lange coupler such as finger width and finger spacing must be optimally characterized for a good flatness and good input/output return losses between 18 to 40 GHz.

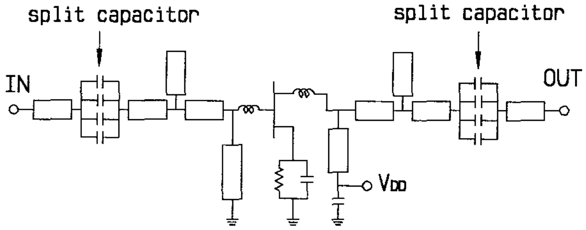

Fig.4 Schematic diagram of the single-ended circuit of the 18-40GHz balanced amplifier

FABRICATION

A photograph of the amplifier is shown in Fig.5. The authors already reported the 2 to 6 and 6 to 18 GHz balanced amplifiers fabricated in semi-monolithic form[6]. Now, the improved semi-monolithic process technique is applied for 18 to 40 GHz balanced amplifiers. The circuit is characterized by including passive elements such as air bridges and MIM capacitors fabricated monolithically on an alumina substrate with a purity of 99.8 % and a thickness of 0.25 mm. A profile of the semi-monolithic circuit is shown in Fig.6. To avoid adding parasitic inductance of via hole to source inductance Ls shown in Fig.1 and 2, discrete FET chips are directly mounted on Kovar carriers. The Lange coupler is formed from 1st level Au layer which is deposited using reactive sputtering in order to perform accurate finger width and spacing. As the optimum value, 2 micron thick 1st level Au layer was chosen considering both of fabrication accuracy and conductive loss in Lange couplers. The split capacitor is formed by

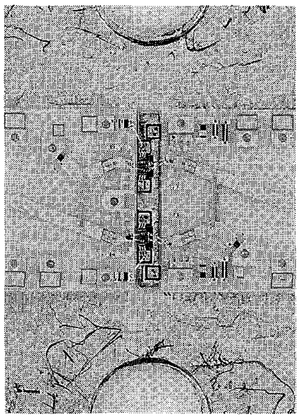

Fig.5 Photograph of the amplifier

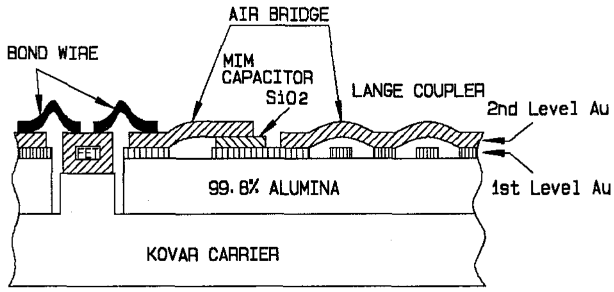

Fig.6 Cross section of the semi-monolithic amplifier

means of dividing its top plate into quarters. All of open and shorted stubs are composed of any number of air bridges in order to ease adjustment of these length. Using these circuit substrate, P-HEMT amplifiers and MESFET amplifiers are fabricated.

PERFORMANCE

Measured gain, input/output return losses and noise figure are shown in Fig.7 and 8 for the P-HEMT amplifier, and measured gain and input/output return losses for the MESFET amplifier are shown in Fig.9. The P-HEMT amplifier exhibits a gain of 5.7 + 0.4 dB, input/output return losses of > 10 dB and a noise figure of < 3.7 dB and the MESFET amplifier exhibits a gain of 3.6 + 0.2 dB and input/output return losses of > 10 dB over 18 to 40 GHz, respectively. Fig.10, 11 and 12 show the measured performance of the three stage amplifier. A gain of 15.6 + 0.8 dB, input/output return losses of > 9.0 dB, a noise figure of < 4.2 dB and an 1 dB power compression of > 11.0 dBm were obtained over 18 to 40 GHz. These data include insertion loss of the test fixture with the hermetic K-connectors for its input and output ports. All data presented were measured at VDS = 2.0 V, IDS = 10 mA for P-HEMT and VDS = 3.0 V, IDS = 20 mA for MESFET, respectively by the use of self-biasing configuration.

CONCLUSION

18 to 40 GHz semi-monolithic balanced cascade amplifiers have been developed by using AlGaAs/InGaAs P-HEMT's and GaAs MESFET's. It has been confirmed that the improved semi-monolithic process technique is very effectual for millimeter wave applications.

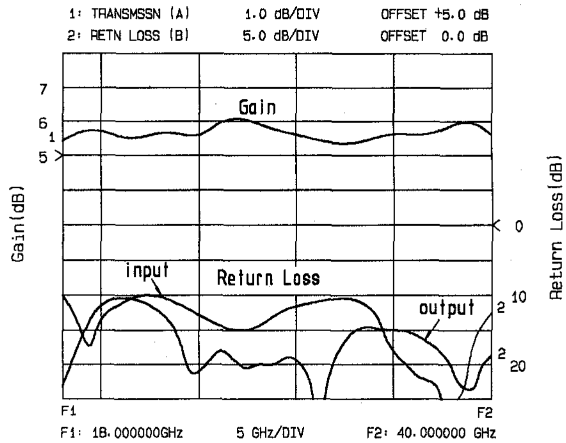

Fig.7 Measured gain and input/output return losses of the P-HEMT amplifier

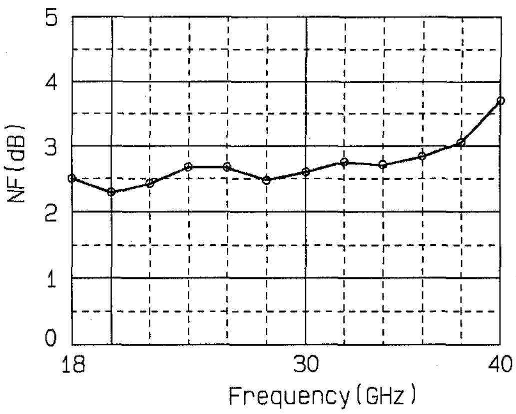

Fig.8 Measured noise figure of the P-HEMT amplifier

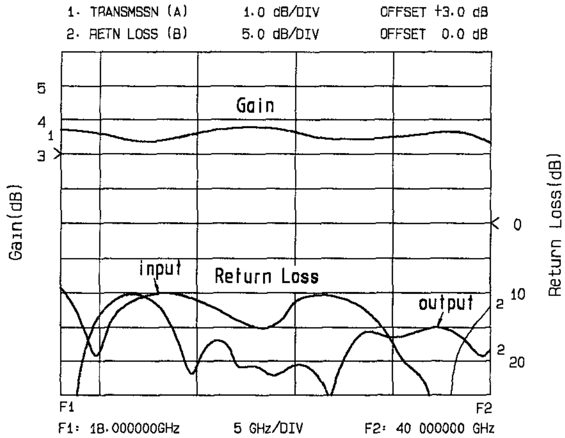

Fig.9 Measured gain and input/output return losses of the MESFET amplifier

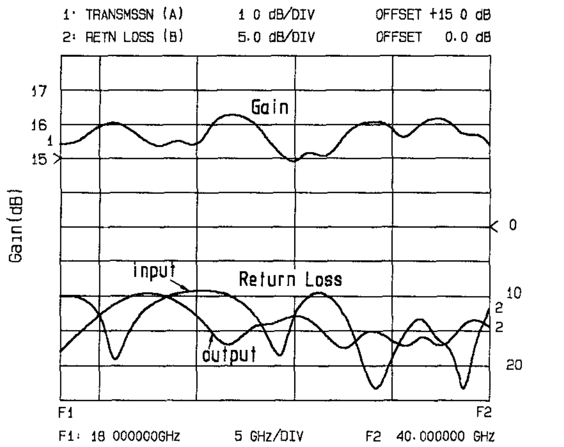

Fig.10 Measured gain and input/output return losses of the three stage amplifier

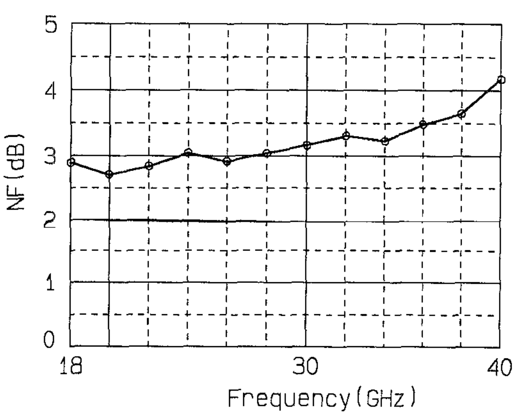

Fig.11 Measured noise figure of the three stage amplifier

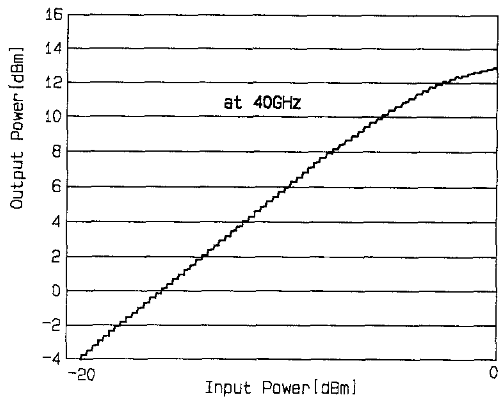

Fig.12 Measured output power performance of the three stage amplifier

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