20-30GHz broadband MMIC power amplifiers with compact flat gain PHEMT cells

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***Abstract* — 20-30GHz band MMICs have been successfully developed using two types of novel compact size flat gain PHEMT cells that have flat maximum available gain and sufficient stabilities over a wide frequency range of 20-30GHz. One type is a feedback type. The other has an equalizer circuit at the gate of a PHEMT. The MMIC delivers gains of over 18dB and P1dB of over 22dBm. These results show this method is very effective in designing broadband MMICs.**

I. Introduction

Demand for low-cost Ka-band MMICs is increasing with the market expansion of communication systems such as LMDS (Local Multipoint Distribution Service). In the LMDS systems, there are several frequency allocations to be selected from corresponding to the environments where the systems are installed. As a result, an MMIC needs to cover several frequency allocations as many as possible with low cost. Therefore, it is particularly essential to design a cost-effective, broadband MMIC in the LMDS systems. The conventional ways to realize a broadband MMIC are to utilize a feedback amplifier [1] or a distributed amplifier configuration [2]. However, it seems that these design techniques often required a large occupied chip area, leading to a cost-ineffective MMIC.

This paper presents a new design method to provide a cost-effective, broadband MMIC operating in the 20-30 GHz band required in the LMDS. In addition, the design and experimental results of two broadband MMICs have been demonstrated to verify the validity of the method. The method presented here utilizes two different types of flat gain PHEMT cells in order to provide a wide operating band for amplifiers. One type is a feedback core cell, and the other is an equalizer type core cell. These two core cells are designed to have a completely flat gain and sufficient circuit stability in the frequency band of interest. The core cells are then matched to each other through a band-pass filter which translates interstage impedance. Because the core cells have complete stability, they provide a easy optimization for an overall broadband MMIC design, and also enables significant chip size reduction. The main characteristics of the fabricated MMICs are as follows: again and gain flatness of 21 ±1.5dB, and a P1dB of over 22dBm over a wide frequency range from 20 to 30GHz.

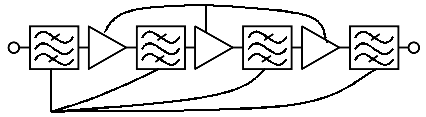
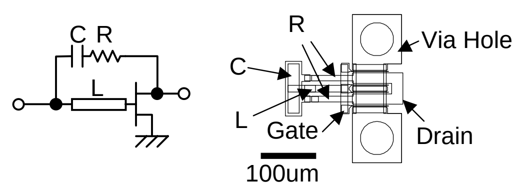


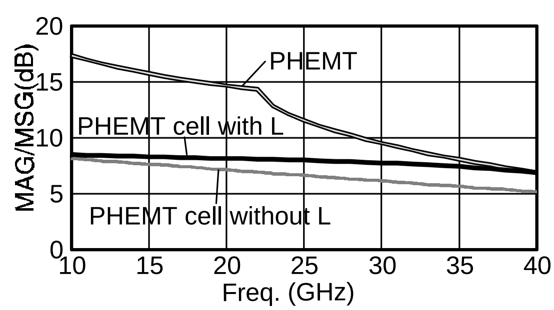
Fig.1. Basic configuration of the MMIC

II. Flat Gain PHEMT Cells

As described before, the flat gain PHEMT cell makes a MMIC design easy. After preparing the flat gain PHEMT cell, an MMIC design is done by optimizations of impedance transformers connecting each flat gain PHEMT cell. Stability and gain flatness are automatically achieved by the flat gain PHEMT cell. The flat gain PHEMT cell, with its stabilizing circuit positioned right next to the PHEMT,



(a) Circuit configuration and layout pattern



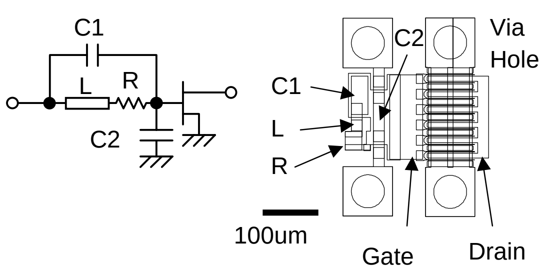
(b) Characteristics of the feedback type flat gain PHEMT cell

Fig.2. Feedback type flat gain PHEMT cell

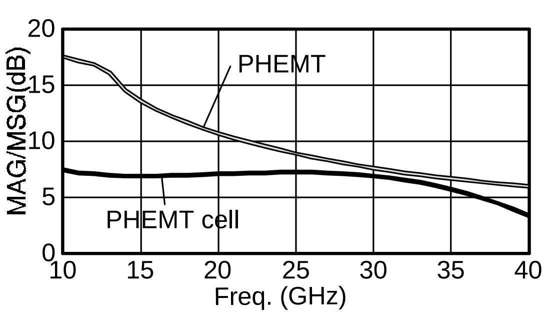
has a very small risk of unstable operation that is caused by unexpected parasitic impedance between the stabilizing circuit and the PHEMT, or influence of a biasing circuit in the conventional design method. Figure 1 shows the basic configuration of the MMIC. PHEMT cells in the MMIC are designed to achieve flat gain and sufficient stability over a wide frequency range. The matching circuits in the MMIC are band pass filters matching with the optimum impedance of each flat gain PHEMT cell. This method keeps the component counts in the matching circuit small, compared with the conventional design method that is done by cascade connections of single stage amplifiers matched with an impedance. This method also decreases a risk of a multiple reflection in a matching circuit.

The transistors used in our MMICs are 0.25 um, double-doped, double-recessed T-gate AlGaAs/InGaAs PHEMTs with two end vias formed on 100 um thick GaAs substrates. Gate recesses were formed using wet etching techniques. Double etching stopping layers are grown to obtain good uniformity in saturated drain current, Idss. A typical break down voltage is 15 V and a typical Idss value is 200 mA/mm[3].

Figure 2 (a) shows the first PHEMT cell configuration. It has a feedback circuit that consists of a resistor, a MIM capacitor, and a transmission line. The resistors are connected directly with each drain electrode of the PHEMT to minimize the cell size. Figure 2 (b) shows characteristics of the cell. In the figure, a double line, a gray line, and a solid line show MAG/MSG characteristic of a single PHEMT, a flat gain PHEMT cell without the transmission



(a) Circuit configuration and layout pattern



(b) Characteristics of the equalizer type flat gain PHEMT cell

Fig.3. Equalizer type flat gain PHEMT cell

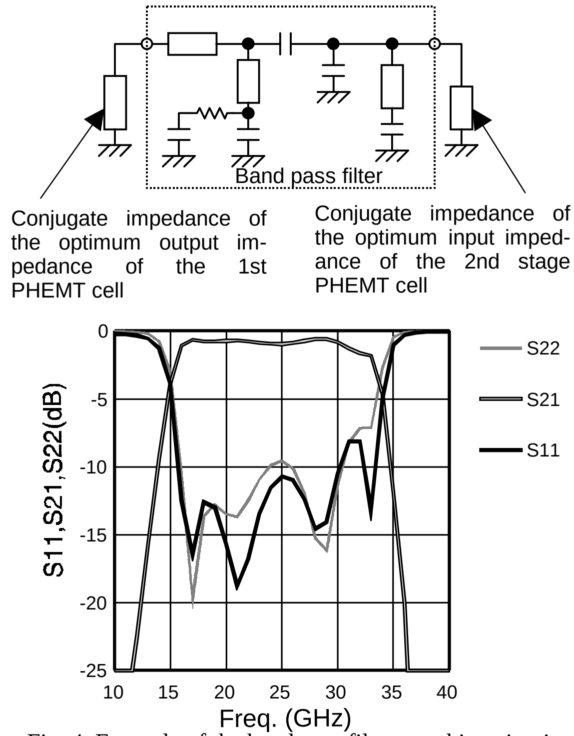
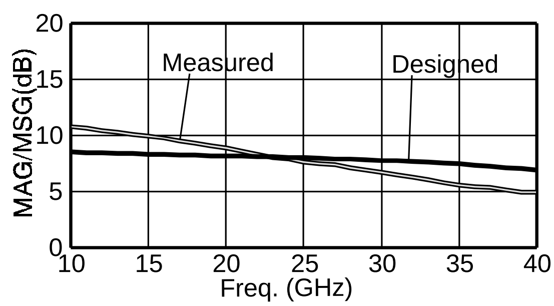
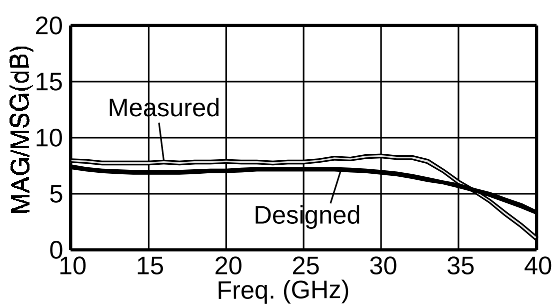


Fig. 4. Example of the band pass filter matching circuit



(a) Feedback type



(b) Equalizer type

Fig.5. Measured MAG characteristics of the flat gain PHEMT cells

line and that with the transmission line, respectively. The transmission line has a role in flattening the MAG of the PHEMT cell.

Figure 3 (a) shows another configuration that provides the flat MAG PHEMT cell. The gate of the PHEMT have equalizer circuits to flatten the MAG characteristics. As frequency increases, the inductor prevents the current through the resistor while the current through the capacitance increases. As a result, the total power loss at the input side of the flat gain PHEMT cell is kept constant for a wide frequency range. Additionally, we put a shunt capacitor at the gate of the PHEMT to gain a constant optimum impedance.

III. CIRCUIT DESIGN

Gate widths of the first, the second and the final stage PHEMTs are 240 um, 400 um and 960 um, respectively. For the first and second stages, we use the feedback type flat gain PHEMT cells because these cells have an optimum output impedance of about 50 Ω. For the final stage, we use the equalizer type flat gain PHEMT cell because the cell has low loss in the output side.

Each matching circuit is tuned to match with the optimum impedance of the PHEMT cells. The matching circuit employs the band pass filter configuration. Figure 4 shows an example of the band pass filter, that is a matching circuit between the first and the second PHEMT cells. At first, we start with ideal lumped elements to determine basic combination of circuit elements. Next, we replace these elements with distributed elements. After a consideration of parasitic components such as via hole's inductors, the layout is optimized by em analysis[4]. Almost all optimizations are done for the separated band pass filter, not for the amplifier. The optimization targets in the band pass filter are very simple under the condition that the S11, the S22 be less than –10dB, and the S21 be 0 dB for the designed frequency range. We effectively use lumped elements to minimize the chip size of the MMIC.

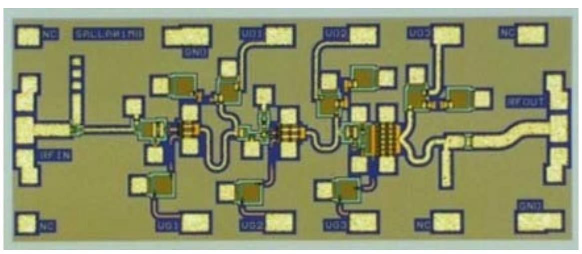


Fig.6. Photograph of the MMIC

IV. MEASURED RESULTS

Figure 5 shows the measured MAG of the first stage PHEMT cell, compared with the designed characteristics. In the feedback type flat gain PHEMT cell, the differences between designed and measured characteristics come from the tight coupling between the feedback resistor and the transmission line. If the flat gain PHEMT cells are prepared before an MMIC design, these problems will be avoided. The equalizer type PHEMT cell has very flat gain from 10GHz to 30GHz. Degradation of MAG is observed over 32GHz. The degradation is caused by a MIM capaci-

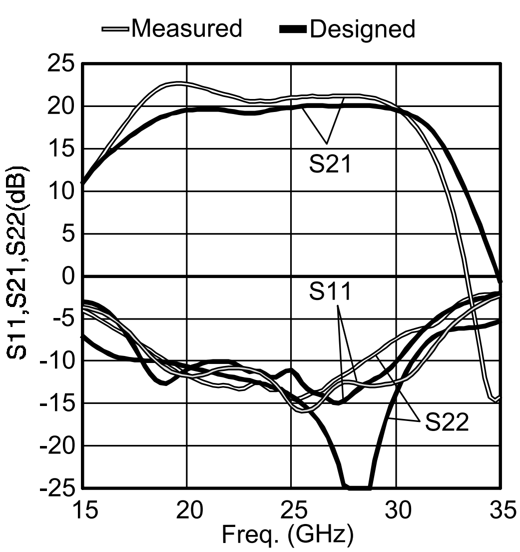


Fig.7. Small signal characteristics of the MMIC

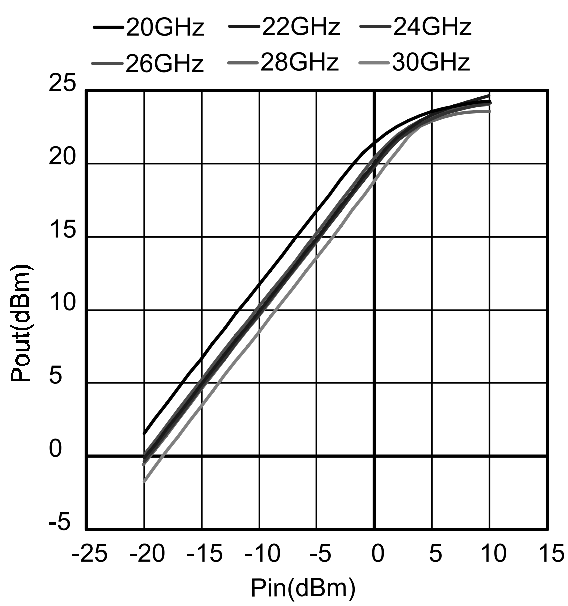


Fig.8. Power characteristics of the MMIC

tor inserted at the gate electrode.

Figure 6 shows a photograph of the MMIC. The chip size of the MMIC is 3.1mm x 1.3mm. Figure 7 shows the small signal characteristics of the MMIC. A gain of over 18dB is obtained for a wide frequency range of 20-30GHz. The bias condition is 5V and 240mA. Gain flatness is 21± 1.5dB for the same frequency range. Figure 8 shows Pin-Pout characteristics of the MMIC. P1dB of over 22dBm is obtained. The flatness of the P1dB is less than 1.5dB peak-to-peak for the same frequency range. There are two reasons why the MMIC has the flat power characteristics. One is that the output matching circuit is made by low loss band pass filter. The other is that frequency dependence of the output optimum impedance is small for a wide frequency range. The temperature dependence of the MMIC is 0.023dB/deg. to 0.039dB/deg for the temperature range of –40deg. to 80deg. The value is relatively small because the temperature dependence of the PHEMTs MAG are about 0.015dB, corresponding to 0.045dB/deg for the 3-stage amplifier. The result is explained by the temperature dependence of the feedback circuits. The resistance become lower as temperature become low.

Figure 9 shows a miniaturized MMIC with the same designing scheme as the former MMIC. The chip size is 2mm x 1mm. Figure 10 shows small signal characteristics of the miniaturized MMIC. Almost same characteristics are obtained. This shows that this method also effective in reducing chip size.

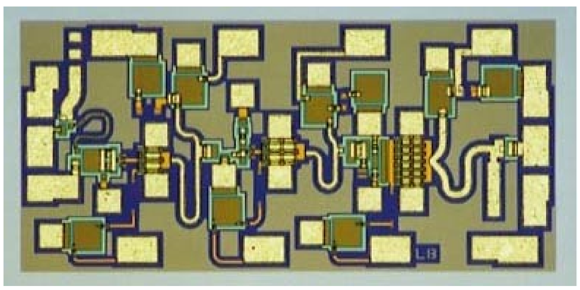


Fig.9. Photograph of the compact size MMIC

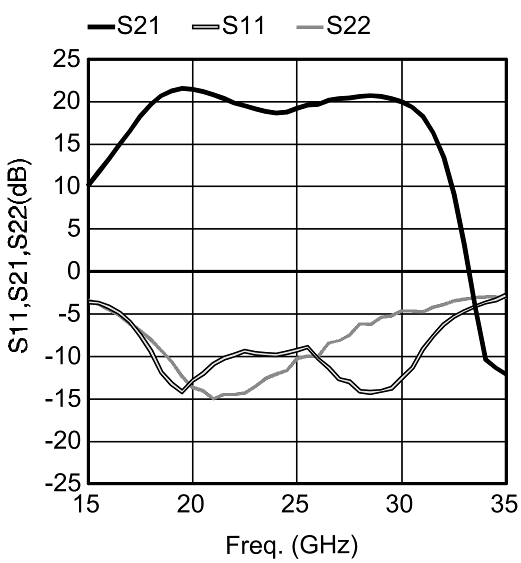


Fig.10. Small signal characteristics of the compact size MMIC

V. Conclusion

20-30GHz MMICs for Ka-band communication systems have been developed using novel compact size flat gain PHEMT cells. Two types of flat gain PHEMT cells are designed and characterized. These PHEMT cells deliver flat MAG for a wide frequency range. Preparing many types of PHEMT cells makes MMIC designs easier. The fabricated MMIC delivers flat gain of 21±1.5dB for the wide frequency range of 20-30GHz. The output power of the MMIC delivers P1dB of over 22dBm for the frequency range of 20-30GHz. The chip compaction has been done with the same configuration. These results show that these PHEMT cells and the design method are very effective for a broadband MMICs.

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