1 Watt Compact Ka-Band MMIC Power Amplifiers Using Lumped Element Matching Circuits

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ABSTRACT

A compact MMIC chip set for Ka-band communication systems has been developed. A two stage power MMIC amplifier using only lumped elements and narrowly spaced lines for the matching circuit delivers 1.44 watt at 30 GHz with a very small die size of 1.94 mm X 2.0 mm. The designing scheme is confirmed to be useful for cost reduction.

INTRODUCTION

For reducing amplifier cost, MMIC chips have been miniaturized for Ka-band monolithic power amplifiers using lumped element matching circuits. A two stage monolithic GaAs PHEMT amplifier delivers 1 watt with a very small die size of 1.94 mm X 2.0 mm using full lumped element matching circuits from 28.5 GHz to 30 GHz. A two stage monolithic medium power amplifier delivers 0.35 watts and a linear power gain of 15 dB from 28.5 GHz to 30 GHz with a very small die size of 1.94 mm X 1.0 mm. A variable gain amplifier for a driving stage has also been designed to provide -5 to 20 dB gain.

These MMICs are created by using high performance double doped AlGaAs/InGaAs PHEMTs and high uniformity MIM capacitors which successfully construct lumped element matching circuits for Ka-band.

In this paper we describe the compact size power amplifiers for Ka-band using lumped matching circuits and a low-cost power amplifier module using a ceramic-wall package. A performance and chip size comparison between published Ka-band monolithic power amplifiers and this work is given in Table 1. Our MMIC provides the highest output power densities which is defined by output power over chip area. This is because others usually employ matching circuits of microstrip lines, which generally require more space.

Table 1. Size and output power comparison of K-band monolithic power amplifiers.

Freq [GHz]	Power [W]	Gain [W]	Stage	Chip Size [mm ^{2}]	Power dencity* [W/mm ^{2}]	Reference	Year
29-35	1.0	6	2	4.13 x 1.78	0 136	1	1992
38	0.4	(11 :2 chip)	1	1 55 x 1.95	(0.132)	2	1992
30	0.5	8.5	2	2 x 1.25	0.2	3	1992
35	1.1	9	2	4.8 x 2.3	0.091	4	1993
33	1.1	12.5	2	2 x 3.84	0.143	5	1995
40	1.0	9	2	5 x 2.6	0.077	6	1995
30	**1.0**	**6**	**2**	**1.94 x 2**	**0.371**	**This Work**	**1998**

* Power dencity=Power/Chip Size

PROCESS DESCRIPTION

The transistors used in our MMICs are 0.2 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 17 V and the typical Idss value is 330 mA/mm with a standard deviation of 10 mA/mm. A 600 um discrete device matched in hybrid fixtures provides 24.0 dBm of output power, 9.0 dB of associated gain, and 58 % of power added efficiency when biased at Vd = 5.0 V and Ids = 1/4 Idss at 18 GHz. The power performance is shown in Figure 1.

Metal Insulator Metal (MIM) capacitors are carefully formed to possess good capacitance uniformity by depositing a SiN film with good thickness uniformity. Because the capacitors in lumped element circuits should have good uniformity in capacitance to obtain a high yield of MMIC amplifiers. The standard deviation of measured capacitances of 220 pF process control monitor capacitors was proven to be as small as 1.3 % across a 3-inch wafer.

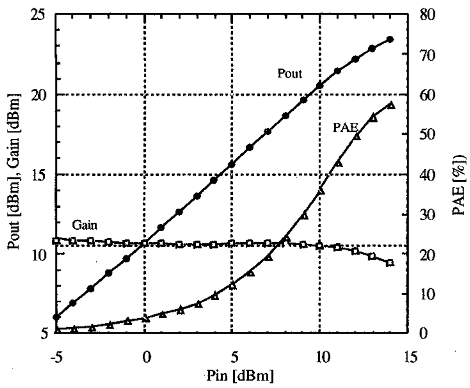

Figure 1. Tuned power and efficiency data of a 600 um PHEMT

MMIC DESIGN AND RESULTS

A 1 watt compact monolithic power amplifier was designed trying to minimize the chip size to reduce the chip cost. Figure 2 shows the comparison of 1 watt power amplifiers between the conventional and the one developed in this work. For Ka-band, conventional amplifiers employ microstrip line based impedance conversion matching circuits, and power dividing, and/or combining circuits as shown in Figure 2(a). We adopted lumped element based matching/dividing/combining circuits as shown in Figure 2(b). Next we considered the distributed effect existing in the actual patterns. The width of the line was simply defined by our design rule and current density limitation. By using the lumped element matching circuit topology and narrowly spaced pattern layout achieved by electromagnetic simulations, we have successfully been able to minimize the chip size to about 50 to 80 % of the size for conventional MMICs. A photograph of the amplifier is shown in Figure 3. The chip size is as small as 1.94 mm x 2.0 mm .

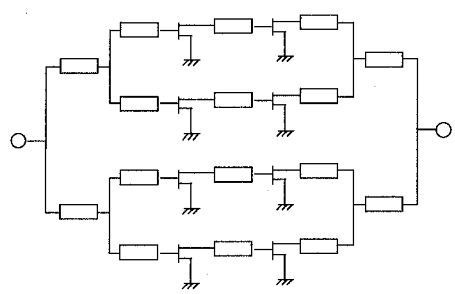

Figure 2-(a). Conventional Ka-band.monolithic power amplifier's configuration

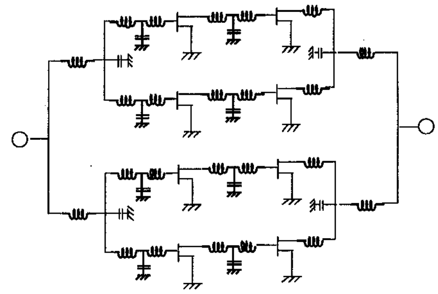

Figure 2-(b). Ka-band power amplifier's configuration using lumped element based matching circuits

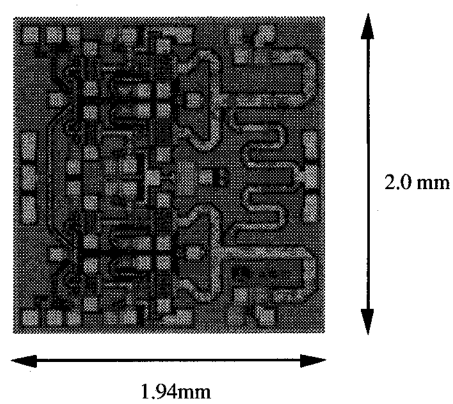

Figure 3. Ka-band monolithic power amplifier using lumped element matching circuits

The measured small signal gain performance of the amplifier is shown in Figure 4. Power measurements were also conducted and the results are shown in Figure 5. An output power of 1.44 watt (31.6 dBm) and power gain of 8.1 dB were obtained at 30 GHz with the bias conditions of Vd = 6 V and Ids = 1000 mA.

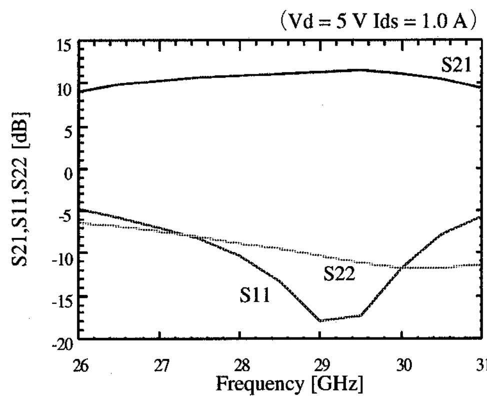

Figure 4. Small signal performances of a Ka-band monolithic power amplifier

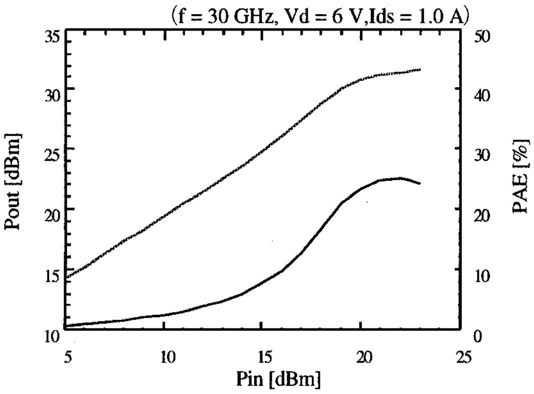

Figure 5. Measured output power and efficiency versus input power of a Ka-band monolithic power amplifier

A medium power amplifier is shown in Figure 6. It is a two stage amplifier with a 600 um and a 1200 um gate-width PHEMT. To reduce the chip-size, lumped element matching circuits and narrowly spaced lines have also been utilized. The matching capacitance used in the design varied from 0.1 to 0.4 pF. The chip size is 1.7 mm x 1.0 mm. Small signal s-parameter measurement results and power measurement results are plotted in Figure 7 and Figure 8, respectively. The amplifier delivers 0.35 watt with a linear gain of 15 dB at 28.5 to 30 GHz.

A gain controlled 2-stage amplifier was also developed. The gate-width of the PHEMT used in the MMIC was 240 um for both stages. The chip size is 1.5 mm x 1.0 mm (Figure 9). The measured results show a maximum gain of 20 dB is obtained from 27 to 30 GHz with Vd = 5.0 V and Ids = 20 mA. (See Figure 10.)

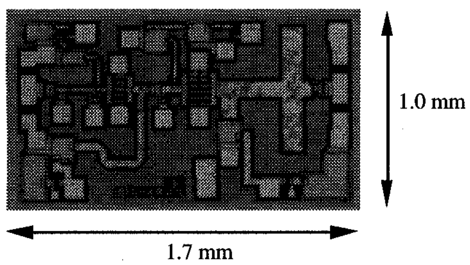

Figure 6. Ka-band monolithic medium power amplifier.

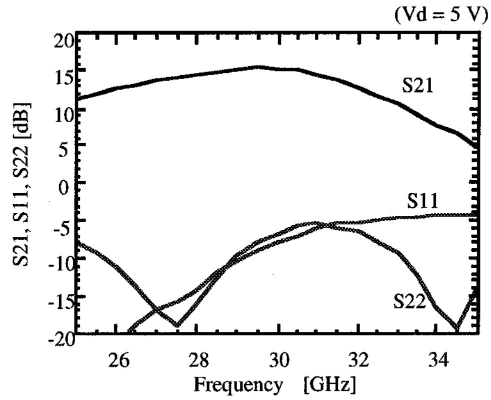

Figure 7. Small signal performances of a Ka-band monolithic medium power amplifier

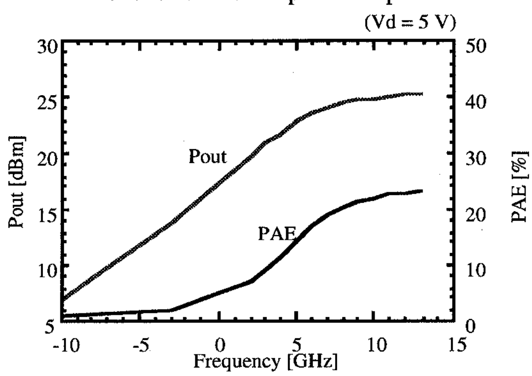

Figure 8. Measured output power and efficiency versus input power of a Ka-band monolithic medium power amplifier

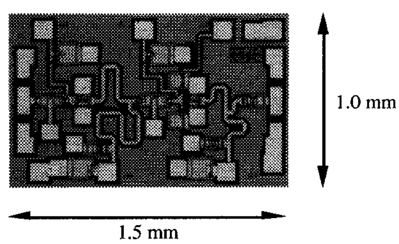

Figure 9. Ka-band monolithic variable gain amplifier using lumped element matching circuits

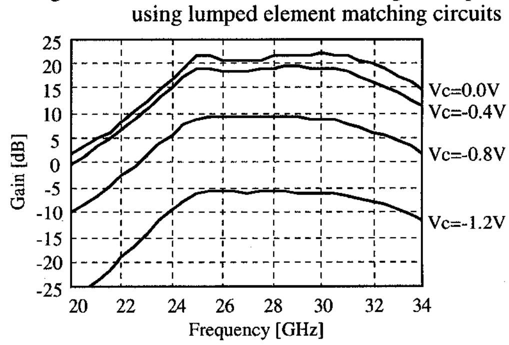

Figure 10. Small signal performances of a Ka-band monolithic variable gain amplifier

MODULE PERFORMANCES

A low-cost ceramic-wall made package was utilized for a Ka-band power amplifier module. The performance of the package measured with 50 ohm through line were a feed-through insertion loss of 0.3 dB and a return loss of more than 12 dB at 40 GHz. The developed MMICs were assembled in the package and the performances of the packaged devices were measured. Figure 11 shows the power amplifier module. The size of those module is 9.6 mm x 6.1 mm x 2.1 mm excluding the screw areas. Small signal performance of the power MMIC amplifier is shown in Figure 12 and power performance is shown in Figure 13. Gain of more than 20 dB is obtained and a maximum output power of 1 W is obtained at 29.5 GHz. By using newly developed MMIC amplifiers, a compact Ka-band 1 W power amplifier module has been successfully realized.

CONCLUSION

A compact MMIC chip set for Ka-band communication systems has been developed. A two stage monolithic GaAs PHEMT amplifier delivers 1 watt with a very small chip size of 1.94 mm X 2.0 mm using only lumped element matching circuits from 28.5 GHz to 30 GHz. A medium power amplifier which delivers 0.35 watt with a linear gain of 15 dB, and a variable gain amplifier with -5 to 20 dB gain has also been realized using high performance double doped AlGaAs/InGaAs PHEMTs and uniform MIM capacitors. By using those newly developed MMIC amplifiers, a compact Ka-band 1 W power amplifier module has been successfully realized. We believe that our design approach to MMICs and packages are promising for low-cost power amplifiers for Ka-band communication systems.

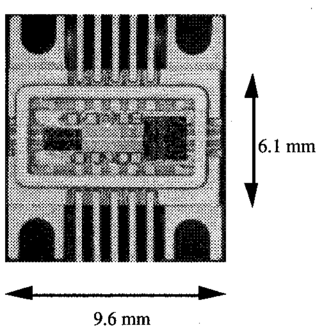

Figure 11. Ka-band power amplifier module

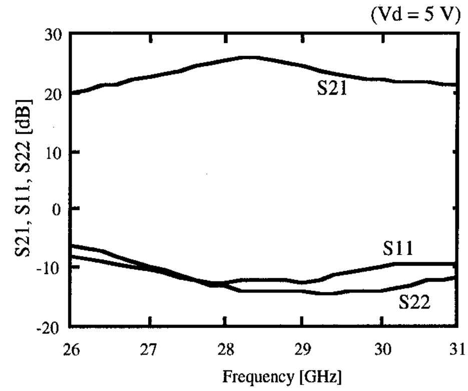

Figure 12. Small signal performances of a Ka-band power amplifier module

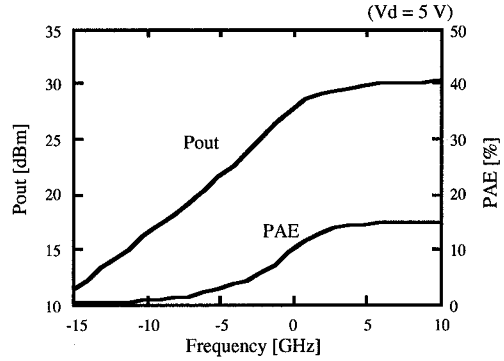

Figure 13. Measured output power and efficiency versus input power of a Ka-band power amplifier module

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