Area Reduction of Millimeter-Wave CMOS Amplifier Using Narrow Transmission Line

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***Abstract*—This paper presents small-area 60 GHz amplifiers using narrow transmission line. All the circuits presented by the authors were designed using narrow transmission line with a 6 μm signal line width. Because the phase constant of a narrow transmission line is larger, impedance matching is achieved using a much shorter line length compared with matching using a wider transmission line. Single-stage amplifiers utilizing narrow and wide transmission lines were fabricated and compared in 65 nm CMOS process. Use of narrow transmission lines can reduce layout area by 60 % while achieving a measured power gain of 6.54 dB, a measured output power at 1 dB compression point of 4.35 dBm and a measured saturated output power of 8.0 dB.**

***Index Terms*—Transmission line, 60 GHz, CMOS, power amplifiers.**

I. Introduction

Recently, wireless communications using 60 GHz ISM frequency band are actively studied. In the 60 GHz band, wide bandwidth can be used without license in many countries as shown Fig. 1. Utilizing such wide bandwidth, high-speed wireless communications can be realized.

On the other hand, in high frequency circuits as the ones operating at 60 GHz, it is difficult to take into account the parasitic impedance. Due to small component values, parasitics have a large effect and greatly varies their value. Moreover, since the wave length is close to component circuit dimensions, 60 GHz circuits have to be treated as distributed constant circuits and not as lumped-constant ones. Therefore, 60 GHz circuits are mainly designed using transmission lines. Transmission lines are useful since they can be used as a capacitor and an inductor by only changing their length. Various kinds of transmission lines are studied. For example, slow-wave transmission line[1] and enhanced hybrid transmission line[2] are used for 60 GHz circuits.

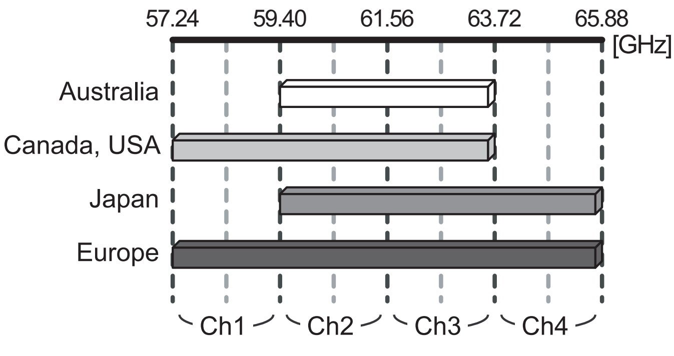

Fig. 1. Unlicensed band in each country.

Transmission line utilized in this work were designed as Guided micro-strip transmission lines since they have low loss. They were modeled using L-2L de-embedding method[3]. L-2L de-embedding method removes the parasitics of the pad and interconnections without approximation since the transmission line is measured twice at different lengths giving more accurate models. Therefore, simulation results become more accurate. The transceiver reported by the authors was fabricated by using a transmission line with a 10 μm signal line width[4]. Large area was occupied by the matching blocks that utilizes the transmission line.

This paper presents small area 60 GHz amplifiers by using a 6 μm-width transmission line. Amplifiers utilizing both narrow and wide transmission lines are compared in terms of area and achievable performance.

In this paper, section II describes transmission line characteristics, section III describes amplifier design, section IV describes measurement results and finally section V gives conclusion.

II. Transmission Line

In this work, Guided micro-strip line (GMSL) is used for matching blocks since it has low loss. Fig. 2 shows the structure of GMSL. it has a ground that consists of side and bottom walls. W and G in Fig. 2 represents the width of the signal line and the gap between it and the ground, respectively. Dummy metals must be placed between the signal line and the ground to satisfy the density rule. However, they degrade the performance of the GMSL due to eddy currents that flow in them and the added parasitic capacitance. However, in this work dummy metals were placed manually away from the signal line thus reducing line loss.

Two transmission lines are compared. One is W of 10 μm and G of 15 μm. The distance between the side grounds is

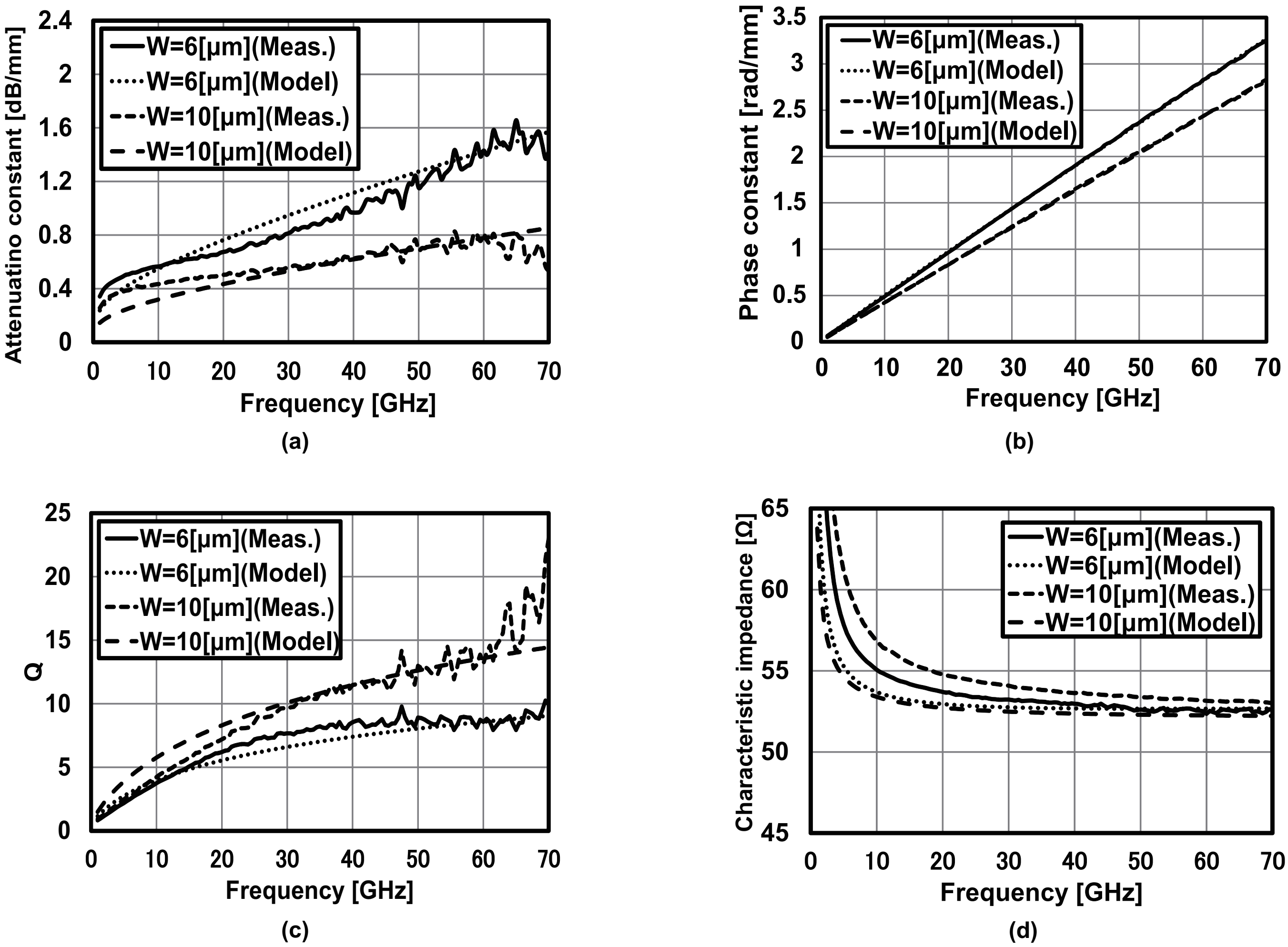

Fig. 3. (a)attenuation constant (b)phase constant (c)Q-factor (d)characteristic impedance.

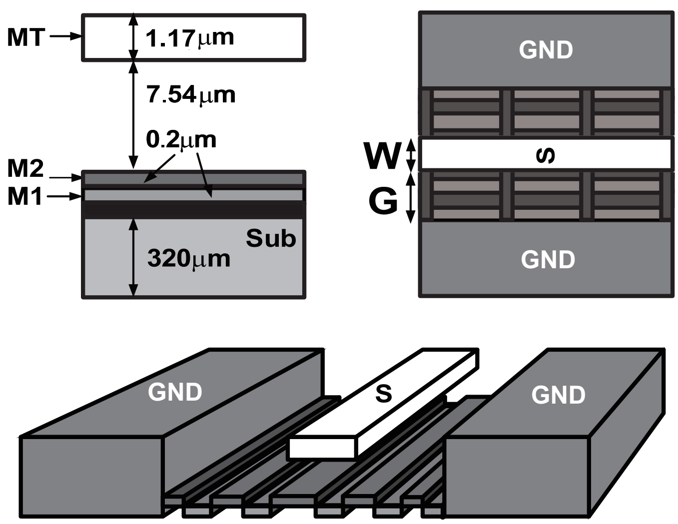

Fig. 2. The structure of Guided micro-strip line.

40 μm. Large area was occupied by the matching blocks that utilized this transmission line. Another one is W of 6 μm, G of 7 μm. The distance between the side grounds is 20 μm.

S-parameters of transmission lines are measured by L-2L de-embedding method as mentioned earlier. From the measurement results, attenuation constant, phase constant, Q-factor and characteristic impedance were calculated[5]. Fig. 3 shows each of these parameters that were calculated from measurement and model results. HFSS is used for model. Measurement results are almost in agreement with model results. The attenuation of the narrow and wide transmission lines are 1.43 dB/mm and 0.80 dB/mm at 60 GHz, respectively. The loss of transmission line becomes larger as width of signal line gets narrower. As for the phase constants, they are 2.8 rad/mm and 2.4 rad/mm for the narrow and wide at 60 GHz, respectively. The wavelength of a transmission line is given by:

$$\lambda = \frac{2\pi}{\beta} \tag{1}$$

Therefore, the wavelength of a transmission line becomes

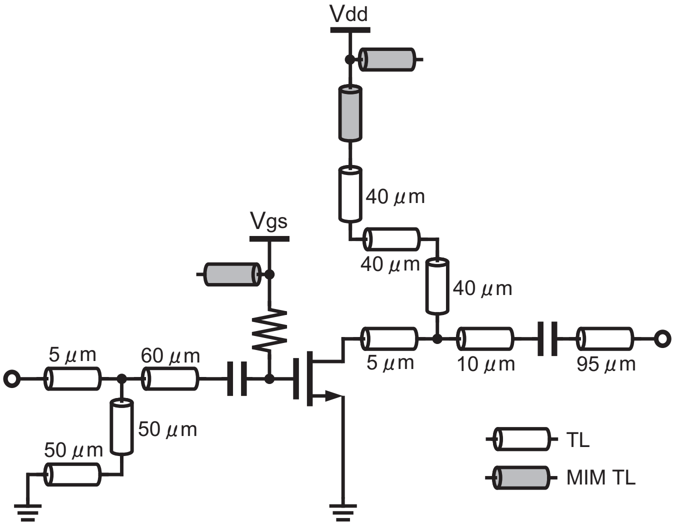

Fig. 4. Common source stage amplifier using narrow transmission line.

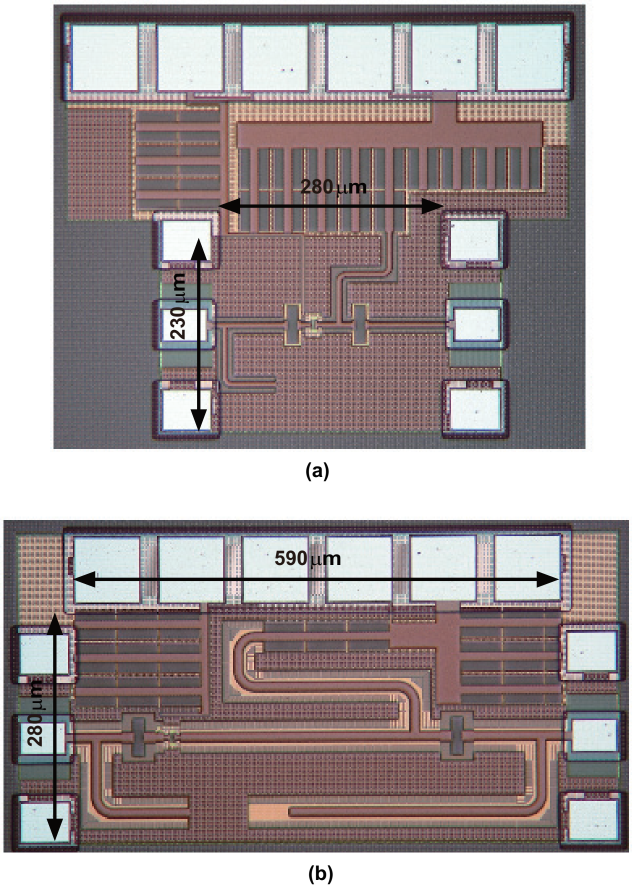

Fig. 5. The die micrograph of amplifiers. (a)W = 6 μm (b)W =10 μm

smaller as the signal line width becomes narrower leading to much smaller and shorter matching blocks compared to the wide one.

III. Amplifier Design

Common-source amplifiers are designed by using the narrow and wide transmission lines for matching blocks. Fig. 4 shows circuit schematic of the amplifier used for a performance comparison of both transmission lines. The width of transistor is $2 \times 20\,\mu$m and 300 fF capacitors are used as DC blocks. MIM transmission lines that have a signal line with low characteristic impedance are used as decoupling capacitors. Since these capacitors were designed as transmission lines, their length is scalable to obtain various capacitance values.

IV. Measurement Results

The two amplifiers are fabricated in 65 nm CMOS process. Fig. 5 shows the die micrograph of these amplifiers. The chip area of the one utilizing narrow transmission lines is larger due to the pad for DC probe which is needed to be placed away from the RF pad to facilitate on-chip probing. The core sizes of narrow and wide transmission line amplifiers are $280\,\mu\text{m} \times 230\,\mu\text{m}$ and $590\,\mu\text{m} \times 280\,\mu\text{m}$, respectively. Using narrow transmission lines reduced area by 60 % compared to using wide transmission line.

S-parameters of these circuits are measured up to 67 GHz by using a network analyzer. Fig. 6 shows S_{21} of both amplifiers. From the figure, maximums of S_{21} is about 6.59 dB for the amplifier with narrow transmission lines and 6.51 dB for the one with wide transmission lines.

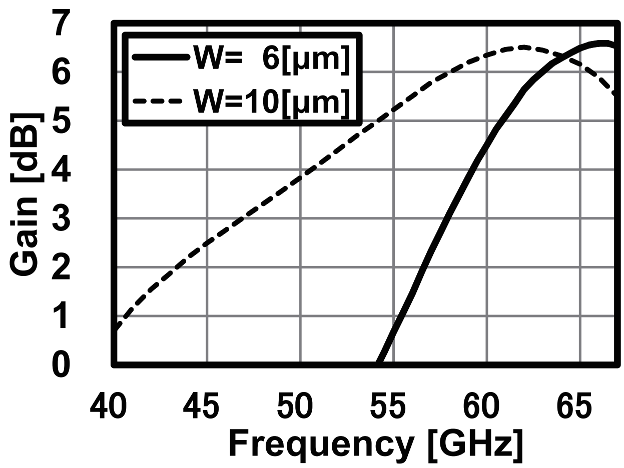

Fig. 6. Power gain.

Fig. 7 shows the output power, the power gain and PAE(Power Added Efficiency) of both amplifiers. The measured output power at 1 dB compression point, the measured saturated output power and the measured PAE at 1 dB compression point are 4.35 dBm, 8.25 dBm and 10.5 % for the amplifier with narrow transmission, respectively. The measured output power at 1 dB compression point, the measured saturated output power and the measured PAE at 1 dB compression point are 4.8 dBm, 8.0 dBm and 12.8 % for the amplifier with wide transmission, respectively.

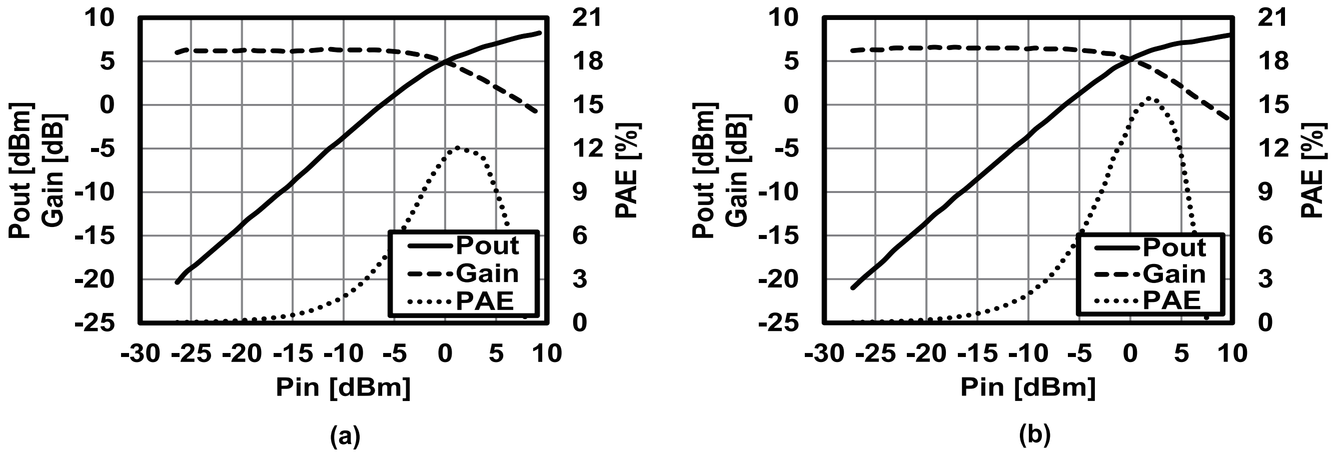

Fig. 7. Output power, Power gain and PAE. (a)W = 6 μm (b)W = 10 μm

Although the resistance per unit length of the narrow transmission line is higher, phase constant is large. Consequently, as matching blocks become smaller and loss is suppressed, the standard performance is achieved.

V. Conclusion

In this work, transmission lines with 6 μm signal line width is used to investigate area reduction of mmW amplifiers. Single stage amplifiers are fabricated using both narrow and wide transmission lines for matching blocks. The performance of both amplifiers is compared. The core size of the amplifier using narrow transmission line is reduced by 60 % while achieving maximum power gain that is smiler to the one using wide transmission lines. Thus, standard performance is achieved while circuit area became smaller when utilizing narrow transmission lines for matching.

Acknowledgment

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