Optimized Noise and Consistent RF Model for 0.18μm MOSFETs

C. H. Huang, H. Y. Li, Albert Chin, V. Liang*, and S. C. Chien*
Dept. of Electronics Eng., National Chiao Tung Univ., Hsinchu, Taiwan
*United Microelectronics Coperation, Hsinchu, Taiwan

Abstract **— Strong dependence of finger number on minimum noise figure (NF_{min}) is observed in 0.18μm MOSFETs. A lowest NF_{min} of 0.93 dB is measured at 5.8 GHz using 50 fingers but increases as either increasing or decreasing finger number. We have used a self-consistent S-parameter and NF_{min} model to analysis this abnormal finger number dependence, and the reason is due to the combined effect of reducing gate resistance and increasing substrate loss as increasing finger number.**

I. INTRODUCTION

By continuously scaling down the VLSI technology, the operation frequency of MOSFET-based ICs is already above GHz. Besides high operation frequency, the RF noise is another important factor for communication ICs that is directly related to S/N and limits the noise floor of a RF system. The noise source of a RF IC may come from both active MOSFET and passive device, and the major source of RF noise in passive device is from the parasitic shunt pass to ground due to the lossy Si substrate. Recently, we are able to tremendously reduce the RF noise from lossy substrate by using proton-implantation [1]-[3] that results in record high performance transmission line [3] and antenna [4] on Si up to 20 GHz. Thus, further reducing the noise floor in a RF IC is therefore relied on the improving noise of active MOSFET. In this paper, we have used different multi-fingered layout to optimize the RF noise in 0.18μm MOSFETs. A minimum noise figure (NF_{min}) of 0.93 dB is measured at 5.8 GHz using 50 fingers, and NF_{min} gradually increases as either increasing or decreasing finger number. To understand such abnormal dependence, we have used a self-consistent NF_{min} and S-parameter model to simulate the MOSFET and extracted the noise source inside the equivalent circuit model. The primary noises are coming from the series gate resistance (R_g) and gate shunt pass to ground ($R_{g\text{-}sub}$ & $C_{g\text{-}sub}$). The reason why a decreasing RF noise as increasing finger number <50 is due to the reduced R_g, while the increasing RF noise as increasing finger number >50 is due to the increased shunt loss to substrate similar to the passive device case [1]-[4]. The optimized noise is therefore from the tradeoff between reducing R_g and increasing shunt substrate loss that can give further device design and layout guideline for deep sub-μm MOSFETs and LNAs.

II. EXPERIMENTAL PROCEDURE

Multi-fingered layout of 0.18μm MOSFETs are used in this study. To achieve a low gate resistance, a silicide gate technology is applied. The finger width is 5 μm and the finger number is ranged from 20 to 70 at an increment of 10. The multi-fingered structure with a small finger width enables us to reduce both the DC silicide gate resistance and the RF non-quasi-static gate resistance [5]. The devices are first characterized by DC I-V and reliability test [6]. Then standard 2-port S-parameters are measured using HP8510B network analyzer and on-wafer probes and de-embedded from the probe pad. The NF_{min} and associate gain are measured using standard ATN-NP5B Noise Parameter Extraction System up to 7.2 GHz that covers the most important frequency range for wireless communication. Numerical simulation was performed by using an equivalent circuit model of intrinsic MOSFET with additional terminal resistance and shunt pass to ground at both input and output ports [7]. To avoid non-physically based data in the equivalent circuit model, DC and low frequency data are measured and referred in circuit model.

III. RESULTS AND DISCUSSION

A. Measured NF_{min} and finger dependence:

Fig. 1 shows the measured NF_{min} as a function of frequency and finger numbers. A general trend of increasing noise is observed for all the multi-fingered MOSFETs as increasing frequency, and a small NF_{min} ranged from 0.5 to 1.5 dB is measured over the measured frequency range that indicates the good noise performance. However, the measured NF_{min} is strongly dependent on the number of fingers.

To further investigate such gate finger dependence, we have plotted the NF_{min} as a function of finger number at a frequency of 5.8 GHz used for wireless local-area network (LAN). As shown in Fig. 2, an abnormal dependence of NF_{min} on finger number is observed: the NF_{min} first decreases as increasing gate finger until a smallest NF_{min} of 0.93 dB is measured at a finger number of 50 and then the NF_{min} increases as increasing finger number above 50.

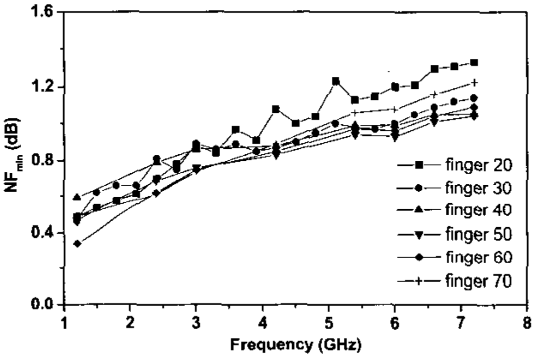


Fig. 1. Frequency dependence on NF_{min} of multi-fingered 0.18μm MOSFETs. A strong finger number dependence is found.

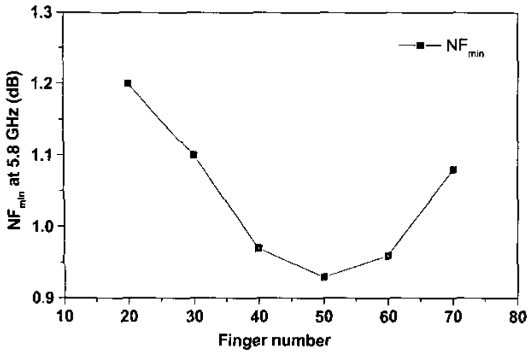


Fig. 2. Finger number dependence on NF$_{min}$ of 0.18μm MOSFETs at 5.8 GHz. The lowest NF$_{min}$ of 0.93 dB is obtained at a finger number of 50.

B. Modeled NF$_{min}$ and S-parameters:

We have used the equivalent circuit model [7] to analyze such abnormal gate finger dependence on NF$_{min}$. Fig. 3 shows the equivalent circuit model used for multi-fingered 0.18μm MOSFETs. The same model is used for all the gate finger numbers from 20 to 70, but each value of the circuit elements is dependent on the different finger numbers. This model also provides a self-consistent simulation between NF$_{min}$ and S-parameters that can be further used to investigate the dominated noise source in 0.18μm MOSFETs.

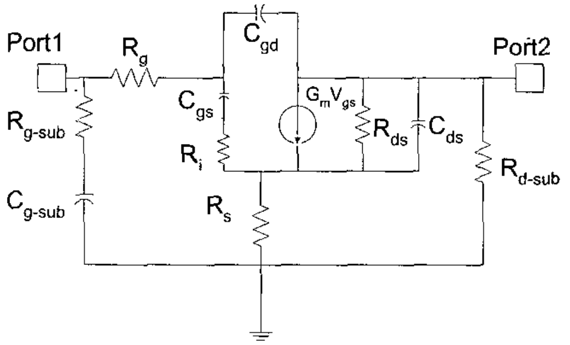
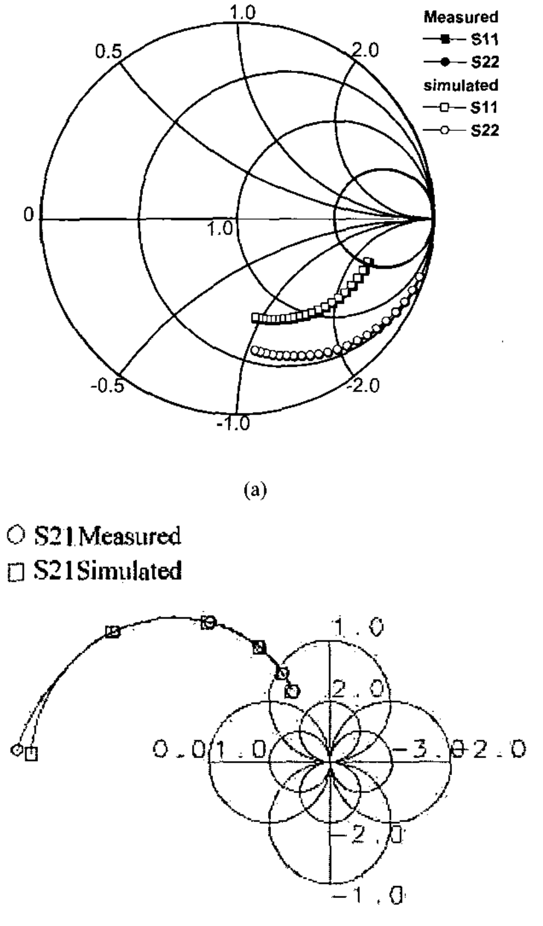


Fig. 3. The equivalent circuit model of multi-fingered 0.18μm MOSFETs.

Figs. 4(a) and 4(b) present the measured and modeled S-parameters plotted at radius of 1 and 6 respectively, with the smallest finger number of 20. Figs. 5(a) and 5(b) show the measured and modeled S-parameters plotted at radius of 1 and 11 respectively, with the largest finger number of 70. Good agreements between measured and modeled data are obtained for finger number of 20 and 70. Although the S-parameters for gate finger from 30 to 60 are not shown, similar good agreement between measured and modeled S-parameters are also achieved. The excellent agreement between measured and modeled S-parameters suggests the good accuracy of our equivalent circuit model.



(a)

(b)

Fig. 4. The simulated and measured S-parameters of 0.18μm MOSFETs plotted in respective radius of (a) 1 and (b) 6, and the finger number is 20.

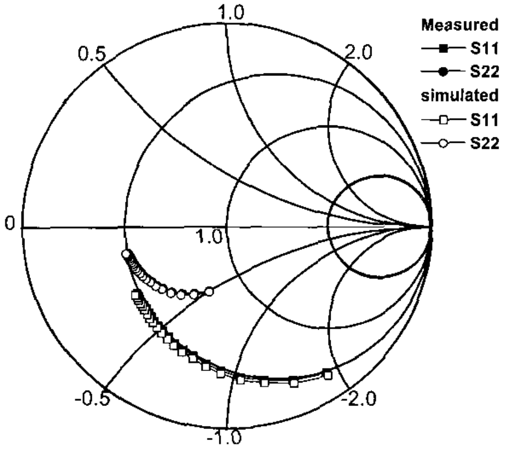
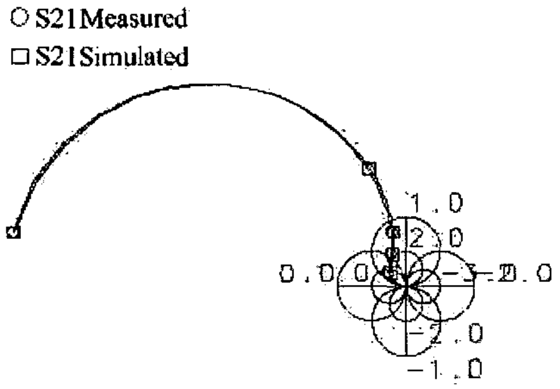


Fig. 5(a) The simulated and measured S-parameters of 70 fingered 0.18μm MOSFETs plotted in respective radius of 1



(b)

Fig. 5(b) The simulated and measured S-parameters of 70 fingered 0.18μm MOSFETs plotted in respective radius of 11.

We have further examined the measured and equivalent circuit modeled NF_{min} among various gate fingers. Figs. 6 and 7 show the measured and modeled NF_{min} for the finger number of 20 and 70, respectively. Good agreement between measured and modeled NF_{min} is achieved for these two gate fingers over the entire measured frequency. Similar good agreement between measured and modeled NF_{min} are also obtained for gate fingers from 30 to 60 (not shown). It is noticed that both S-parameters and NF_{min} are generated at the same model for a specific gate finger without changing any value of equivalent circuit elements. The good agreement between measured and modeled S-parameters and NF_{min} indicate the excellent accuracy of this equivalent circuit model.

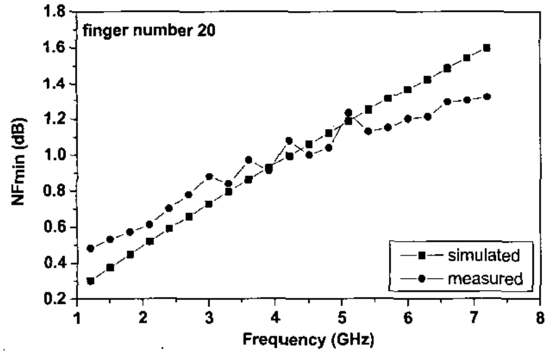


Fig. 6. The simulated and measured NF_{min} as a function of frequency of multi-fingered 0.18μm MOSFET with a finger number of 20.

C. Origin of abnormal NF_{min} dependence on finger number:

After achieving good agreement between measured and modeled S-parameters and NF_{min} among different fingers, we have further compared the equivalent circuit elements and the results are summarized in Table I. Because the noise of a cascade system follows the well known equation,

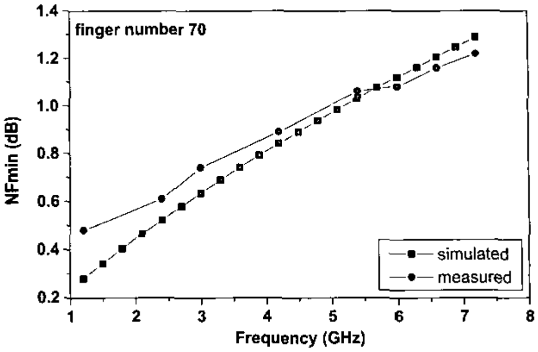


Fig. 7. The simulated and measured NF_{min} as a function of frequency for multi-fingered 0.18μm MOSFET with a finger number of 70.

$$F = F_1 + \frac{F_2 - 1}{G_1} + ... + \frac{F_N - 1}{G_1 G_2 .....G_{N-1}} \qquad (1)$$

the noise in the MOSFET is dominated by gate input terminal before amplified to drain output terminal. However, the influence of drain terminal becomes important at large gate fingers because of the increasing reverse feedback that is not considered in equation (1). Therefore, the thermal noise from R_g is the primary noise source in the MOSFET. This also explains the reduced NF_{min} as increasing gate fingers less than 50. It is noticed that a relatively large R_g listed in Table I may be due to the non-quasi-static effect. The reason why increasing NF_{min} as increasing gate fingers above 50 is due to the increasing shunt substrate loss to ground as evidenced from the decreasing $R_{g\text{-}sub}$ and increasing $C_{g\text{-}sub}$ in Table I. From above discussion, further scaling down the gate length beyond 0.18μm will be probably unable to further reduce the RF noise, because of the increasing R_g by a smaller gate area, the existing same shunt substrate loss as 0.18μm case, and the increasing reverse feedback from output terminal (short channel effect).

IV. CONCLUSION

We have measured and modeled the NF_{min} and S-parameters of multi-fingered 0.18μm MOSFETs. Strong dependence of NF_{min} on layout finger number is found that is due to the combined effect of R_g and shunt pass to substrate. A very small NF_{min} of 0.93 dB is measured for a finger number of 50 at 5.8 GHz that indicates the good potential application for high performance LNA for wireless LANs.

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Table I.

Important device parameters used for multi-fingered 0.18μm MOSFETs.

Parameter/ Finger no.	$C_{g\text{-sub}}$ (pF)	$R_{g\text{-sub}}$ (Ohm)	R_g (Ohm)	C_{gs} (pF)	G_m (ms)	C_{gd} (pF)	C_{ds} (pF)	R_{ds} (Ohm)	$R_{d\text{-sub}}$ (Ohm)
20	0.05	80	28	48	19.81	0.08	0.14	199.93	299
30	0.06	50	18	47.65	26.48	0.08	0.3	100	200
40	0.08	45	15	50	30	0.11	0.76	50.85	180
50	0.10	42	12	45	40	0.15	0.99	50.07	160
60	0.12	39	10	44.87	42	0.2	1.51	45	110
70	0.15	36	8.5	49.75	50	0.21	3.9	10	50

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