

行政院國家科學委員會專題研究計畫 期中進度報告

子計劃一：矽射頻元件模型與技術(1/3)

計畫類別：整合型計畫

計畫編號：NSC91-2215-E-009-070-

執行期間：91年08月01日至92年07月31日

執行單位：國立交通大學電子工程學系

計畫主持人：荊鳳德

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(計畫名稱)

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中 華 民 國 九 十 二 年 三 月 五 日

一、中文摘要

本計畫主要研究矽射頻元件 0.18 μm MOSFETs 其閘極數對於雜訊之影響。而發現最低之雜訊取得在 50 個閘極數時其值為 0.93 dB 在 5.8GHz，無論是增加閘極數或減少都會提高其雜訊指數，另一方面，在高頻之 S 參數量測及雜訊模型去分析其不同之閘極數對於其雜訊影響，其為當增加閘極數目時會因降低閘端之阻值而雜訊減少和基板之損失而造成雜訊之增加。

關鍵詞：矽射頻元件，S 參數量測。

二、英文摘要

Strong dependence of finger number on minimum noise figure (NF_{\min}) is observed in 0.18 μm 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

關鍵詞： NF_{\min} , S-parameter, gate resistance, substrate loss

三、報告內容：

甲、前言：

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 0.18 μm 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.

乙、研究方法

Multi-fingered layout of $0.18\ \mu\text{m}$ MOSFETs are used in this study. To achieve a low gate resistance, a silicide gate technology is applied. The finger width is $5\ \mu\text{m}$ 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.

丙、結果與討論 (結論與建議)

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

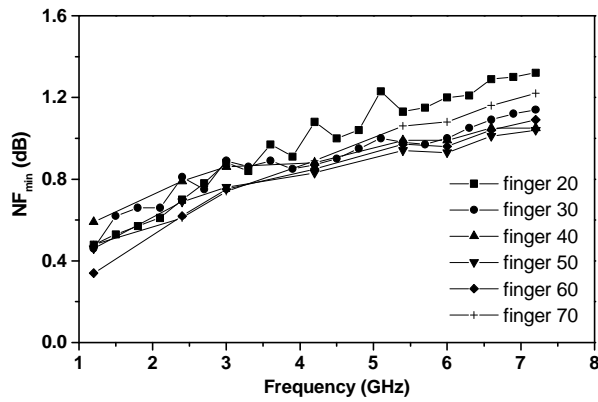
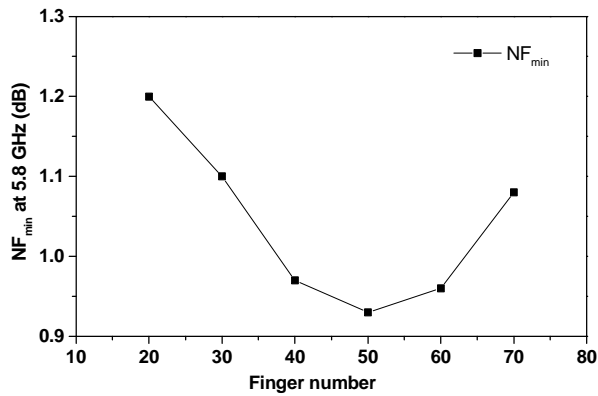


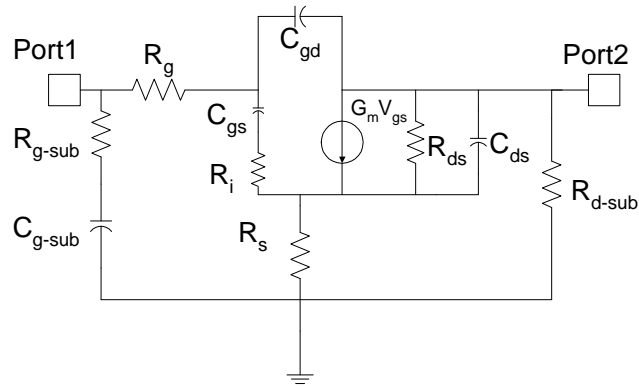
Fig. 2



B. Modeled NF_{min} and S-parameters:

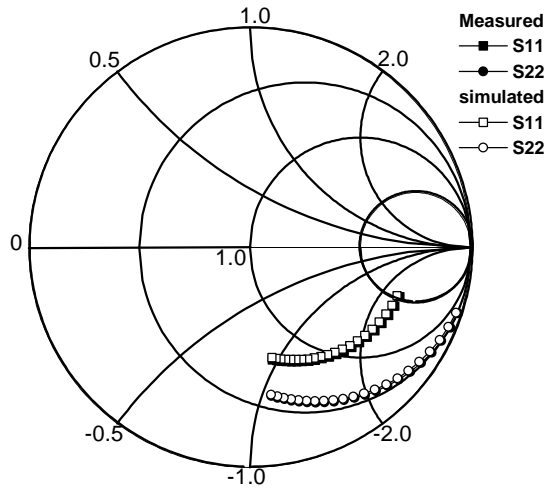
We have used the equivalent circuit model [7] to analyze such abnormal gate finger dependence on NF_{\min} . Fig. 3 shows the equivalent circuit model used for multi-fingered $0.18\mu\text{m}$ MOSFETs. The same model is used for all the gate finger numbers from 20 to 70, but each value of the circuit 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 $0.18\mu\text{m}$ MOSFETs.

Fig. 3

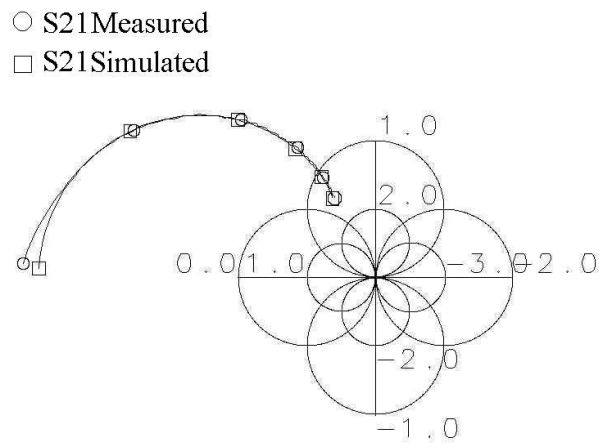


Figs. 4(a) and 4(b) present the measured and modeled S-parameters plotted at radius of 1 and 6 respectively, with the smallest finger number of 20. Figs. 5(a) and 5(b) show the measured and modeled S-parameters plotted at radius of 1 and 11 respectively, with the largest finger number of 70. Good agreements 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.

Fig. 4

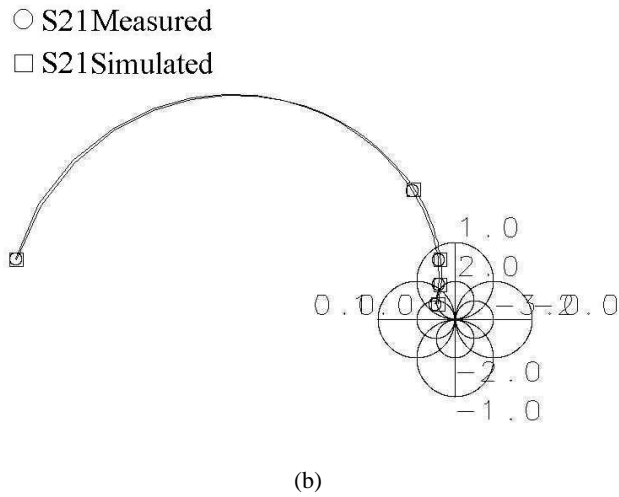
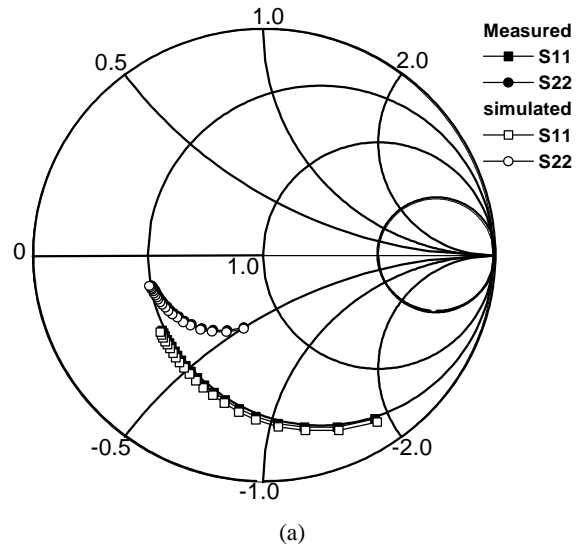


(a)



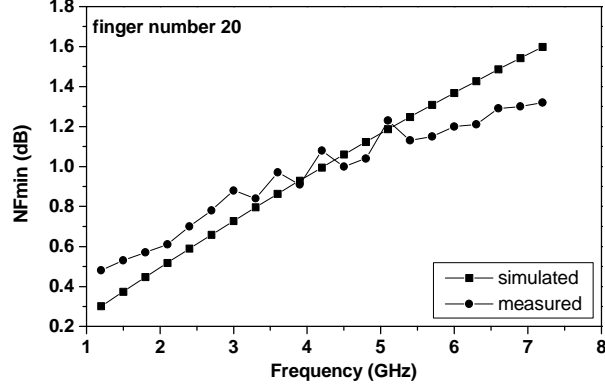
(b)

Fig. 5



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.

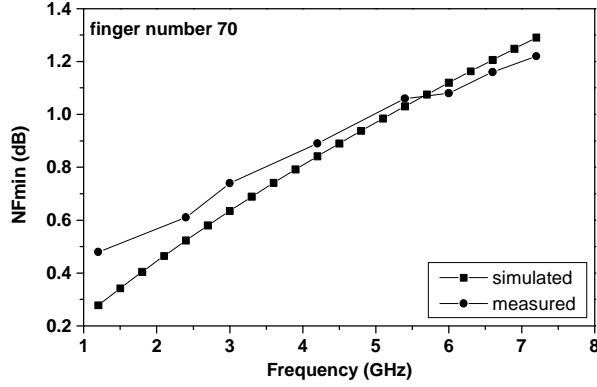
Fig. 6



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



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

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-sub} in Table I. From above discussion, further scaling down the gate length beyond 0.18 μ m 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 0.18 μ m, and the increasing reverse feedback from output terminal (short channel effect).

丁、已有論文發表附錄

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五、計畫成果自評

We have measured and modeled the NF_{min} and S-parameters of

multi-fingered 0.18 μ m 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.