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Accurate Prediction of Transimpedances and Equivalent Input Noise Current Densities of Tuned Optical Receiver Front Ends

Qing Zhong Liu

Abstract

Novel analytical expressions have been derived for calculating transimpedances and equivalent input noise current densities of five tuned optical receiver front ends based on PIN diode and MESFETs or HEMTs. Miller's capacitance, which has been omitted in previous studies, has been taken into account. The accuracy of the expressions has been verified by using Touchstone simulator. The agreement between the calculated and simulated front end performances is very good.

Introduction

In optical fiber transmission systems, the optical receiver front end plays an important role [1]. The sensitivity of the receiver is limited by different noise factors. Among these factors, the f^2 thermal noise term from FETs channel is a dominating one for high frequency and wideband applications. To suppress f^2 noise, different tuning networks have been applied between the photo detector and the FETs preamplifier. Consequently, the receiver sensitivity has been improved significantly. Some analysis and design information on the tuned optical receiver front ends have been reported in [2]-[4]. In order to make further complex computer simulations and optimizations of the front ends, it is necessary to be able to provide a good starting point and to avoid the local minima in the optimizations.

In this paper, we present some novel analytical and simple expressions which can be used to calculate the transimpedances and equivalent input noise current densities of the most widely used tuned front ends based pin diode and FETs. The expressions have been verified by using Touchstone. The comparison between the calculated and simulated front end performances is shown.

Derivation of Expressions

A diagram of a tuned optical receiver front end based on a pin diode and a FET is shown in Fig.1. The diode is modelled as a current source, a junction capacitance, and a series resistor. The FET is represented by an equivalent circuit, which is valid for both MESFETs and HEMTs. The five different tuning networks are shown in Fig.2 (a)-(e), respectively.

To derive the expression for transimpedance of the front end, we calculate the voltage drop V_1 on C_{gs} as function of current I_s. The output voltage V_o of the front end amplifier is then determined and finally the transimpedance is obtained by dividing V_o by I_s.

In [5], an analytical expression was given for calculating the equivalent input noise current density of a T equivalent transformer tuned front end, where the correlation between the gate and drain noises has been taken into account. Based on that work, we derived the expressions for determining the equivalent input noise current densities of all other tuned front ends.

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In the present work, Miller's capacitance, which has been omitted in previous studies, has been included. In fact, neglecting the Miller's capacitance results in an over-estimation of transimpedance and underestimation of input noise current density of the front ends. The accuracy of the calculation has also been improved by taking into account of resistance R_{in}, R_g and R_s.

In the following we will only show the expressions for calculating the transimpedance and equivalent input noise current density of a π equivalent transformer tuned front end. The expressions can be applied to other tuned front ends by simple modifications.

It can be shown that the transimpedance of the π equivalent transformer tuned front end is given by:

$$Z_{tm} = \frac{-g_m R_{ds} R_L Z_{gs} Z_a Z_2 Z_4}{[Z_{em} + Z_{gs} + Z_{in} + Z_{ss}\,(1 + g_m Z_{gs})]\,[R_{ds} + R_L + Z_{ss}](Z_3 + Z_4)Z_1} \quad (1)$$

where

$$Z_{gs} = \frac{1}{j\omega C_{gs}} \qquad Z'_{gd} = \frac{1}{j\omega C'_{gd}} \qquad Z_a = \frac{1}{j\omega C_j}$$

$$Z_{p1} = j\omega L_{p1} \qquad Z_{p2} = j\omega L_{p2} \qquad Z_s = j\omega L_s$$

$$C'_{gd} = \left[1 + g_m\,(R_{ds} \| R_L)\right] C_{gd} \qquad Z_{in} = R_g + R_{in}$$

$$Z_{ss} = j\omega l_s + R_s \qquad Z_1 = Z_a + R_j$$

$$Z_2 = Z_1 \| Z_{p1} \qquad Z_3 = Z_2 + Z_s$$

$$Z_4 = Z_{p2} \| Z'_{gd} \qquad Z_{em} = Z_3 \| Z_4$$

Since the f^2 thermal noise term from FETs channel is a dominating factor for high frequency and wideband applications, we will only consider its contribution in the following. It can be shown that the equivalent input noise current density of the π equivalent transformer tuned front end is given by:

$$\frac{\overline{i^2_{in}}}{\Delta f} = \frac{4KT}{g_m} \frac{1}{|Z_{21}/A|^2} \{ P + R|Z_{GO}|^2(\omega C_{gs})^2 - 2C_{or}\sqrt{PR}\,(\omega C_{gs}\,\mathrm{Im}\,[Z_{GO}])\} \quad (2)$$

where

$$Z_{21} = \frac{Z_a Z_2 Z_{gs} Z_{em}}{Z_1 Z_3\,[(1 + g_m Z_{gs})Z_{ss} + Z_{in} + Z_{gs} + Z_{em}]}$$

$$Z_{GO} = Z_{gs} \| (Z_{em} + Z_{ss} + Z_{in})$$

$$A = \frac{Z_{ss} + Z_{in} + Z_{gs} + Z_{em}}{(1 + g_m Z_{gs})Z_{ss} + Z_{in} + Z_{gs} + Z_{em}}$$

Eqs.(1) and (2) can be used for other tuned front end configurations. To calculate the transimpedance and input equivalent noise current density of a serially tuned front end, Z_{p1} is set to be infinite, and Z_{p2} is replaced by a load resistance R_b. A noise term $4KT/R_b$ resulting from R_b has to be added in the calculation of the noise current density. The expressions for a parallel tuned front end are obtained by letting L_s be infinitesimal. By using the well known π to T network transformation, transimpedance and equivalent input noise current density of the T equivalent transformer tuned front end can also be calculated. The expressions are obtained for 3rd order bandpass tuned front end by replacing the series inductance Z_s with $Z_s + Z_c$, where Z_c is the reactance of series capacitance C_c in the tuning network.

Comparison Between Calculations And Simulations

To demonstrate the accuracy of the expressions, the transimpedances and equivalent input noise current densities of five different tuned front ends have been calculated by using the expressions and simulated by using Touchstone simulator, respectively. The photo diode used is a pin diode from BT&D (PDC 4300) with C_j of 0.12 pf and R_j of 10 Ω. The FET is a HEMT from NEC (NE20200).

In Fig.3 (a)-(e), comparisons between the calculated and simulated transimpedances of the front ends are shown. For a serially tuned front end, the maximum deviation between the calculated and simulated results is about 2.5 dB from DC to 12 GHz. For all the bandpass tuned front ends, the maximum deviation is less 2 dB. It can be seen that the parallel tuned front end is only suitable for narrow band applications. Compared with the T equivalent transformer and π equivalent transformer tuned front ends, the 3rd order bandpass tuned end offers wider bandwidth. In Fig.4 (a)-(e), comparisons between the calculated and simulated equivalent input noise current densities of different front ends are shown. The agreement between the calculated and simulated results is good. The maximum deviation between the calculated and simulated results is less than 2 pA/√Hz for the serial tuned front end. For the bandpass tuned front ends, the maximum deviations are less than 2.5 pA/√Hz. The results shown above are not the optimized ones, and further computer simulations and optimizations are needed to obtain better performances of the front ends for specified applications.

Conclusions

In this paper, we presented some novel and analytical expressions for calculating the transimpedances and equivalent input noise current densities of five tuned optical receiver front ends based on the PIN diode and FETs. The expressions can be used for analysis of front ends built with either MESFETs or HEMTs. The accuracy of the expressions has been verified by using Touchstone simulator. The expressions will find applications in predicting performances and providing a starting point for simulation and optimization of the optical receiver front ends.

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References

[1] S.D.Personick, The Bell System Technical Journal. Vol.52, No.6, 1974, pp.843-886.

[2] T E. Darcie et al, J. of Lightwave Technology. Vol.6. No.4. 1988. pp.582-589.

[3] N.Ohkawa, J. of Lightwave Technology. Vol.6. No.11. 1988. pp.1665-1671.

[4] G.Jacobsen et al, J.of Lightwave Technology. Vol.7. No.1. 1989. pp.105-114.

[5] K E. Alameh et al, IEEE Trans. MTT., Vol.38, No. 5, 1990, pp.546-551.

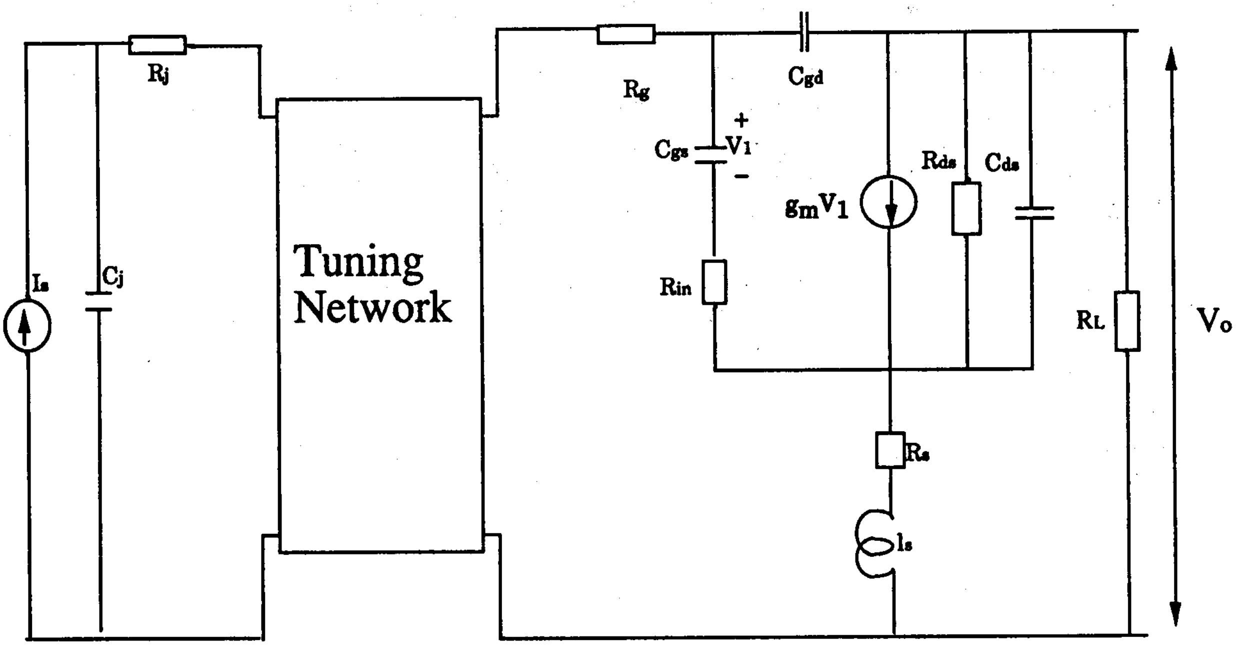

Fig.1 Diagram of a general tuned optical receiver front end based on PIN diode and FET

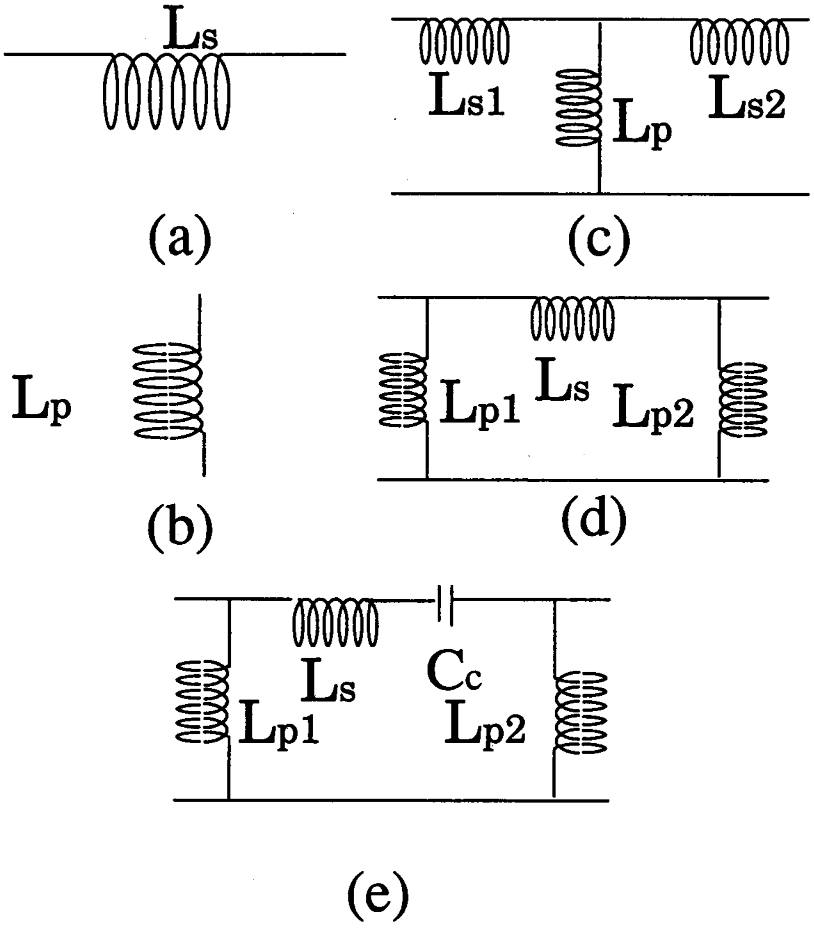

Fig.2 Tuning networks of (a) serially (b) parallel (c) T-equivalent transformer (d) π equivalent transformer (e) 3rd order bandpass

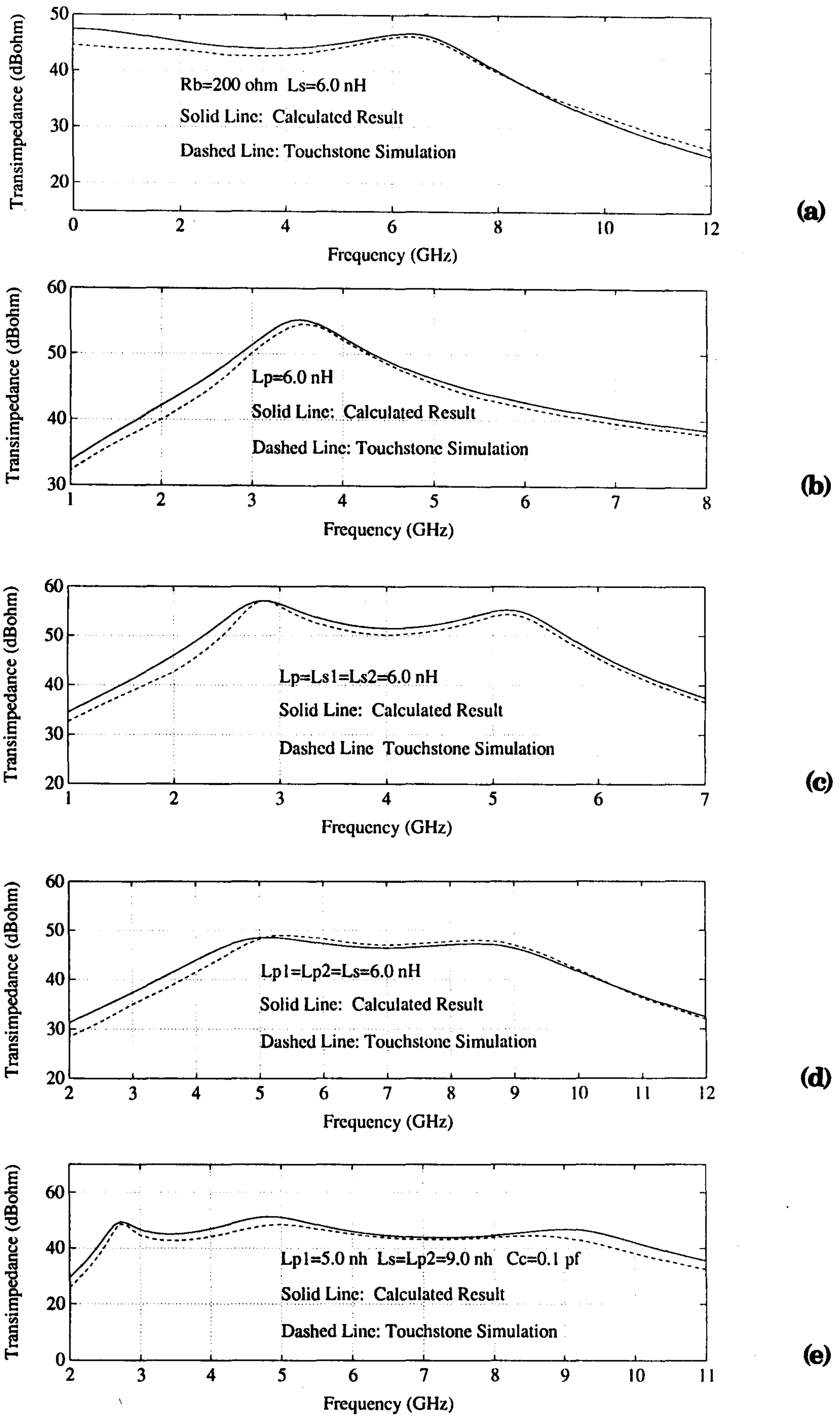

Fig.3 Comparisons between the calculated and simulated transimpedances of the front ends with tuning network of (a) serially (b) parallel (c) T-equivalent transformer (d) π equivalent transformer (e) 3rd order bandpass

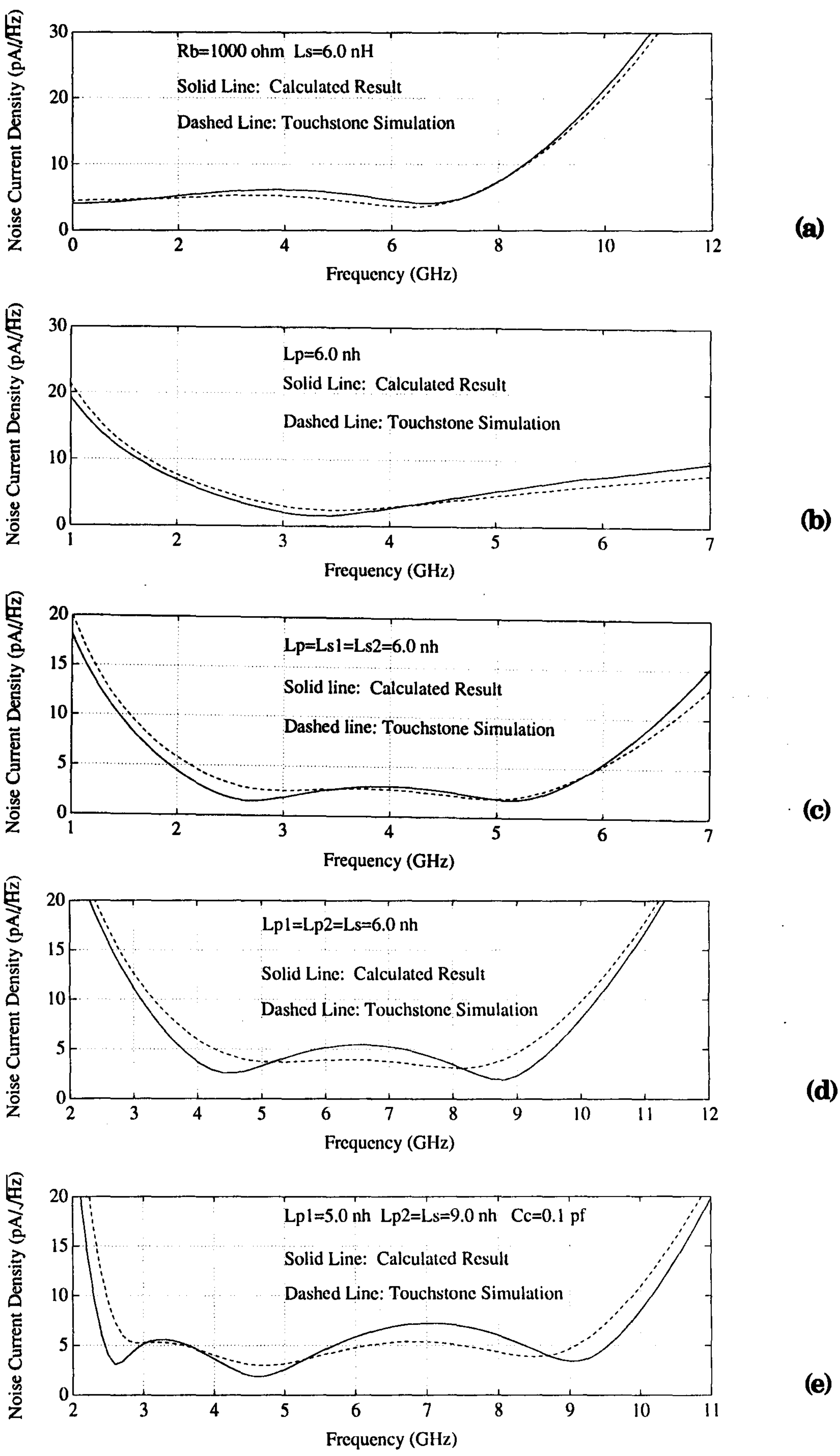

Fig.4 Comparisons between the calculated and simulated equivalent input noise current densities of the front ends with tuning network of (a) serially (b) parallel (c) T-equivalent transformer (d) π equivalent transformer (e) 3rd order bandpass