# A Low Noise Broadband GaAs MESFET Monolithic Distributed Preamplifier



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## Abstract

It is shown that the equivalent input noise current density of a distributed preamplifier of an optical receiver can be improved by using large gate line matching impedance. A monolithic GaAs MESFET distributed preamplifier utilizing this design consideration was fabricated. Using a 35 μm InGaAs p-i-n photodiode, it was shown to have an equivalent input noise current density of 8 $pA/\sqrt{Hz}$ and an 8 GHz bandwidth. To date, this is the best known result for a 0.8 μm GaAs MESFET process.

## Introduction

As the bit rate of optical communications systems increases into the 10 Gb/s and beyond, there is interest in the development of large bandwidth low noise receivers[1]. A GaAs MESFET transimpedance preamplifier using a gate length of 0.5 μm was able to obtain an equivalent input noise density of 12 $pA/\sqrt{Hz}$ and a transimpedance gain of 44 dBΩ over a frequency range of DC - 7.8 GHz [1]. The first demonstrated distributed preamplifier had a bandwidth of 23 GHz with an input noise of greater than 20 $pA/\sqrt{Hz}$ [2] and was fabricated using a MESFET process that utilized a gate length of 0.3 μm. Recently, the distributed preamplifier was demonstrated using a HEMT process which had an improved noise performance of 15 $pA/\sqrt{Hz}$ over the operating frequency band of 2-18 GHz [3]. All the previously demonstrated distributed preamplifiers used a gate line impedance of 50 Ω [2][3].

It is shown that an improved noise performance can be obtained by using a gate line impedance of 100 Ω. A single photodiode distributed preamplifier was constructed using a 0.8 μm GaAs MESFET process available at Northern Telecom (NT). This distributed preamplifier was shown to have a bandwidth of 8 GHz . It also has an equivalent input noise current density of 8 $pA/\sqrt{Hz}$, which gives a predicted receiver sensitivity of -21 dBm for a 10 Gb/s intensity modulated direct detection system. To date, this is the best known result for a 0.8 μm GaAs MESFET process.

## Preamplifier Design

A simplified schematic of the optical preamplifier is shown in Fig. 1. The inductors $L_g$ and the input capacitors of the MESFET $C_{gs}$ form a transmission line with an impedance equal to $Z_{\pi g}=\sqrt{L_g/C_{gs}}$. Similarly, the drain line impedance is given by $Z_{\pi d}=\sqrt{L_d/C_{ds}}$. The gate and drain lines are matched with the terminating resistors equal to $Z_{\pi g}$ and $Z_{\pi d}$ so that input and output impedances of the preamplifier remain constant over a large frequency bandwidth. The magnitude of the transimpedance [4] in the passband is given by

$$|Z_{Tf}| = \frac{1}{2} g_m Z_{\pi g} Z_{\pi d} n \quad (1)$$

where $g_m$ is the transimpedance of the MESFET and n is the number of MESFETs in the distributed preamplifier structure. The equivalent input noise current density of the distributed preamplifier [4] is given by

$$\langle i^2\rangle = \left(1+\frac{2}{n}\frac{\sin n\phi}{\sin\phi}\cos n\phi+\frac{1}{n^2}\left(\frac{\sin n\phi}{\sin\phi}\right)^2\right)\langle i^2_{Z_{\pi g}}\rangle$$
$$+\frac{|Z_{\pi d}|^2}{4|Z_{Tf}|^2}\langle i^2_{Z_{\pi d}}\rangle$$
$$+\frac{1}{4}\sum_{r=1}^{n}(A(r,\phi)^2+B(r,\phi)^2)\langle i_g^2\rangle$$
$$+\frac{n|Z_{\pi d}|^2}{4|Z_{Tf}|^2}\langle i_d^2\rangle$$
$$+\frac{Z_{\pi d}}{2|Z_{Tf}|^2}\sum_{r=1}^{n}\mathrm{Re}\left(Z_{Tf}(A(r,\phi)+jB(r,\phi))e^{j(n-2r-1)\phi}\langle i_g i_d^*\rangle\right) \qquad (2)$$

where

$$\langle i^2_{Z_{\pi g}}\rangle=\frac{4kT}{Z_{\pi g}},\quad \langle i^2_{Z_{\pi d}}\rangle=\frac{4kT}{Z_{\pi d}},$$

$$A(r,\phi)=\frac{(n-r+1)}{n}\cos(2r-1)\phi+\frac{\sin(r-1)\phi}{n\sin\phi}\cos(r-1)\phi+1$$

and

$$B(r,\phi)=\frac{(n-r+1)}{n}\sin(2r-1)\phi+\frac{\sin(r-1)\phi}{n\sin\phi}\sin(r-1)\phi$$

$\phi=\omega\sqrt{L_gC_{gs}}=\omega\sqrt{L_dC_{ds}}$, *k* is Boltzmann's constant, and *T* is temperature in degrees Kelvin. The first two terms of $\langle i^2\rangle$ are the noise densities produced by the terminations $Z_{\pi g}$ and $Z_{\pi d}$. The remaining contributions are the noise sources produced by the MESFET. $\langle i_g^2\rangle$ and $\langle i_d^2\rangle$ are the gate and drain noise sources for the MESFET, and $\langle i_g i_d^*\rangle$ is the correlation between the gate and drain noise sources [5]. $\langle i^2_{Z_{\pi g}}\rangle$ dominates the noise contribution in $\langle i^2\rangle$[6]. Thus to reduce this noise contribution, one must make the termination $Z_{\pi g}$ as large as possible. The plots $\langle i^2\rangle$ versus frequency are shown in Fig. 2 for two impedances $Z_{\pi g}$= 50 Ω and 100 Ω. The following parameters were used in the calculation: $Z_{\pi d}$ = 50 Ω, $L_g$ = 0.5 nH ($Z_{\pi g}$= 50 Ω), $L_g$ = 2 nH ($Z_{\pi g}$= 50 Ω), n = 5, $c_{gs}$ = 200 fF, $g_m$ = 20 mS and p-i-n photodiode capacitance $c_d$ = 200 fF.

## Results

A monolithic distributed preamplifier was designed, Fig. 3, using Touchstone by HP/Eesof with $Z_{\pi g}$=100 Ω and constructed using a 0.8 μm self-aligned gate process at NT. The preamplifier chip was then wire bonded to a 35 μm NT p-i-n. The bond wire inductance was $L_S$ = 2 nH, which was used as inductive tuning [6]. Measured results of the distributed preamplifier are shown in Fig. 4. It can be seen that the receiver has an equivalent input current density of 8 pA/$\sqrt{Hz}$, a transimpedance gain of 46 dBΩ, and a 3 dB bandwidth of 8 GHz. Using 8 pA/$\sqrt{Hz}$ and 8 GHz bandwidth, the predicted best receiver sensitivity can be shown to be -21 dBm [7] for a 10 Gb/s system.

## Conclusion

A low noise broadband GaAs MESFET monolithic distributed preamplifier has been presented. High gate line matching impedance improves the noise performance of the distributed preamplifier. A monolithic distributed preamplifier demonstrated -3 dB bandwidth of greater than 8 GHz and an average input noise current density of 8 pA/$\sqrt{Hz}$. The predicted best receiver sensitivity at 10 Gb/s is -21 dBm. To our knowledge, the preamplifier described has the lowest noise performance in this band based on 0.8 μm GaAs MESFET technology.

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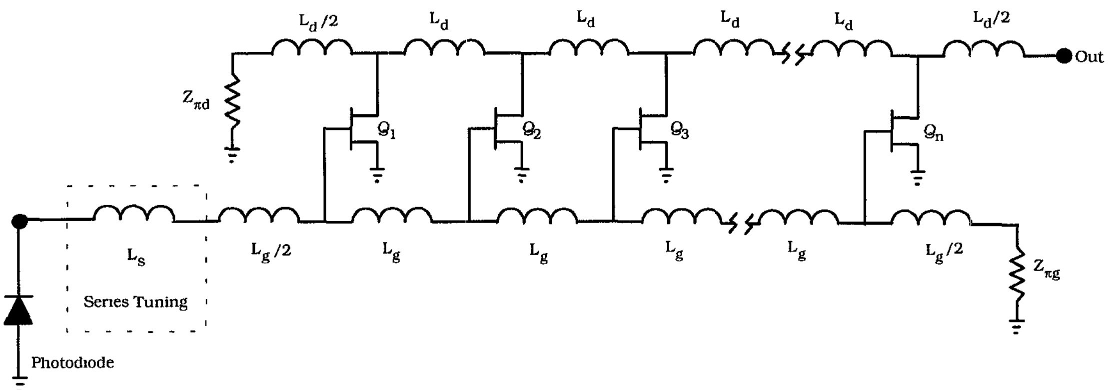


Fig. 1 Distributed preamplifier with series tuning inductor.

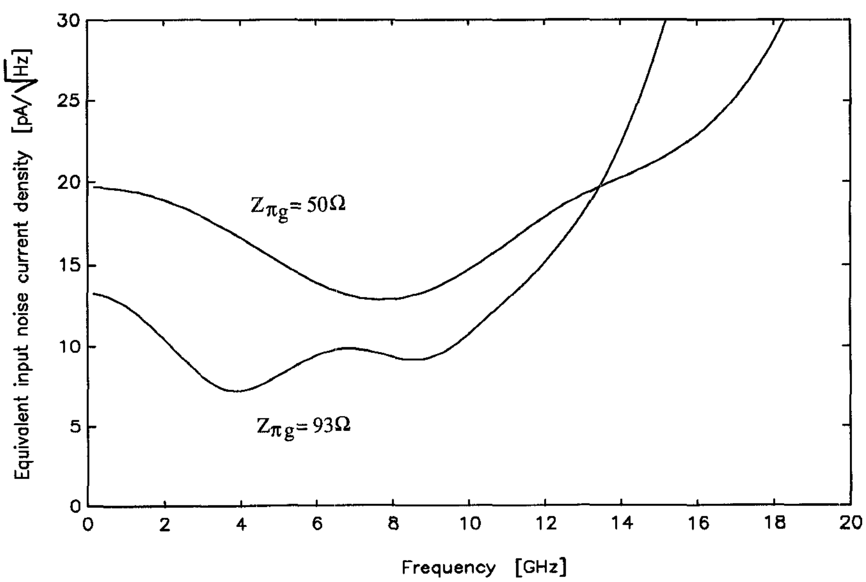


Fig. 2 The modelled equivalent input noise current densities of various components in the distributed preamplifier. $L_S = 0$.

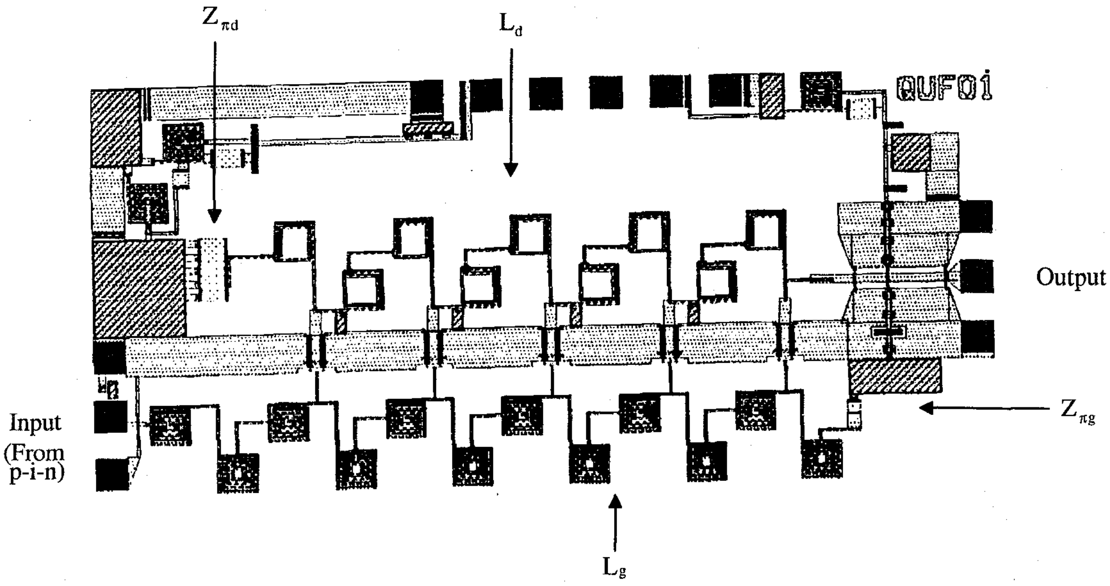


Fig. 3 Distributed preamplifier layout. Note the large inductance of $L_g$ is to obtain $Z_{\pi g}$=100 Ω.

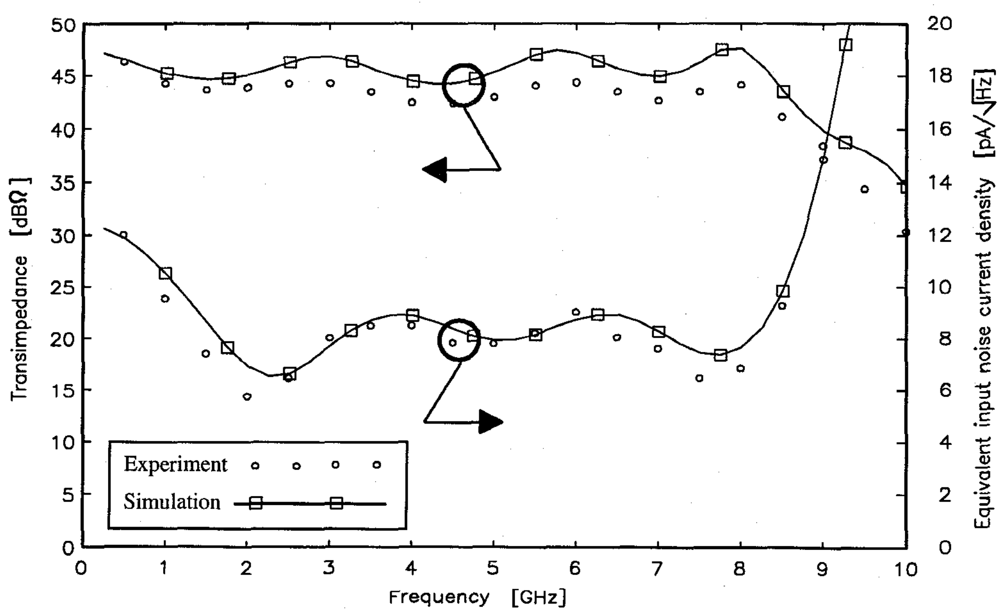


Fig. 4 The simulated and measured transimpedance and equivalent input noise current densities of a distributed preamplifier.