Low-Noise Distributed Amplifier with Active Load

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***Abstract*—Conventional distributed amplifiers show a marked increase in noise figure at frequencies below $2\cdots6$ GHz, depending on the design, because of noise emanating from a resistor that terminates the input line. It is shown in this letter that a low-noise device can be configured to emulate a one-port resistor, but with lower apparent noise temperature than the physical ambient temperature. The use of such an "electronically cold" resistor in the design of a low-noise distributed amplifier is discussed together with simulated results. The new distributed amplifier shows improved noise performance.**

I. INTRODUCTION

THE distributed amplifier (DA) can be designed to give flat gain response from very low frequencies (in principle, dc) up to the tens of GHz, depending on the active device. However, for low-noise operation, the noise performance of a DA is poorer at low frequencies than at mid-band frequencies even though the intrinsic noise figure of the active devices gets better at low frequencies. This occurs, because at low frequencies the noise from the gate line termination dominates over the noise of the active devices. It has been shown that this "corner frequency" is lower and the overall noise figure is lower at low frequencies as the number of devices in the DA increases [1]. However, for many reasons, the number of devices cannot be increased indefinitely. Practical DA designs with four to eight active devices show noise figure increase at frequencies below 6–2 GHz [2]–[4].

This letter proposes a novel design that uses an active device as the gate line termination. Electronically, the active termination appears as a (approximately 50 Ω) resistor over a wide band of frequencies. Its noise contribution, however, is less than that of a room temperature resistor. "Electronically cold" resistors have been proposed before [6] in different circuit configurations. However, the application discussed in this letter is new.

II. ACTIVE GATE LINE TERMINATION AND ITS NOISE

Consider the circuit shown in Fig. 1(a). The capacitance CFB between the gate and drain is assumed to be large enough to appear essentially as a short (at signal frequencies). Resistors $R1$ and $R2$ are for biasing purposes and have values much larger than 50 Ω. It is easy to show that at low frequencies the admittance seen looking into port 1 on the left is

$$Y_{\text{in}} \approx g_m + g_{\text{ds}} \approx g_m \tag{1}$$

where g_m and g_{ds} are the transconductance and output conductance, respectively, of the transistor. The second approximation in (1) is justified if the device has large voltage gain.

Next consider the noise properties of the this circuit. Let us use Pospieszalski's noise model [7] and compute the short circuit noise current [see Fig. 1(b)]. The result is

$$i_{\text{sc}} = i_{\text{nd}} + e_{\text{ng}}\frac{g_m - j\omega C_{\text{gs}}}{1 + j\omega C_{\text{gs}}R_i}. \tag{2}$$

At low to moderate frequencies the strength of the short-circuit noise current simplifies to

$$\langle |i_{\text{sc}}|^2\rangle \approx \langle |i_{\text{nd}}|^2\rangle + g_m^2\langle |e_{\text{ng}}|^2\rangle \tag{3}$$

where the brackets $\langle\rangle$ indicate time averaging to obtain the strength of a noise source. Equation (3) makes use of the property of the noise model [7] that the drain and gate noise sources are essentially uncorrelated. Because we now have established that the circuit of Fig. 1(a), at low frequencies, approximates a resistor of value $\frac{1}{g_m}$ and has a short-circuit noise current as given by (3), we can say it has an apparent noise temperature of

$$T_{\text{app}} = \frac{\langle |i_{\text{nd}}|^2\rangle}{4kBg_m} + \frac{g_m\langle |e_{\text{ng}}|^2\rangle}{4kB} \tag{4}$$

where k is the Boltzman constant and B is the incremental bandwidth. Substituting typical values, extracted from experimental data taken from low-noise GaAs-based pHEMT's [8], into (4) we get an apparent noise temperature of 163 K for device operation at room temperature. Thus, an active termination should contribute only about half as much as noise as a room temperature resistor of equal value. It is interesting to note that for the numerical values from [8] ($\langle |i_{\text{nd}}|^2\rangle = 1.6 \times 10^{-22}$ A^2/Hz, $\langle |e_{\text{ng}}|^2\rangle = 1.2 \times 10^{-19}$ V^2/Hz, and $g_m = 0.029$ S for a device with 75 μm gate width and 0.25 μm length), the first term (drain noise) contributes 100 K while the second term (gate noise) contributes 63 K. The apparent temperature given by (4) is independent of device size to the extent that equivalent circuit components scale "normally" (g_m is proportional, R_{ds} and R_i inversely proportional to gate width). This results is expected as this type of active termination has the same apparent noise temperature regardless of the value of resistor is emulates. However, the noise temperature is a function of bias and it is obvious

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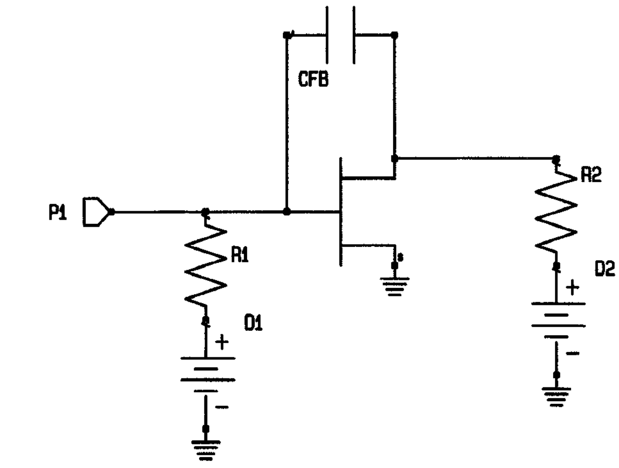
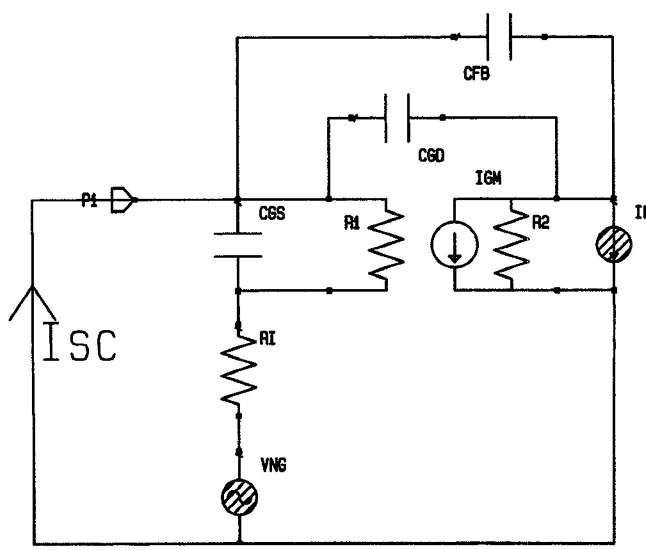


(a)



(b)

Fig. 1. (a) The active low-noise termination. (b) Simplified equivalent circuit.

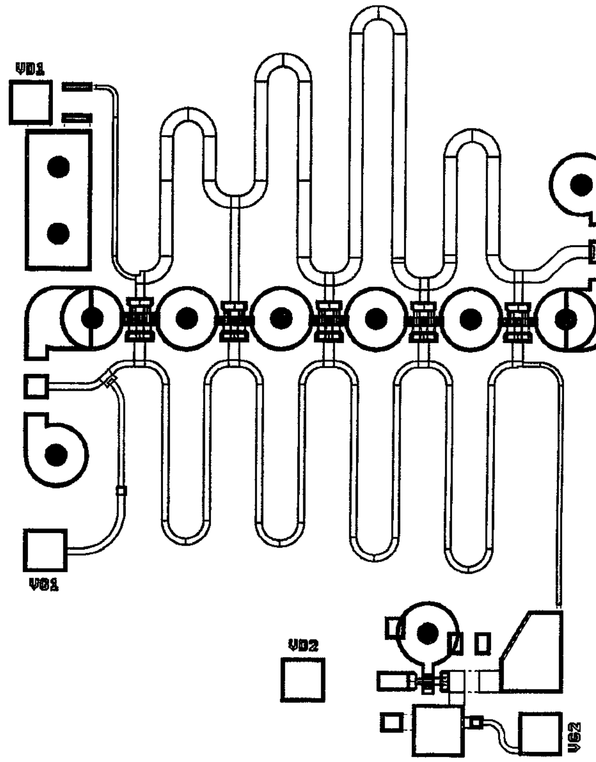


Fig. 2. Layout of a low-noise distributed amplifier designed with novel low-noise active gate-line termination. The active termination is at lower right.

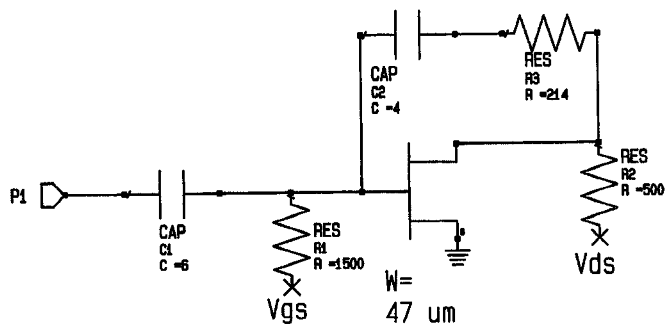


Fig. 3. The schematic of the active low-noise termination (lower right in the layout of Fig. 2). Capacitances are in pF and resistances are in Ω.

that for emulating a certain value of resistance an optimum device size and bias exist. The drain noise current tends to be proportional to the dc drain current [9] while the gate noise voltage tends to be a weaker function of bias. In the low-noise operating region transconductance g_m is proportional (though not necessarily linearly) to bias. These arguments suggest it may be advantageous to use a large device operated at low current density to achieve a low-noise active termination. Determination of the exact optimum is subject of future study. All numerical results in this paper relate to operating devices near a bias point that gives minimum noise figure in the usual two-port sense.

III. Distributed Amplifier Design with Active Gate Line Termination

A low-noise DA was designed using an active termination at the end of the gate line instead of the usual resistor termination. Fig. 2 shows a layout of the amplifier. It has five amplifying devices in a rather conventional DA design except for the active termination. The active termination is shown in the lower right corner of the layout. A schematic of the termination is shown in Fig. 3. The 214-Ω resistor has been added for stability purposes. Figs. 4 and 5 show simulated results for the amplifier shown in Fig. 2. The simulation used the device model discussed in [8]. Figs. 4 and 5 also show simulated results with a conventional 50-Ω resistive termination. Fig. 4 clearly displays the advantages of the active termination. With the active termination simulated noise figure is less than 2.2 dB from 1–24 GHz while the resistive termination shows a marked increase in noise figure below 7 GHz with noise figures near 3.8 dB at low frequencies. At high frequencies both simulations show about the same noise performance.

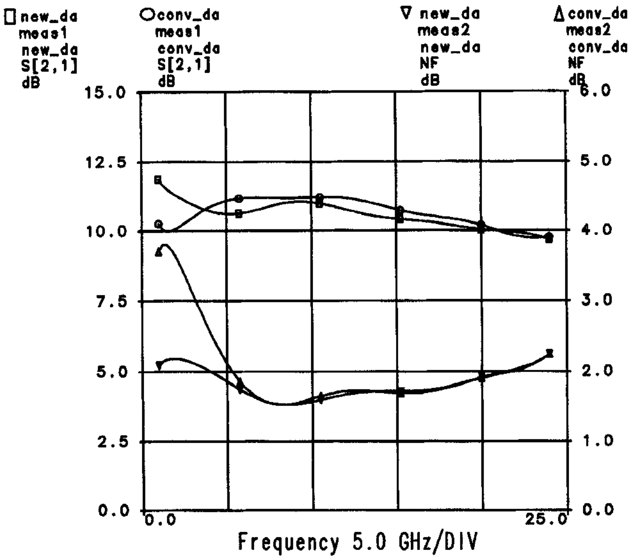


Fig. 4. Simulated gain and noise figure of the amplifier of Fig. 2 are shown with an active low-noise termination in the gate line (labeled "new_da") and with a 50-Ω resistor termination (labeled "conv_da").

Gain performance is not much affected by either type of termination. Fig. 5 shows simulated return losses of the DA. The input return loss shows differences between the two types of gate terminations, but in either case is better than -10 dB for the simulation band. The design discussed here uses a resistive termination for the drain line. We could have used an active termination for the drain line, as well, but because its contribution to the overall noise figure is small it was not implemented.

IV. Conclusion

It was shown that a low-noise pHEMT can be used to emulate an electronically cold resistor. A typical 0.25-μm gate length device was simulated to have an apparent noise temperature of 163 K when configured as a one-port resistor. Lower apparent (electronic) noise temperatures may be obtainable by optimizing the bias point of the device. Simulations show that an active gate line termination gives a clear improvement in the low-frequency ($<6 \cdots 7$ GHz) noise of a distributed amplifier while having little or no impact on gain and return losses of the amplifier.

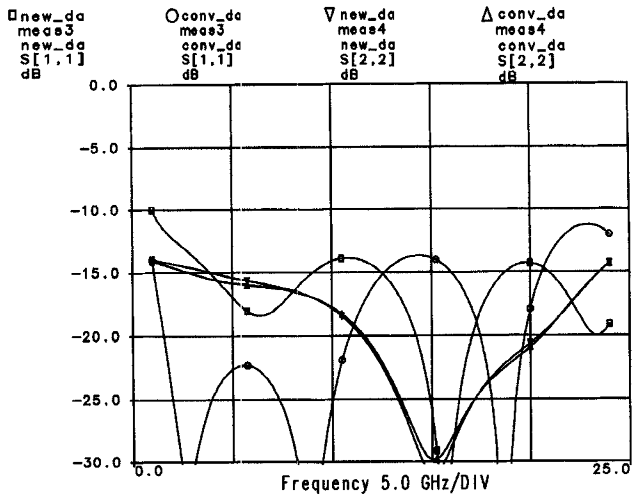


Fig. 5. Simulated return losses of the amplifier of Fig. 2 are shown with an active low-noise termination in the gate line (labeled "new_da") and with a 50-Ω resistor termination (labeled "conv_da").

Acknowledgment

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