DESIGN AND CHARACTERIZATION OF FET BASED COLD/HOT NOISE SOURCES

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ABSTRACT

Innovative design, modeling, and characterization methods are described for FET cold noise sources. A developed InP HEMT cold/hot noise source demonstrates 105K in the 18-22GHz range; the highest reported frequency for a FET cold noise source. Measurements confirm variable source temperature from 105K to over 1000K.

INTRODUCTION

The concept of using a one-port FET circuit as an equivalent cold noise source was established several years ago[1]. With the drain circuit terminated, an equivalent temperature of less than 50K was demonstrated for the noise power exiting the gate port of a hybrid circuit at a frequency of 1400MHz. One other notable work explored gate-to-drain feedback[2]. Results from this work were somewhat inconclusive and failed to benchmark a working cold noise circuit. Thus, until now, only limited demonstrations of FET cold noise sources at low microwave frequencies have been reported. This paper describes significant advances in the area of modeling, design, and characterization of FET based cold, as well as hot, solid-state noise sources. A prototype circuit establishes a new state-of-the-art with a cold noise temperature on the order of 100K in the 18-22GHz frequency range. Variability to over 1000K is demonstrated through bias adjustment and port switching. Also clarified is the theory for calculating the temperature of interest from measured noise parameters or a noise model [3].

The primary motivation behind the work is the need for variable (at least two) temperature noise calibration standards for microwave and millimeter-wave radiometry. One calibration temperature is usually at ambient. The second temperature would best be within, or near, the temperature range of measurement interest. Typical brightness temperatures measured by both ground- and satellite-based radiometers are in the range of 10-300K. The stepped cold/hot noise source is a simple device that can be used to internally calibrate radiometer sensors and other low noise receivers. Raytheon E-Systems and USF have submitted two patent applications on this circuit that will potentially replace complex, bulky external sky calibration mechanisms. The device will eliminate significant problems in spacecraft payload integration that currently require sky horns or large external cold calibration feedhorn reflectors and large heated targets(absorbers). In addition, it can eliminate or reduce the need to roll the spacecraft for cold sky temperature calibration verification. When mounted close to the antenna feed, the device can be readily switched to the input of the receiver to provide radiometer calibration, receiver linearity measurement, noise figure measurement and it also provides an inherent Built-In-Test capability. Moreover, it provides complete flexibility in selecting calibration time intervals so that the measurement intervals of earth can be maximized. The approach is readily adaptable to MMIC integration, hence, is amenable to development of on-wafer noise standards.

APPROACH AND THEORY

Figure 1 shows the design approach. Similar to earlier work [1], source inductance provides series feedback. Here, however, design is based on very complete noise equivalent circuit models[3]. We have also investigated adjustable cold and hot temperature performance, for the first time, through bias dependent simulations and measurement. The passive circuit design involves choosing the proper amount of series inductive

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feedback, and the construction of input/output matching networks, complete with stabilization and bias circuitry. With a dc bias applied, the circuit presents a variable cold equivalent temperature (Ts = Pavail/kB) at the input (gate) port with a termination at the output (drain) port of the circuit. Hot source temperatures are achieved at the output by terminating the gate port of the circuit.

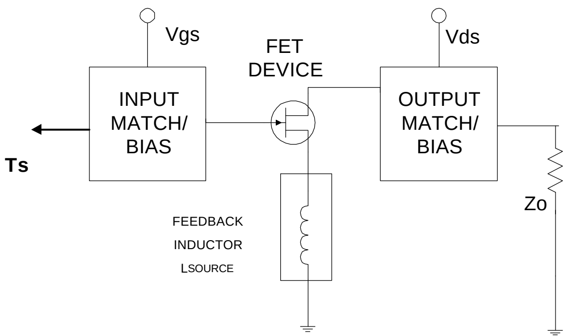

Figure 1. Basic topology for design of a FET cold noise source.

The theory for predicting the 1-port source temperature, Ts, from two-port noise simulations was also established and utilized with the CAD simulations presented. The temperature Ts exiting the input of the source (Fig. 1) is found using the alternative noise parameter Trev [4], which can be calculated from conventional noise parameters. Trev represents the noise power exiting the input of a two-port terminated in a reflection-less load held at 0K. In calculating Ts, to Trev must be added the ambient temperature noise of the opposite port termination transformed through the device using the appropriate (forward or reverse) available power gain. The port 1 and port 2 source temperatures, so calculated are labeled Tout1 and Tout2 hereafter.

RESULTS

Figure 2 shows Trev calculations, versus source inductance for three very different FET types: a 0.25µm (gate length) GaAs MESFET, a 0.25µm GaAs PHEMT, and a 0.15µm InP HEMT. These calculations were enabled by USF developed noise equivalent circuit models [3] for each device implemented in HP-EESOF's Libra™. Trev represents the noise power exiting the input of a two-port terminated in a reflection-less load held at 0K [4]. The InP HEMT displays the lowest cold noise source potential and was chosen as the basis for further study and design.

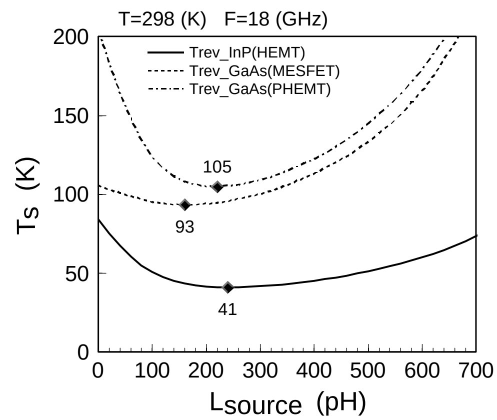

Figure 2. Simulated FET noise temperature performance for several FET types, biased respectively for minimum noise figure at 18GHz. Markers indicate minimum temperatures.

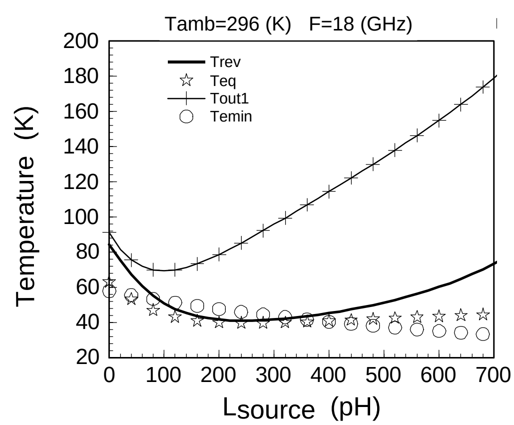

Figure 3. Comparison of various input noise temperature calculations, for the InP HEMT versus source inductance (Vds=1V, Vgs=-0.4V).

Trev and Tout1, are compared in Figure 3 to two other temperature definitions labeled Temin and Teq. Temin is simply the effective minimum noise temperature, defined as $T_{e\,min} = T_o(F_{min} - 1)$. Teq is the temperature defined in [1] as the equivalent noise temperature of the short circuit noise current in the 50 ohm port at the input. Note that only Tout1 includes the noise contribution of the ambient termination, adding it to the device-only input source temperature Trev. The authors believe Tout1 to be the most appropriate measure of the source temperature of interest.

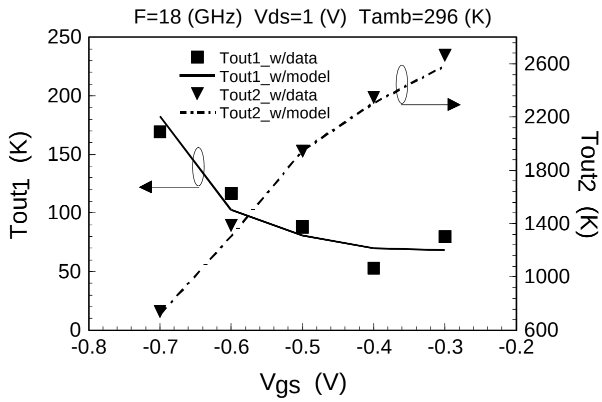

Figure 4. Simulated comparison of Cold and Hot noise source performance of the HEMT with Lsource = 0.1nH. Tout1 and Tout2 are the value of Ts at the input and output ports, respectively.

Figure 4, shows a device-level simulation of Ts as a function of Vgs (Vds = 1v, Ls = 0.24nH) for the InP device. Ts is shown with respect to both the input port (Tout1) and the output port (Tout2), with the opposite port terminated. Tout1 and Tout2 calculations performed with the bias dependent FET models closely track calculations made using measured noise parameters and S-parameters at each bias. This portrays good model accuracy over bias, as Tout calculations involve all four noise parameters as well as the S-parameters.

Using the described models and temperature prediction methods a hybrid cold noise source circuit was constructed and measured in two separate laboratories. The circuit uses an InP HEMT as the active device, and was measured without any post fabrication tuning. One set of measurements was made at the National Institute of Standards and Technology (NIST) using an 18-26GHz substitution radiometer, referenced to a cryogenic waveguide noise standard. The other measurements were taken at USF, using the noise power measurement mode of a 0.01-18GHz HP8970B/HP8971B noise figure measurement system. This measurement is referenced to a HP346B solid-state noise diode. While additional work remains to assess the measurement uncertainty, Figure 5 shows good correlation for the trends in 18GHz input port (cold) noise measurements. As expected, at zero Vds, or low bias with the gate pinched off, the temperature is equal to the ambient room temperature (~296K). Variable equivalent temperatures between 105K and room temperature were achieved from the input port of the prototype. 22GHz NIST measurements (not shown) exhibit variability from 126K through room temperature. The reflection coefficient magnitude also varies with bias as shown in Figure 6. This variation may necessitate the use of a circulator for some applications, and is responsible for some of the differences between the USF and NIST temperature data in Figure 5. That is, the effect of source reflection was corrected for in the NIST measurements, but not (yet) in the USF noise temperature measurements.

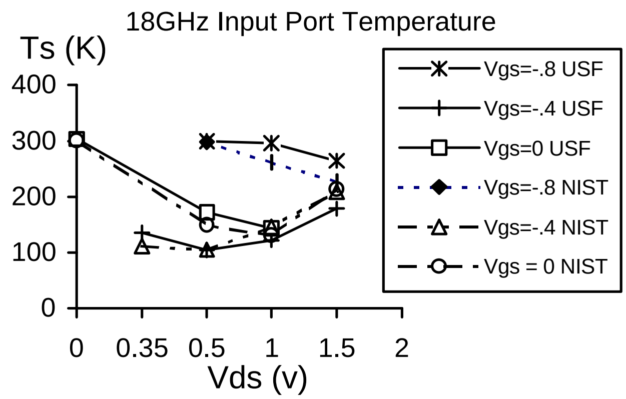

Figure 5. Comparison of measured data for InP HEMT (FET) hybrid noise source circuit at 18GHz. A minimum temperature of 105K was achieved.

Output port (hot) noise source measurements were made only at USF, and are shown in Figure 6. Hot source variability from room temperature to over 1000K was observed. The forward gain for the circuit was lower than the device, which is consistent with the lower hot (output port) noise temperature observed (Fig. 7) than predicted for the device (Fig. 4) at similar biases. Circuit level simulations of the hybrid prototype are in preparation. Figure 8 shows the output port reflection coefficient measurement.

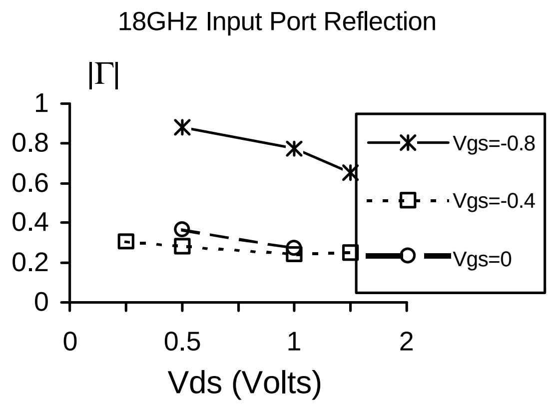

Figure 6. Measured (USF) variation of cold noise source (port 1) reflection coefficient magnitude.

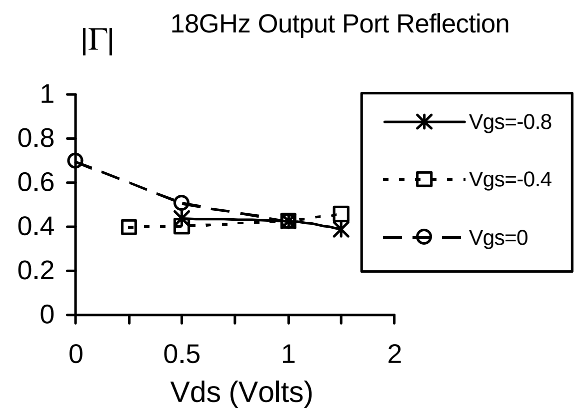

Figure 8. Measured (USF) variation of warm noise source (port 2) reflection magnitude.

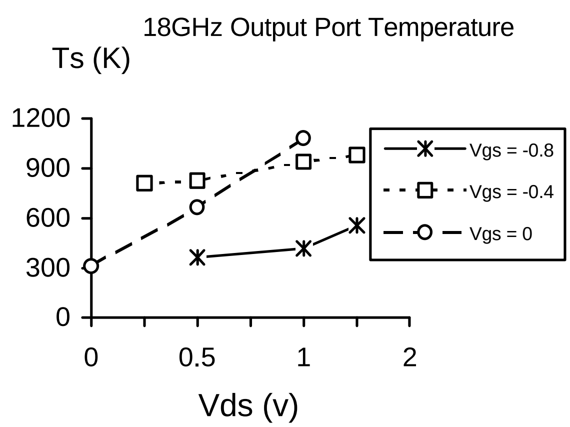

Figure 7. USF measured data for source temperature taken at output of circuit with the input terminated, at 18GHz.

In summary, this work makes significant advances to the state-of-the-art of FET cold/hot noise source development. In comparison to broad-band diode hot noise sources, the FET cold noise sources are a solution that needs to be tailored to a specific frequency range. Effective design and modeling tools, enabled by accurate bias dependent FET modeling, have been established and demonstrated for development and optimization of variable solid-state noise sources. The performance of the 18-22GHz prototype circuit represents the highest frequency reported for a FET cold noise source. The flexibility of the circuit in providing a variable hot or cold noise temperature should prove useful in a number of applications.

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