AN IMPROVED SOLID STATE NOISE SOURCE

Motohisa Kanda
Electromagnetics Division
National Bureau of Standards
Boulder, Colorado 80302

Abstract

An improved solid state noise source is discussed. By implementing such modifications as 1) heat sinking of a silicon avalanche noise diode, 2) proper DC RF decoupling, and 3) impedance matching, the stability of the NBS solid state noise source is improved significantly over that of typical commercial solid state noise sources. The paper describes these modifications, how they are implemented, and the resulting improvement in stability.

I. Introduction

The convenience of a high level noise output with a potential for fast switching makes a solid state noise source ideal for system noise monitor applications. However, solid state noise sources are relatively easily influenced by their environment, and an unsuitable environment can cause unstable operation.

A preliminary study on the stability of typical commercial solid state noise sources indicated that the fluctuations of the output noise for a typical commercial solid state noise source exhibit a random walk noise behavior (which is divergent toward lower frequencies) in its average noise output. The square root of the variance of the average output noise power for a 1-day sampling time interval is typically 0.008 dB.[1,2] The low frequency divergent instability is attributed to the noise diode itself and to the external circuit in which it is used. The stability of a solid state noise source can be improved by properly mounting the noise diode with adequate consideration being given to both DC and RF decoupling, and to impedance matching.

The purpose of this paper is to describe one way by which to improve the stability of a solid state noise source. A schematic diagram for a typical commercial solid state noise source is shown in figure 1. There are three areas that can be modified to improve its stability; namely 1) heat sinking of the noise diode, 2) proper DC and RF decoupling, and 3) impedance matching. These modifications significantly improve the stability of the NBS solid state noise source over that of a typical commercial solid state noise source.

II. Noise Diode Characteristics

Generally, a silicon avalanche diode is suitable for use as a noise diode. The characterization of silicon avalanche diodes has been studied considerably.[3,4] The purpose of this section is to describe typical characteristics of the silicon avalanche diode which can be used for the solid state noise source.

Commercially-available silicon avalanche noise diodes revealed large variations from diode to diode, and the breakdown voltage of these diodes lies typically between 8 and 12 volts.

A semiconductor p-n junction under reverse bias can be modeled by a combination of a depletion layer capacitance C_j, a space-charge resistance R_{sc},[5] a spreading resistance R_{sp},[5] and a lead inductance L_p.

The value of the depletion layer capacitance, which can be measured at low frequencies, is assumed to be invariant up through the microwave frequencies of interest. The capacitance of the diode was measured by use of an impedance bridge. The junction capacitance was found to follow more closely the $(V + V_b)^{-1/3}$ behavior which is predicted for a graded p-n junction than the $(V + V_b)^{-1/2}$ behavior which is predicted for a step p-n junction.[6] The junction capacitance of approximately 1.2 pF at a reverse bias voltage, V, of 5 V with a built-in voltage, V_b, of about 1 V was found.

The magnitude of the space-charge resistance R_{sc}, and the spreading resistance R_{sp} depend strongly on the diameter of the breakdown region. The spreading resistance, R_{sp}, usually includes the resistance of the gold lead and ohmic contacts as well as the non-depleted region of the silicon substrate. The total series resistance, R_s, ($R_s = R_{sc} + R_{sp}$) is readily obtained from the slope of the current-voltage relationship.

The characteristics of the silicon avalanche noise diode used are summarized below.

$V_{breakdown}$	$C_j(-5V)$	R_s	R_{sc}	R_{sp}	L_p
8.2 V	1.2 pF	∿14Ω	∿12Ω	∿2Ω	∿1.5 nH

Silicon avalanche diodes which exhibit similar characteristics to those indicated above are expected to be suitable for use as a noise diode.

III. Design Features

Several 50 Ω strip-lines were fabricated. The center strip at the end launcher was trimmed slightly to compensate for the extra capacitance created by the end launcher. The silicon avalanche diode is mounted on the ground plane of the 50 Ω strip-line using a gold conductive epoxy. A TDR (time domain reflectometers) signature indicates that the maximum VSWR for this 50 Ω strip-line with a miniature connector launcher was 1.04. This configuration incorporates a good heat sinking of the diode active region. A 50 μm (2 mil) gold wire is bonded to the top of the diode and subsequently to the 50 Ω strip-line.

The DC bias input to the diode passes through a low-pass DC stabilization circuit to isolate the power supply from the active device and to prevent any bias interaction. A strip-line 3-dB quadrature coupler is used to decouple DC and RF ports neatly. The schematic diagram and the photograph of the NBS solid state noise source are shown respectively in figure 2 and figure 3. In figure 3 a silicon avalanche diode is connected to each connector of the strip-line, either of which can be used as a noise diode.

IV. Diode Impedance Matching

Changes in the magnitude and/or the phase of the diode impedance can cause unstable operation of a solid state noise source. Therefore, stable operation of a noise diode requires precise impedance matching of the silicon avalanche diode to its adjoining 50 Ω strip-line. The small-signal RF impedance of the diode at 2 GHz was measured in a 50 Ω strip-line using an automated network analyzer. The standard calibration program for the network analyzer used incorporates two reference shorts approximately 180° apart at the frequency of interest and a 50 Ω termination.

Conventional schemes such as 1) an impedance transformer and 2) an impedance tuner are very useful for providing a good transition from the relatively low diode impedance to the 50 Ω strip-line, although these techniques are frequency sensitive and, hence, relatively narrow-banded in nature. However, relatively broadbanded matching can be achieved by using two similar diodes mounted onto strip-line 3-dB quadrature couplers as shown in figure 4. By selecting two diodes with nearly identical impedances (both amplitude and phase), an improvement in the VSWR from 2 to 1.2 was readily achieved at 2 GHz.

Possibly one of the best and perhaps the easiest way to achieve the proper impedance would be to fabricate one side arm of the strip-line 3-dB quadrature coupler with the same impedance as the diode at the operating bias ($\sim$ 8.2 V).

V. Experimental Results

The NBS solid state noise source shown in figure 2 and figure 3 are used for the experiments of a statistical stability measure at 3 GHz. The effective noise temperature from this solid state noise source is typically 290000 K, and a corresponding excess noise ratio (ENR) is about 30 dB. As a meaningful statistical measure for the stability of solid state noise sources, the Allan variance analysis technique is used. Detailed discussions on Allan variance analysis are given elsewhere.[1,2,7,8,9]. The stability of the intensity of noise from a noise source can, in general, be measured only by comparing its output noise level with two other noise sources. Therefore, the direct result of any such measurement includes not only the instability of the noise source under test, but also that of a reference noise source. A triangulation technique is employed to estimate the instabilities of the individual noise sources.[1,2].

Figure 5 shows the results of the Allan variance analysis for the NBS solid state noise source. For a 1-day sampling time interval the square root of the Allan variance σ of $\delta T/T$, where T is the output radiation noise temperature from the NBS solid state noise source, is 0.0005. This value can be expressed in dB as $10 \log_{10}(1 + \sigma_{\delta T/T}) = 0.002$ dB. Since the Allan variance is independent of sampling time interval, τ, the fluctuations of the output noise from this solid state noise source behave as a flicker noise process.

To compare the stability of this solid state noise source with that of a typical commercial solid state noise source, the square root of the Allan variance of a typical commercial solid state noise source is also shown in figure 5. The fluctuations of the output noise from the commercial solid state noise source behave as a random walk noise process. For a 1-day sampling time interval the square root of the Allan variance of $\delta T/T$, where T is the output radiation noise temperature from this solid state noise source is about 0.0018. This value corresponds to 0.008 dB. For comparison purposes, the results of the Allan variance of a typical commercial argon gas-discharge noise source are also shown in figure 5. For a 1-day sampling time interval the square root of the Allan variance of $\delta T/T$, where T is the output radiation noise temperature from this commercial argon gas-discharge noise source, is about 0.0002. This value corresponds to about 0.001 dB. The stability of the commercial argon gas discharge noise source is found to be very good.

VI. Conclusion

This paper describes the modifications made on a typical commercial solid state noise source in order to improve its long term stability. The modifications made are: 1) heat sinking of the silicon avalanche noise diode, 2) proper DC RF decoupling, and 3) impedance matching. It is found that the fluctuations of the output noise from this NBS solid state noise source behave as a flicker noise process, and the square root of the variance of its noise output for 1-day sampling time is 0.002 dB. In contrast, the fluctuations of the output noise from the typical commercial solid state noise source behave as a random walk noise process, and the square root of the variances for its output noise for 1-day sampling time interval is about 0.008 dB. Thus, the stability of the NBS solid state noise source is improved significantly over that of commercial solid state noise sources.

References

1. Kanda, M., "A Measure for the Stability of Solid State Noise Sources," 1975 IEEE-MTT-S International Symposium Digest, pp. 315-317, Palo Alto, California (May 1975).

2. Kanda, M. and D. Halford, "A Statistical Measure for the Stability of Solid State Noise Sources," to be published in IEEE Trans. on Microwave and Techniques.

3. Hines, M.E., "Noise Theory for the Read Type Avalanche Diode," IEEE Trans. on Electron. Devices," Vol. ED-13, No. 1, pp. 158-163 (Jan. 1966).

4. Haitz, R.H., "Noise of a Self-Sustaining Avalanche Discharge in Silicon: Studies at Microwave Frequencies," Journal of Applied Physics, Vol. 39, No. 7, pp. 3379-3384 (June 1968).

5. Shockley, W., "Problems Related to p-n Junctions in Silicon," Solid-State Electronics, Vol. 2, No. 1, pp. 35-36 (1961).

6. For example, Moll, J.L., Physics of Semiconductors, McGraw-hill Book Company (1974).

7. Allan, D.W., "Statistics of Atomic Frequency Standards," Proc. IEEE, Vol. 54, No. 2, pp. 221-230 (Feb. 1966).

8. Barnes, J.A., et al., "Characterization of Frequency Stability," IEEE Trans. Instrum. & Meas., Vol. IM-20, No. 2, pp. 105-120 (May 1971).

9. Shoaf, J.H., D. Halford and A.S. Risley, "Frequency Stability Specification and Measurement: High Frequency and Microwave Signals," NBS Technical Note 632 (January 1973).

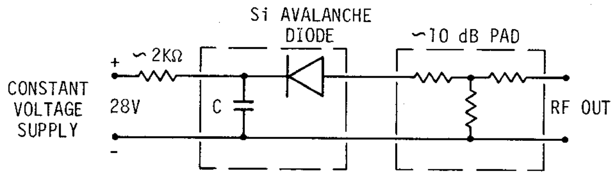

Figure 1. Schematic diagram for typical commercial solid state noise sources.

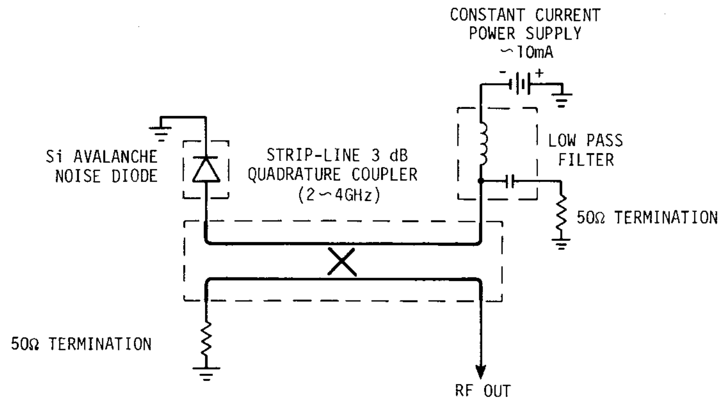

Figure 2. Schematic diagram of NBS solid state noise source.

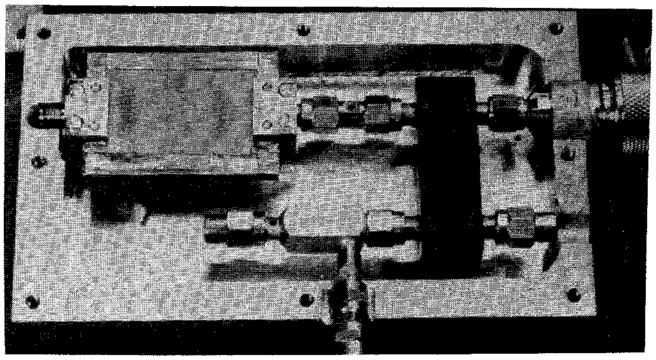

Figure 3. Photograph of assembled NBS solid state noise source.

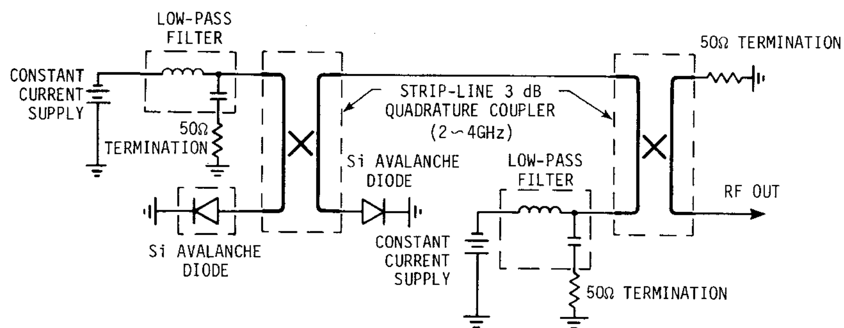

Figure 4. Broadband matching technique using two identical noise diodes.

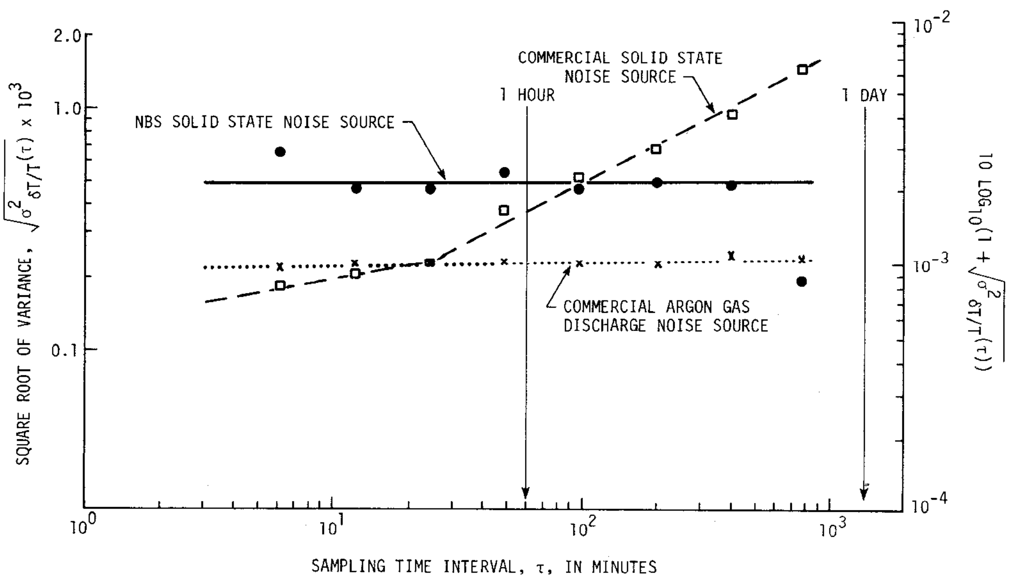

Figure 5. Allan variance for fluctuations of noise intensity of noise sources, as a function of sampling time interval, τ.