A Broadband Microwave Noise Generator Using Zener Diodes and a New Technique for Generating White Noise

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***Abstract*— A microwave noise generator using Zener diodes as the source of noise has been designed and built. It generates almost constant noise power about 20 dB above the noise floor up to 3.2 GHz. The noise generator circuit employs two independent current sources and two identical Zener diodes to generate independent noise powers optimized for lower frequencies (<1.4 GHz) and higher frequencies (>1.4 GHz). When the noise powers are combined on the same resistive load, the result is an almost flat noise power over the measured spectrum.**

***Index Terms*— Microwave noise generators, noise measurements, semiconductor device noise, white noise, Zener diodes.**

I. Introduction

A BROADBAND microwave noise generator, as a low-cost tracking generator to measure two-port networks, is presented in this letter. Noise generator circuit was designed and built using a stable constant current source to reverse bias a Zener diode for different drive currents. Output of the noise generator is a broadband noise similar to white noise, and is about 20 dB above the noise floor up to 3.2 GHz.

The first noise generators were based on hot resistors or temperature-limited diodes, and could generate noise for short-wave and ultrashort-wave region. They had issues generating noise in the microwave region since they needed to match the system impedance by using suitable resistances at high temperatures. Mumford [1] in 1949 introduced an ordinary gaseous discharge fluorescent lamp for broadband and stable microwave noise source. However, this consumed too much energy. Skolnik [2] introduced a noise generator using an arc discharge tube, and large amount of noise power was generated at very high frequency (VHF) band, and at UHF band up to 1 GHz. Skolnik's method was dangerous due to required high voltages in the order of thousands of volts, was not cost effective, and not practical. Susans [3] performed research on the noise properties of Si and GaAs diodes as noise sources at VHF and UHF bands. He found that all types of Si and GaAs diodes generate high amount of noise in the reverse breakdown region. He stated that Zener diodes have the most stable breakdown voltage; however, they have large capacitances that limit the frequency generated. Somlo [4] made detailed research on the noise performance of Zener diodes. He found that for low-voltage Zener diodes, noise increases with the increasing reverse current, and for high-voltage Zeners, the operating point should be selected as the threshold avalanche point for maximum noise output. The noise power measurements presented in this letter are compatible with the findings of Somlo [4]. Susans [5] designed a noise generator circuit using Zener diode and generated noise power from 30 to 900 MHz. Low-cost white noise generators using a Zener diode as the noise source were commercially produced by Maxim Integrated [6] up to several hundreds of megahertz. Maxim [6] tested 4-, 5.1-, 7.5-, and 12-V Zener diodes. The design presented in this letter can produce noise power at microwave frequencies, and in addition, Zeners having higher breakdown voltages have been tested for this work. Abdipour *et al.* [7] designed a VHF/UHF band white noise generator that uses 8.2-V Zener diode in the breakdown region as noise source. The signal in their design degraded dramatically beyond 1.2 GHz. In this letter, a novel technique is presented to obtain a flat noise power up to 3.2 GHz. Noise diodes with large bandwidths up to about 18 GHz, whose noise spectral density is constant within less than 1 dB, are commercially available. However, they are very expensive. This letter uses two ordinary Zener diodes at a fraction of the cost of a commercial noise diode.

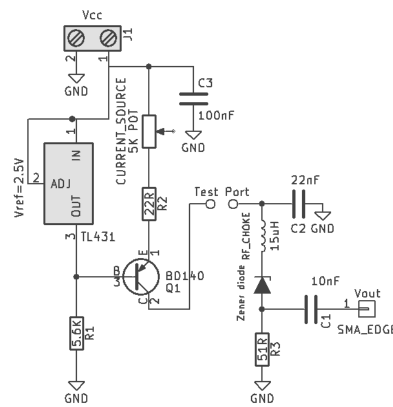

Fig. 1. Schematic of the noise generator circuit.

II. Design of the Noise Generator

The broadband microwave noise generator presented in this letter consists of two circuit blocks. The first block is a

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constant current source, and the second block is a Zener diode-based noise source. Schematic of the circuit is shown in Fig. 1. A simple and adjustable constant current source was designed to test various Zener diodes. The current source was built around a PNP-type transistor and a TL431 adjustable shunt voltage regulator. Very stable driving currents are required for testing various Zener diodes for generating broadband microwave noise. For this reason, a TL431 reference has been preferred over a Zener reference in the current source section. TL431 provides a 2.5-V reference for all bias currents when testing different Zener diodes. Current provided by the current source can be adjusted using a 5-KΩ potentiometer connected to the emitter lead of the transistor. $R2$, a 22-Ω resistor, is connected in series with the potentiometer to limit the maximum current. $C3$ is a 100-nF filter capacitor to reduce the supply line voltage fluctuations. The resistor $R1$ (5.6 KΩ) is used to provide a current return path for the base of the transistor and TL431. The current provided by the current source is adjustable from 2 to about 86 mA. Zeners specified at 15, 18, 22, and 24 V were tested for different biasing currents.

Constant current is delivered to the Zener diode under test from the collector of BD140 through an radio frequency (RF) choke inductor. The circuit board has two test ports to attach an ammeter between BD140 and the RF choke to monitor the biasing current. Noise generating part of the circuitry was designed using high-frequency circuit design techniques and 0805-type SMD components, except the Zener diode. The RF choke is a 15-μH inductor and exhibits a high-impedance path to the noise generated by the Zener diode. This way, high-frequency noise is confined in the RF section of the circuit and delivered to R3 which is a 51-Ω resistor. Noise power is taken from this resistor, and for the purpose of impedance matching its value is set to 51 Ω. There may be voltage fluctuations in the circuit at the location of the ammeter test ports since the test cables of the ammeter may act as antennas. $C2$ is a 220-nF capacitor and shorts these voltage fluctuations to ground. $C1$ is a 10-nF capacitor and is used to block dc and pass only high-frequency noise. Generated noise is taken out from a 50-Ω edge mount SMA connector.

Noise powers of 15-, 18-, 22-, and 24-V Zener diodes were measured under low-bias (2 mA), medium-bias (14 mA), and high-bias (32 mA) drive currents, and the results are shown in Figs. 2–4, respectively. A SIGLENT SSA3032X 3.2-GHz spectrum analyzer was used for noise power measurements, and for this reason measurable spectrum is limited to 3.2 GHz. It is observed in Fig. 2 that under 2-mA bias, general behavior of the Zener diodes are about the same that is; under low-current biasing, low-frequency noise power is high and tends to decrease with increasing frequency. The 22-V Zener has a different manufacturer than that of other Zeners. Due to this fact, it gives slightly higher noise power than the 24-V Zener.

When Zener diodes are biased at 14 mA, noise power increases from about 500 MHz to about 2 GHz, and then decreases again. Noise power from dc to about 500 MHz exhibits a decreasing profile as well. It is clearly seen that the 22-V Zener diode generates about 5 dB more noise power than the 24-V Zener around 2 GHz. These results are shown in Fig. 3.

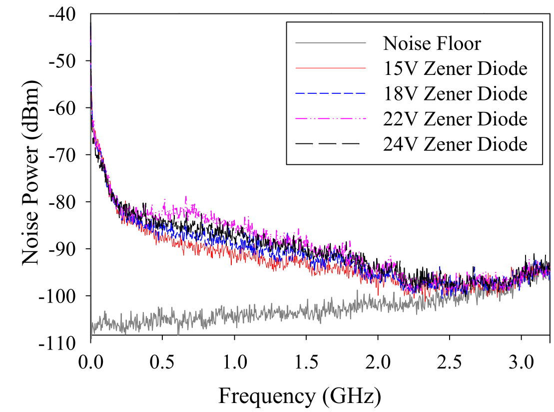

Fig. 2. Noise power of tested Zener diodes when the drive current is 2 mA.

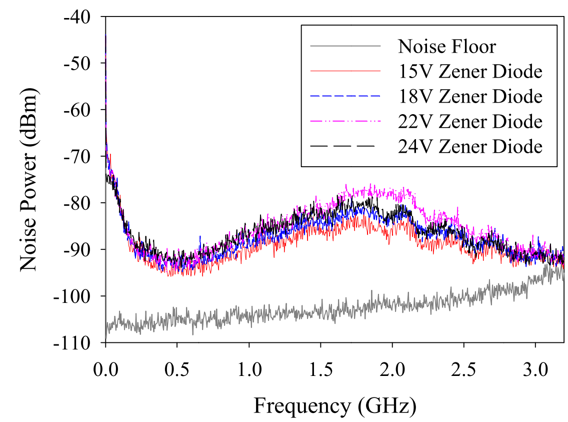

Fig. 3. Noise power of tested Zener diodes when the drive current is 14 mA.

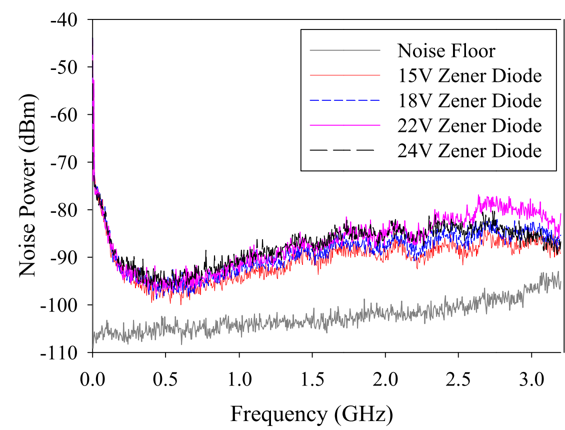

Fig. 4. Noise power of tested Zener diodes when the drive current is 32 mA.

When the drive current is set to 32 mA, the noise power increases with increasing frequency above 500 MHz up to about 3 GHz, as shown in Fig. 4. Since the measurement range of the SSA3032X spectrum analyzer is limited to 3.2 GHz, more than 3.2 GHz cannot be shown, but it can be said that the generated noise power extends beyond 3.2 GHz. The 22-V Zener diode generates about 5 dB more noise power than the 24-V Zener around 3 GHz. The noise power for the 32-mA drive current at about 500 MHz is the lowest in the spectrum. It is also lowest when compared to 2- and 14-mA drive currents. According to [8], the avalanche frequency varies

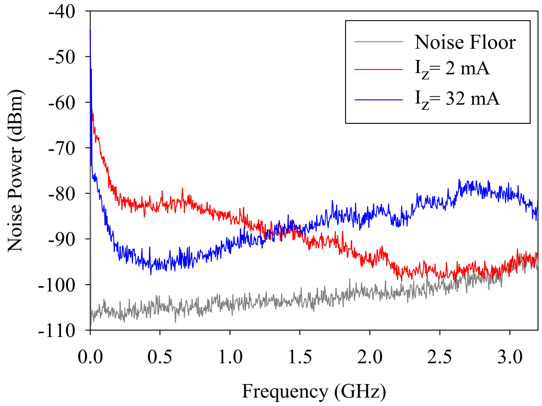

Fig. 5. Noise power of the 22-V Zener diode under 2- and 32-mA drive currents.

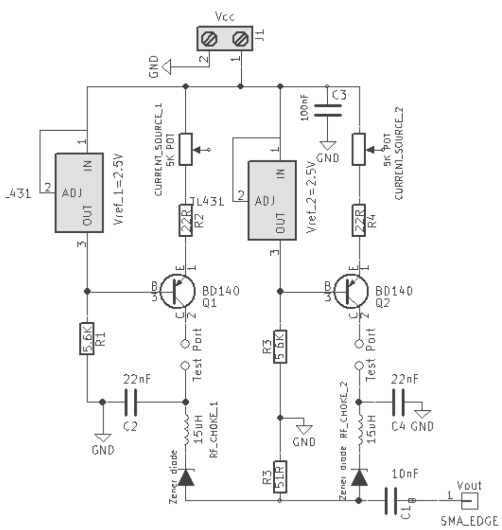

Fig. 6. Schematic drawing of the novel noise generator circuit with double constant current source.

with the square root of the diode bias current. Excess noise at low- and high-bias currents is caused by nonuniformities of avalanche breakdown and thermal effects, respectively. The measurements in this letter are in good agreement with the theory presented in [8]. The 22-V Zener diode generates more noise power for all biasing currents than other Zener diodes tested. An important issue as observed in noise power measurements of the Zener diodes so far is that the noise response is not flat over the measured frequency spectrum. To obtain a flat noise power response, a novel technique by using two current sources has been developed.

III. Noise Generator With Two Current Sources

It is clearly seen from Fig. 5 that for the 22-V Zener diode, if the noise power generated under low-current bias and high-current bias are combined, it is possible to obtain a flat noise power distribution over the frequency spectrum of interest. Fig. 5 shows noise power distribution of the 22-V Zener for 2- and 32-mA bias currents.

To achieve a flat noise power response, two independent current sources driving two separate 22-V Zener diodes have been constructed. Anodes of the Zeners are connected to a 51-Ω load resistor and the output is taken through a 10-nF coupling capacitor. Schematic of the novel double current source circuit is shown in Fig. 6. Current sources can be adjusted independently. Initially, one of the current sources is set to 2 mA and the other is set to 32 mA. The resultant noise power distribution, shown in Fig. 7, is nearly flat. By making a fine tuning at 4.3- and 40.5-mA drive currents, an even flatter noise power distribution has been obtained. The generated noise power has white noise characteristics. By adjusting the current levels, it is possible to obtain a band-limited noise generator.

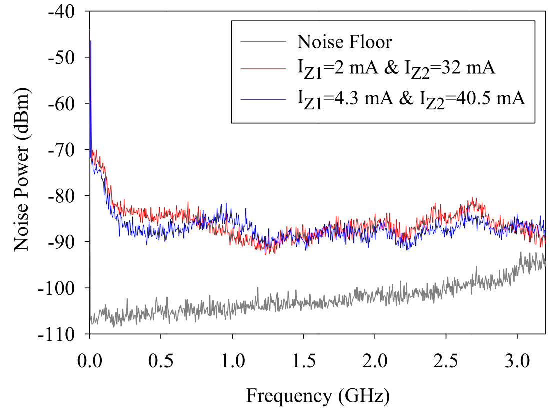

Fig. 7. Noise power distribution of the 22-V Zener diode for 2- and 32-mA drive currents, and after fine tuning with 4.3- and 40.5-mA drive currents.

IV. Conclusion

A broadband white noise generator has been designed using ordinary and low-cost Zener diodes driven by a stable current source as a low-cost tracking generator. Noise power of different voltage-rated Zener diodes has been measured and investigated. Among the tested Zeners, the 22-V Zener gives the best noise performance. A novel technique of using two independent current sources driving two separate Zener diodes has been designed and built. Double current source noise generator provides an almost flat noise power. Different noise characteristics can be obtained by adjusting bias currents independently.

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