Int. J. Electron. Commun. (AEÜ) 96 (2018) 13–17

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Regular paper

A novel white noise generator as the tracking generator for filter measurements

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ARTICLE INFO

Article history:
Received 26 April 2018
Accepted 15 August 2018

Keywords:
Microwave noise generators
Noise measurements
Tracking generators
Filter measurements

ABSTRACT

A novel and low-cost white noise generator using an ordinary Zener diode as the source of noise is presented. The Zener diode is driven by a stable dc current source such that the noise signal power generated by the Zener diode increases with increasing frequency under right dc current biasing. A 6-stage MMIC amplifier block was designed to increase the noise power further. Since the gain-frequency response of the amplifier block has a negative slope as the frequency increases, the positive slope of the noise power produced by the Zener diode is balanced with the negative slope of the amplifier gain. The resulting amplified noise signal appears to have almost constant power at the output of the amplifier. As a result, the designed noise generator exhibits white noise characteristics, and is used as a tracking generator to measure insertion loss of a RF/microwave filter.

1. Introduction

A low-cost and broadband microwave noise generator is presented in this paper. The design is motivated to build a low-cost tracking generator (TG) to measure insertion loss of RF/microwave filters. The noise generator circuit has two parts. The first part generates the noise signal. It was designed and built using a stable constant current source to reverse bias an ordinary Zener diode. Noise produced by the Zener diode increases with increasing frequency under right dc bias current. This signal is then amplified using a 6-stage MMIC (monolithic microwave integrated circuit) amplifier block consisting of six ERA-1SM MMICs. Gain of the RF amplifier block exhibits a decrease with increasing frequency. This negative slope of amplifier gain response is compensated with the positive slope of the noise power produced by the Zener diode. The result is an almost constant noise power level at the output of the amplifier. This is the novel aspect of the presented design.

The first noise generators could generate noise for short-wave and ultra-short wave region and were based on temperature limited diodes or hot resistors. These initial noise generators had problems about noise generation in microwave region because the system impedance could not be matched effectively by using appropriate resistances at high temperatures. An ordinary gaseous discharge fluorescent lamp as a stable microwave noise source was designed by Mumford in 1949 [1]. However, this method had high energy consumption. A noise generator using an arc discharge tube was introduced by Skolnik, and noise power generated at VHF/UHF bands up to 1 GHz was very high [2]. Due to required high voltages up to three thousands of volts, Skolnik's method was not cost effective, and was dangerous. Susans made studies on the noise properties of Si and GaAs diodes at VHF and UHF bands, and figured out that all types of Si and GaAs diodes generate high noise in the reverse breakdown region [3]. Somlo found that noise increases with the increasing reverse current for low-voltage Zener diodes, and to obtain high noise output for high-voltage Zeners, the operating point should be chosen as the threshold avalanche [4]. Susans generated noise power from 30 MHz to 900 MHz using a Zener diode [5]. Low-cost white noise generators using 4 V, 5.1 V, 7.5 V, and 12 V Zener diodes were commercially produced by Maxim Integrated up to several hundreds of MHz [6]. Zeners having higher breakdown voltages have been tested in this paper. In addition, the design presented in this paper can produce noise power at microwave frequencies. Abdipour, Moradi, and Saboktakin used 8.2 V Zener diode in their designed noise generator to generate white noise signal at VHF/UHF bands [7]. However, the noise power in their design decreased sharply beyond 1.2 GHz. White noise generators are used in various civilian and military applications. The usage of narrowband white noise in characterization of in-band nonlinear distortion in WCDMA systems is explained in [8]. White Gaussian noise is also used to jam the receiver of a missile-borne monopulse radar system as explained in [9], and in microwave imaging [10].

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https://doi.org/10.1016/j.aeue.2018.08.019
1434-8411/

Noise diodes with large bandwidths up to 18 GHz are commercially available. However, they are very expensive. For example, the cost of an 18 GHz noise diode is more than 80€ currently. This work uses a single ordinary Zener diode at a fraction of the cost of a commercial noise diode. The cost of the presented work including the MMIC amplifiers, circuit board, and all other components cost less than 9€ currently. Another novel aspect of the presented design is its very low cost. Section 2 describes the noise generating circuit using an ordinary Zener diode. The noise signal is then amplified by a 6-stage MMIC amplifier block. The design of the integrated noise source and the amplifier are described in Section 3. The amplified noise signal was used as a TG to measure the insertion loss of a 2.45 GHz band-pass filter. The same measurement was also performed using the internal TG of a spectrum analyzer, and the results are presented and compared in Section 4.

2. Zener diode as the source of noise

The core of the noise generator circuit is the Zener diode driven by a current source, as suggested in [3]. A constant-current source, shown in Fig. 1, was constructed using a BD140 PNP BJT transistor and a voltage reference circuitry consisting of a TL431A integrated circuit (IC). Current is adjustable from about 2 mA to about 80 mA using a potentiometer. This current is then injected to the Zener diode through L1 which is an RF choke inductor. C1 filters out fluctuations on the biasing current and is responsible to deliver a stable DC current to the Zener diode. R1 is a 51 Ω resistor and is used as the load resistor to match the 50 Ω impedance of the measurement equipment. C2 is a coupling capacitor. The generated noise signal is taken out from the 51 Ω load resistor through C2. The RF part of the noise generator is composed of SMD (surface mount device) type components to minimize parasitic inductances and capacitances. Zener diodes generate excess noise if they are biased at threshold avalanche region [3]. In this paper, 1 W version of 15 V, 18 V, 22 V, and 24 V Zener diodes are tested under reverse bias currents of 2 mA, 8 mA, 14 mA, 20 mA, 24 mA, and 32 mA. Noise power responses of the Zener diodes are measured using a SSA3032X 3.2 GHz Siglent Spectrum Analyzer.

Noise responses of the tested Zener diodes under different current biasing are shown in Figs. 2–5. If Zener diodes are biased under low current (2 mA), low frequency noise power is high. If the bias current increases to medium level (8–14 mA) noise power increases from 1 GHz to 2 GHz. For the high current biasing (26–32 mA), noise power is higher in the spectrum beyond 2 GHz up to 3.2 GHz. Upper frequency limit of the noise measurement is 3.2 GHz due to the 3.2-GHz spectrum analyzer. As explained in [11], the avalanche frequency is directly proportional to the square root of the bias current. The reason of the excess noise at low and high bias currents is non-uniformities of avalanche breakdown and thermal effect, respectively.

It can clearly be seen from these measurements that 22 V and 24 V Zener diodes generate more noise power then 15 V and 18 V Zeners. So 15 V and 18 V Zeners are not taken into consideration for the design of the noise generator circuit. Furthermore, a decision has also be made between 22 V and 24 V Zeners. By analyzing Figs. 2–5, it is observed that when the drive current is high, the noise power of tested Zener diodes increases with increasing frequency. This is a very desirable trait. Because the gain of an RF amplifier tends to decrease with frequency, a positive slope of the noise power is required to achieve almost constant noise power level at the output of an amplifier. In order to choose the most suitable Zener diode for the noise generator, 22 V and 24 V Zener diodes have to be compared. Noise power spectrums of 22 V and 24 V Zener diodes are shown in Fig. 6. Noise responses of both diodes are almost the same up to about 2.3 GHz. Beyond this point, generated noise power of the 22 V Zener diode is higher. For this reason, the 22 V Zener diode driven by 32 mA current was chosen as the source of noise for the noise generator circuit. It should be mentioned that the manufacturers of 22 V and 24 V Zeners are different.

The differences in the noise powers of the tested 1 W zener diodes can be explained as follows. Zener diodes produce avalanche noise when a high reverse voltage develops across their p-n junction. Electrons under high potential gradient rapidly gain

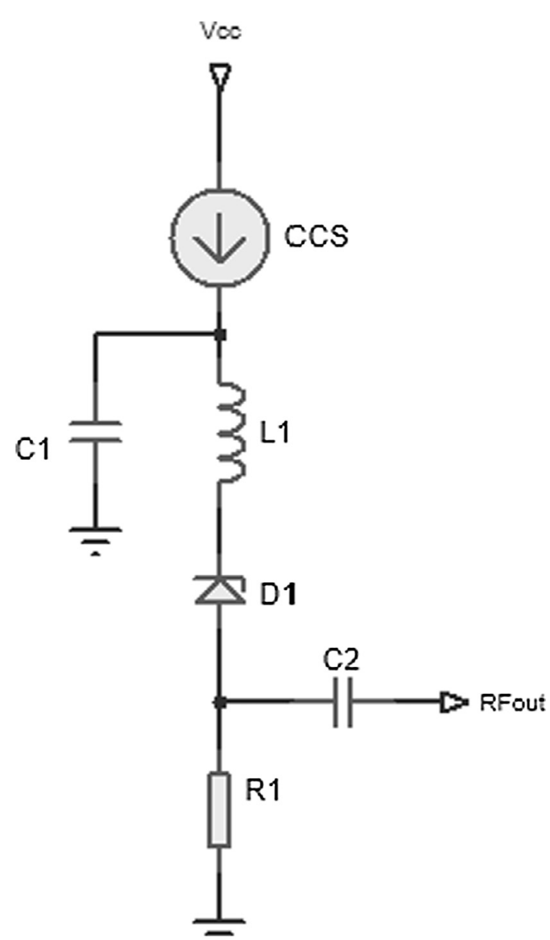

Fig. 1. Simplified schematic of the noise generator circuit.

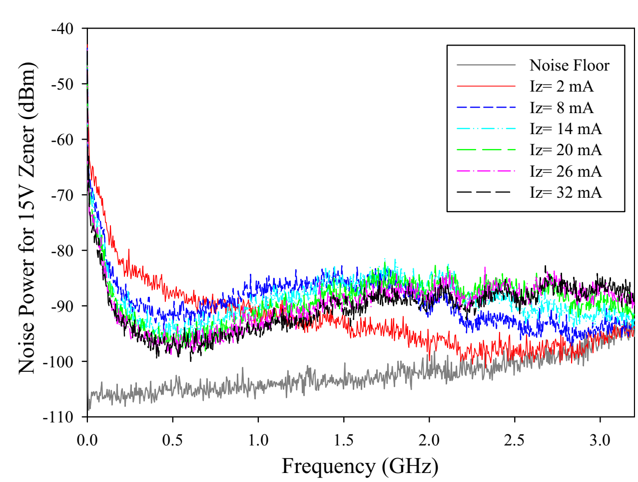

Fig. 2. Noise power for 15 V Zener diode under different biasing currents.