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MUĞLA SITKI KOÇMAN UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

ANALYSIS AND DESIGN OF SEMICONDUCTOR NOISE GENERATORS IN VHF AND UHF BANDS

MASTER OF SCIENCE THESIS

SERDAR ARSLAN

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APPROVAL OF THE THESIS

The thesis submitted by **SERDAR ARSLAN** with the title of "**Analysis and Design of Semiconductor Noise Generators in VHF and UHF Bands**" has been unanimously accepted by jury members on the 19th of December, 2017 to fulfil the requirements for the degree of Master of Science in the Department of Electrical and Electronics Engineering.

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Serdar ARSLAN

19/12/2017

ABSTRACT

ANALYSIS AND DESIGN OF SEMICONDUCTOR NOISE GENERATORS IN VHF AND UHF BANDS

Serdar ARSLAN

Master of Science (M.Sc.)

Graduate School of Natural and Applied Sciences

Department of Electrical and Electronics Engineering

Thesis Advisor: Assoc. Prof. Dr. Bahadır S. YILDIRIM

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The subject of this thesis is the analysis and design of noise generators that have nearly flat noise power output in VHF and UHF bands (10 MHz - 3 GHz) by using semiconductor components as noise sources. Currently, operating frequency range of a diode-based noise source reaches up to 18 GHz. In this thesis, different voltage and power rated Zener diodes, and different transistors are investigated, analyzed and compared for their noise characteristics. It has been observed that 22V Zener diodes generate noise from about 10 MHz to about 3 GHz. 22V Zener diodes are chosen as the noise generating component due to their higher noise power output at higher frequencies. 22V Zener diodes generate the highest noise power around 3 GHz compared to other Zener diodes. A new technique using two independent current sources driving two identical 22V Zener diodes has also been developed to achieve an almost flat noise power output in VHF and UHF bands up to 3 GHz.

RF and general purpose bipolar junction transistors (BFG35, 2N2222, and 2N3904) are also investigated for their noise characteristics. It’s seen that RF transistors have very low noise characteristics since they are inherently low-noise devices. Tested general purpose transistors also generate noise but they have lower noise power in contrast to Zener diodes.

A single-stage Monolithic Microwave Integrated Circuit (MMIC) amplifier and a 6-stage MMIC amplifier are designed to amplify the generated noise signal for specific applications. For the amplifier design, ERA-1SM MMIC is selected and all passive components are chosen to be SMDs (Surface Mount Device). ERA-1SM amplifies signals from about 10 MHz to about 8 GHz with a gain of about 10 dB. The designed single-stage amplifier gives about 10-dB gain and the 6-stage amplifier gives a frequency dependent total gain varying from about 65 dB to 40 dB.

The amplified noise signal is used as a tracking generator to test a commercially available band-pass filter and the result is compared to that obtained using spectrum analyzer’s internal tracking generator. Both results show excellent agreement and indicate that the designed white noise generator works like a tracking generator.

Key words: Noise, Noise Generator, Zener Diodes, MMIC Amplifiers, White Noise

ÖZET

VHF VE UHF BANDLARINDA YARIİLETKEN GÜRÜLTÜ KAYNAKLARININ ANALİZİ VE TASARIMI

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Tez konusu, VHF ve UHF bandlarında (10 MHz - 3 GHz) yarıiletken elemanların birer gürültü kaynağı olarak kullanılarak, 10 MHz – 3 GHz aralığında neredeyse sabit bir gürültü gücü veren gürültü üreteçlerinin yapılmasıdır. Halihazırda diyot tabanlı gürültü kaynaklarının çalışma frekansları 18 GHz'e kadar çıkabilmektedir. Bu tezde çeşitli gerilim ve güç değerlerine sahip Zener diyotlar ve çeşitli tranzistörler incelenerek analiz edilmiş ve gürültü karakteristikleri bakımından karşılaştırılmıştır. Çalışma sonunda 22V gerilim değerindeki Zener diyotların teze konu olan 10 MHz ile 3 GHz arasındaki frekanslar boyunca diğer Zener diyotlara nazaran daha fazla gürültü ürettikleri tespit edilmiştir. 22V zener diyotlar yüksek frekanslarda daha fazla gürültü üretmeleri sebebiyle tezin ileriki aşamaları için gürültü kaynağı olarak seçilmişlerdir. 22V değerindeki Zener diyotların test edilen diğer diyotlar ile karşılaştırıldığında 3 GHz civarında en yüksek gürültüyü ürettikleri gözlemlenmiştir. VHF ve UHF bandlarını da içeren ve 3 GHz’e kadar neredeyse sabit bir gürültü gücü verebilen, ve bunu iki adet 22V Zener diyotu birbirlerinden ayrı olarak iki adet bağımsız akım kaynağı ile sürerek gerçekleştiren yeni bir teknik geliştirilmiştir.

RF ve genel amaçlı transistörler de (BFG35, 2N2222 ve 2N3904) gürültü karakteristikleri bakımından incelenmiştir. Yapılan incelemeler sonucunda RF transistörlerin doğaları gereği daha az gürültü ürettikleri görülmüştür. Test edilen genel amaçlı transistörlerin de gürültü ürettikleri, fakat RF transistörlere nispeten daha fazla gürültü üretseler de bu konuda Zener diyotlar kadar başarılı olamadıkları gözlemlenmiştir.

Tek katlı MMIC yükselteçler ve 6 katlı MMIC (Monolitik Mikrodalga Tümleşik Devre) yükselteçler, üretilen gürültü sinyalinin yükseltilmesi ve uygulamalarda kullanılacak hale getirilmesi amacıyla tasarlanmıştır. Yükselteç tasarımında entegre olarak ERA-1SM MMIC, yükselteç bloklarında kullanılan tüm pasif komponentler ise SMD (Yüzeye Monte Devre Elemanları) olarak seçilmiştir. ERA-1SM tümdevresi 10 MHz ile 8 GHz arasındaki sinyalleri 10-dB kadar yükseltebilmektedir. Tasarlanan tek katlı yükselteç devresi yaklaşık olarak 10 dB, 6 katlı yükselteç ise frekansa bağlı olarak toplamda 65 dB ile 40 dB arasında değişen bir kazanç vermektedir.

Yükseltilen gürültü sinyalleri piyasadan satın alınmış olan band geçiren filtrenin test edilmesinde kullanılmıştır. Aynı filtre daha sonra spektrum analizörün dahili izleme

üreteci kullanılarak test edilmiş ve daha önce gürültü sinyalleri kullanılarak elde edilen sonuç ile karşılaştırılmıştır. Her iki testin sonuçları mükemmel bir uyum içerisindedir ve bu da tasarlanan beyaz gürültü üretecinin bir izleme üreteci olarak kullanılabileceğini göstermektedir.

Anahtar Kelimeler: Gürültü, Gürültü Üreteci, Zener Diyotlar, MMIC Yükselteçler, Beyaz Gürültü

To My Wife, My Lovely Daughters & My Parents

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LIST OF SYMBOLS AND ABBREVIATIONS

N_p	Noise Power
k	Boltzmann Constant
T	Temperature
B	Bandwidth
S_{shi}	Noise Spectral Density Function
q	Electron Charge
I	Forward Junction Current
f	Frequency
τ	Carrier Lifetime
RF	Radio Frequency
VHF	Very High Frequency
UHF	Ultra High Frequency
dB	Desibel
dBm	Desibel with Milliwatt Reference
MHz	Mega Hertz
GHz	Giga Hertz
Si	Silicone
GaAs	Gallium Arsenide
SRF	Self Resonance Frequency
TG	Tracking Generator
NG	Noise Generator
ENR	Excess Noise Ratio
CAD	Computer Aided Design
PTH	Plated Through Hole
G-R	Generation-Recombination
BJT	Bipolar Juntion Transistor
NF	Noise Figure
SNR	Signal-to-Noise Ratio
MOS	Metal Oxide Semiconductor

1. INTRODUCTION

There are some phenomena that at first impression they may appear non-beneficial, but later on it's observed that they have some useful properties. Noise is a good example. Noise is described as spontaneous fluctuations in voltage or current (Konczakowska and Wilamowski, 2011). There are two main categories of noise; extrinsic noise and intrinsic noise. Extrinsic noise (also called interference) is the noise that is injected to the instrument/circuit externally, i.e. electromagnetic waves. Intrinsic noise (also called inherent noise) is the noise generated by spontaneous fluctuations of charged carriers in electrical equipment (HP-Application Note 57-1, 1983). There are different types of inherent noise. These are thermal noise (Johnson noise), shot noise (Shottky noise), flicker noise (1/f noise), burst noise (popcorn noise), generation-recombination noise (G-R noise), $1/f^2$ noise, and avalanche noise. In this thesis, noise generating circuits are analyzed, designed, and built using Zener diodes and bipolar junction transistors (BJTs) as the source of noise. The designed circuits generate avalanche noise.

All semiconductor devices generate noise due to their nature, and the generated noise depends on production quality, device type, and operating environment. Receivers may have a serious problem of processing desired weak signals due to noise if their internally generated noise levels are very high. Since noise is a serious problem for weak signals, one solution is to raise the transmitter power, use of a larger antenna, or use of a high gain antenna, etc. These solutions are costly, and a better way of solving this problem is to reduce the internally generated noise of a receiver. Two specifications of a receiver, sensitivity and noise figure (NF), can be engineered to achieve high signal-to-noise ratio (SNR) at the output of a receiver while keeping the noise floor as low as possible. Despite its undesired nature, noise can be useful in characterizing receiver noise performance, can be used as a cost-effective alternative to tracking generators, and can be employed in jamming systems to save lives.

1.1. Types of Noise in Semiconductor Devices

1.1.1. Thermal noise (Johnson noise)

Einstein (1905) released his theory of fluctuating movement of charge carriers in thermal equilibrium in 1905. Johnson (1927), proved Einstein's idea and concluded that ordinary electric conductors are the sources of spontaneous fluctuations. This property is a result of thermal agitations of electric charges in the material of conductor. On the basis of this idea, Konczakowska and Wilamowski (2011), defined the thermal noise as generated by random motion of charge carriers due to thermal excitation. When electrons are exposed to heat, they gain kinetic energy, move in a random fashion in the conductor, and create a fluctuating voltage at the terminals of a component. If a transmission path is provided, kinetically excited electrons are transferred. Thermal noise is generated by all resistors and can be expressed by equation (1.1).

$$N_p = kTB \tag{1.1}$$

where N_p is the energy removed from body (noise power), k is the Boltzmann constant (1.38×10^{-23} Joules/Kelvin), T is the absolute temperature and B is the bandwidth. As can be seen from the equation (1.1), power of thermal noise is directly proportional to bandwidth B and absolute temperature T. Here we note that frequency has no effect on spectral noise density. Thermal noise has white noise amplitude distribution.

1.1.2. Shot noise

The nature of the current in a semiconducting component causes shot noise. Excited charges move randomly and reach the potential barrier of a pn junction at random times. The time passed for consecutive excited charges to reach the barrier is different at each time. This phenomenon causes fluctuations at the output. When a DC current is applied to the input of an electronic component, value of the DC current at the output of the component exhibits fluctuations, however, the observed DC output is the average value (HP-Application Note 57-1, 1983). If the resulting current passes through a load resistor, the shot noise is formed. Shot noise is observed in pn junctions, and in resistors just thermal noise is observed.

Power spectral density of shot noise is;

$$S_{shi} = 2qI \tag{1.2}$$

where q is the electron charge and I is the forward junction current (Konczakowska and Wilamowski, 2011). As can be seen from the equation (1.2). the noise spectral density function has no relation with temperature and bandwidth.

1.1.3. Flicker noise (1/f noise)

Flicker noise is dominant at low frequencies than other types of noise and its spectral density function is proportional to 1/f. The reason of this noise is generally based on bad fabrication quality of electronic components while purification of the silicon wafer or during doping processes, or material failures. Flicker noise increases with the decreasing size of the components. Since nowadays, nano size fabrications are in demand, flicker noise becomes an important problem to solve. Flicker noise level is the measure of quality of devices (Konczakowska and Wilamowski, 2011).

1.1.4. Burst noise (Popcorn noise)

Burst noise is observed in BJTs and MOS transistors. If there are imperfections of the lattice crystal of the material, gain of the transistor may not be stable during operation. When the gain increases and returns the normal value suddenly due to imperfection, the output has a pop for a very short duration. This noise is heard like a popcorn sound, in audio amplifiers. That’s why it’s sometimes called as popcorn noise. Transistors with well-doped semiconductors have less burst noise but like flicker noise, burst noise increases with the decreasing size.

1.1.5. Generation-Recombination noise (G-R noise)

In semiconductor pn junction components, sometimes generation-recombination centers exist and this causes change in the numbers of charge carriers. The fluctuations in the number of charge carriers cause voltage fluctuations. This noise is called generation-recombination noise.

1.1.6. 1/f^2 noise

1/f^2 noise exists usually in metal conne ctions of integrated circuits and it's used to measure the quality of metal interconnections.

1.1.7. Avalanche noise

Avalanche noise is seen in reverse biased pn junctions when the biasing conditions are very close to breakdown voltage. The avalanche noise is greater than other types of noise. The charge carriers in semiconductors under reverse bias condition are subject to high electric fields and collide with the crystal lattice in the junction. If the energy during collision is great enough, electron-hole pairs are generated and reverse biased current is multiplied (Konczakowska and Wilamowski, 2011). Power spectral density function of avalanche noise is;

$$S_{av}(f) = \frac{2qI}{(2\pi \cdot f \cdot \tau)^2} \tag{1.3}$$

where I is the average value of the reverse biasing current and τ is the carrier lifetime. Semiconductor devices operating in breakdown region are not damaged permanently. When the semiconductor device bias conditions are set to out of breakdown region, the low noise properties again exists for this device.

1.1.8. Quality of noise performance: noise figure

The noise figure F of a network is defined as the ratio of the available signal-to-noise ratio at the input terminals to the available signal-to-noise ratio at its output terminals (Friis, 1944). This definition states that noise figure F is the measure of the degradation of the signal-to-noise ratio through the device/circuit. We can apply noise figure concept to the circuit that has signal processing ability, one input and one output ports. Expression can be written as in equation (1.4).

$$SNR_{\text{input}}\ (\text{dB}) = SNR_{\text{output}}\ (\text{dB}) + F \tag{1.4}$$

1.2. Noise Source Characteristics

1.2.1. White noise

The white noise has equal noise energy in equal bandwidths. For example, the noise energy of 1 KHz - 10 KHz band is equal to the noise energy of 3001 MHz – 3010 MHz band. This noise is called white because it contains all frequencies with equal energy within a specific bandwidth, just like white light contains all visible colors (wavelengths). Since white noise is used in testing of equipment and devices due to its property of containing of all frequencies in equal portion, a calibrated white noise source became a standard laboratory instrument.

1.2.2. Pink noise

The pink noise has equal noise energy in percentage change in the bandwidth. To be clear, noise energy of 10 Hz - 20 Hz band, that is %100 change in frequency has the same energy as 2 GHz - 4 GHz band. Flicker noise is one type of pink noise.

1.3. Objectives of the Research

The proposed study aims to focus on generation of white noise by using different semiconductor devices such as noise generating diodes (i.e. Zener diodes), reverse biased transistors, and comparison of the resulting noise characteristics. In addition, techniques that increase noise power will be examined. Once a solid noise generating circuit is designed, noise signal will be amplified using a multi-stage high-gain amplifier. The final noise generator circuit will be used as a tracking generator to test two-port passive networks.

Design steps are expressed as

i. Literature review

ii. Design of noise generator circuits

iii. Design of a broadband RF amplifier (from a few tens of MHz to 3.2 GHz)

iv. Integration of noise generator circuit and RF amplifier

v. Testing of a filter

The thesis has been organized as follows. An introduction and a literature review have been given in Chapter 1. Noise generator circuits have been described and designed in Chapter 2. A broadband RF amplifier design is presented in Chapter 3. Integration of the noise generating circuit and the amplifier, and testing of the integrated unit by measuring the insertion loss of a band-pass filter are presented in Chapter 4. A conclusion is given in Chapter 5.

1.4. Literature Review

1.4.1. First noise generators

Due to improvements and new inventions in RF technology, signal sources are needed to test RF components and circuits before commercial use. Before semiconductor electronic components were invented and improved, the first noise generators were based on hot resistance or temperature limited diodes. These techniques are used for making noise figure measurements of receivers in short-wave or ultra-short wave regions. However, these techniques were difficult for testing in microwave region. In microwave region, it’s needed to match the impedance by using suitable resistances but since these techniques needed high temperatures, resistances could not stand for long time. For the purpose of making broadband noise sources, electrical gas discharge and arc discharge phenomena were developed.

Mumford (1949), introduced an ordinary fluorescent lamp as gaseous discharge with broadband, stable, microwave and calculable noise source in 1949. The ordinary fluorescent lamp contains Argon and mercury gases inside. The argon initiates the discharge and mercury assures the radiation excites the fluorescent material. He tested about 32 different fluorescent lamps having different colors and a germicidal lamp with no fluorescent coating. After his tests he concluded that microwave noise power is independent of the current, and source of generated microwave noise energy is due to gaseous discharge rather than the fluorescent coating. And the level of noise energy is constant with respect to time and it's affected slightly by temperature.

Skolnik (1955), introduced noise generator by using arc discharge tubes in 1955. This technique produces large amount of noise power by using large amplitude and short duration pulses. Skolnik used an RC relaxation oscillator circuit with 0-3000 V DC feed to create series of pulses with uniform amplitude and short duration. The resulting noise spectrum is broadband including VHF and UHF bands. So the arc discharge noise generator is suitable to test VHF and UHF receivers. The noise factor is about 90 dB that is such noise sources produce higher noise power compared to diodes and fluorescent-type noise sources mounted in waveguides.

Gas discharge tubes, however has operating frequencies over about 1 GHz. Spencer W.H and Strum (1955) offered a solution to generate noise below 1 GHz, by using a gas discharge tube as a slow-wave structure. This structure includes coaxial lines with helical center conductors and low-pass filters. The experimentally resulting frequency range of this structure varies between 200 MHz and 3 GHz with a flat spectrum of noise.

1.4.2. Researches on semiconductor noise sources

Due to the improvements in the semiconductor technology, different noise types naturally generated by the nature of the components are investigated for different semiconductor devices. These noise types have negative effect on the receiver circuit performance and they are explained in previous sections in detail.

Hot resistance and temperature limited diode techniques need too much energy to produce noise. On the other hand gas-discharge tube and arc-discharge tube techniques need high voltages to generate noise. However, since semiconductor devices need low voltage levels to generate noise, they are much cheaper and more efficient than discharge tubes. Susans (1968) made research about noise properties of Si and GaAs diodes as noise sources within VHF and UHF bands. He found that all types of Si and GaAs diodes generate high levels of noise in the reverse breakdown region. He suggested biasing the diode by a current source instead of a voltage source because of the negative temperature effects on the noise characteristic at high frequencies. He investigated and compared Zener and varactor diodes. Zener diodes have the most stable breakdown voltage, however, they have large capacitances that limit frequency response. Varactor diodes have stable breakdown voltages by changing bias currents. Susans suggests using a varactor diode biased by a current source as a noise source rather than Zener diode. He modelled the noise power generated in reverse-breakdown region by the mathematical formula;

$$P_N = a\left(1-\frac{r}{R}\right)(|V|+|v|)^{3/2} qB + \frac{r}{R} kTB \quad (1.5)$$

where a is a constant (~1.4), B is the bandwidth in Hz, k is Boltzmann's constant (1.38×10^{-23} J/ºK), P_N is the noise power in Watts, q is the charge of an electron (1.6×10^{-19} J/ºK), R is the total resistance of the diode in ohms at the frequency of measurement. r is the combined lead and bulk resistances of the diode in ohms. T is temperature in Kelvin, V is voltage across the diode in volts. v is the contact potential of the junction in volts (0.7 V for silicon, 1.1 V for gallium arsenide)

Somlo (1975) made a detailed research on the noise performance of Zener diodes. He figured out that ENR (Excess Noise Ratio) is a function of Zener voltage and for low voltage Zener diodes, noise increases with the increasing reverse current.

1.4.3. Design of noise generator circuits

There are different types of noise sources and noise generators. But the common point of these designs is that they need to have high ENR (60-70 dB) to overcome the noise floor of the measuring instruments.

Kanda (1976) made some modifications on the noise generator circuits to ensure the long term stability. He introduced three modifications; heat sinking of an avalanche diode, proper DC RF decoupling, and impedance matching. His design consists of reducing the negative effect of the temperature of the noise power by using heat sinking for the diode. He used low-pass DC stabilization filter to isolate any bias injection and 3-dB stripline quadrature coupler to decouple DC and RF ports. Since the output of the coupler causes magnitude change and 90° phase shift on the output signal, the unmatched circuit may cause unstable operation. He solved this problem by using two identical avalanche diodes on the output of the 3-dB stripline quadrature coupler and reached a VSWR value of 1.02. After his experiments for a period of one day, he had great stability of the noise signal according to the commercially used avalanche diodes.

Inaba and Mori (1989) found that if a diode is used as an ON-OFF switch, oscillation frequencies are generated. They change the oscillation frequency range by using capacitors and inductances. Katsunori, Shinsaku and Yoshifumi (1995) expanded their new approach of using diodes as a noise sources. They explained that in the switching operation of the diode, change in the value of inductance is the reason of several different oscillation frequencies generated. They called these signals as chaotic signals.

In 2005, modern sense low-cost white noise generators were commercially produced (Maxim, 2005). A reverse biased avalanche Zener diode is used as the noise source of several hundred MHz, and two cascaded low-noise amplifiers (LNA) are used to amplify the generated noise signal as seen in Figure 1.1. Maxim also tested several Zener diodes with different breakdown voltages (i.e. 4V, 5.1V, 7.5V, and 12V). They figured out that the noise power generated by the 12V Zener diode is about 15-20 dB higher than the noise power generated by the 5V Zener diode. One problem for the amplifier circuits is that the gain of the amplifier decreases as the frequency increases. In this circuit noise power at 10 MHz decreases by about 10 dB at 100 MHz. Solving this problem (obtaining an almost flat noise power output) will be one of the focusing points in this thesis.

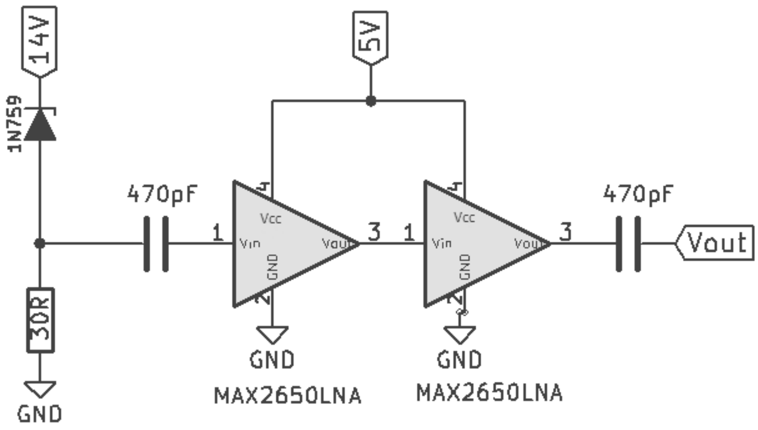


Figure 1.1. Noise generator circuit designed by Maxim Integrated Circuits.

Rota (2008) designed a low-cost white noise generator with a range of 10 MHz – 10 GHz by using NS-303 diode as the noise source. NS-303 is a metal-ceramic gold plated noise generator diode with an output level of 30-dB ENR when biased with 8-10 mA. A highly precise voltage regulator is used to stabilize the voltage for the noise diode. Generated noise signal passes through attenuators just before the output port. These attenuators have two main purposes; to obtain the output ENR value of 15 dB and to match the network. Mismatch uncertainty is the main factor of errors in noise figure measurements.

In the same year, AtlanTecRF (2008) designed a noise generator with a range of 10 Hz to 18 GHz. This ultra-wide band high output noise generator allows making tests of various applications from audio tests to satellite and military radar tests.

In 2008, Abdipour, Moradi and Saboktakin (2008) designed a VHF/UHF band white noise generator by using very cheap components and reached a higher bandwidth value of 1.2 GHz than that of Maxim (Maxim, 2005). They also used an 8.2 V Zener diode in breakdown region as the noise source in contrast to Maxim's 12 V. Avalanche noise is very similar to shot noise but it has much flatter frequency spectrum. A three-stage amplifier circuit is designed to amplify the signal to an acceptable value. 1^{st} stage has a gain of 20 dB and the next two stages have a total gain of 24 dB. Therefore the overall gain of the amplifier circuit is 44 dB. Again it is observed by spectrum analyzer that beyond 1.2 GHz, the noise signal is degrading dramatically. This noise generator can be used to test noise performance of VHF/UHF devices.

Gholam Reza Askari , Norooz Motamedi and Masoud Karimian (2008) designed an X-band (8-12 GHz) white noise generator that has Gaussian probability density function with a 3 dB bandwidth of 4 GHz (7-11 GHz) with a 60-dB ENR (Excess Noise Ratio) and ± 1.5 dB flatness. Noise diode NW401 is used for the noise source and generates noise from 10 MHz to 18 GHz. For the amplification of noise signal, a four-stage amplifier circuit is designed. To flatten the gain and increase the band-width of the amplifier, a lossy matching technique combined with reactive matching is used. To maximize the output noise density over the desired bandwidth, a 3rd order Chebyshev filter with 0.5-dB ripple, 9-GHz center frequency, and a 5-GHz band-width is designed and implemented.

By the improvements in technology, digital techniques are developed for generating Gaussian white noise. Bodong et al. (2016) generated Gaussian white noise signal by using FPGA (Field Programmable Gate Array) and AD9957. The idea is based on generating baseband Gaussian digital signal by using Box-Muller transform and con-verting it to analog Gaussian white noise signal. The noise generator is based on based on the AD9957's built-in 14 bits' digital/analog converter and high-speed di-rect digital frequency synthesizer. This technique has good performance, simple and the noise parameter can be adjusted by external serial port according to the needs of device under test.

2. DESIGN OF NOISE GENERATOR CIRCUIT

2.1. Principles of Noise Generating Circuits

Noise generating circuits employ reverse-biased Zener diodes and/or reverse-biased bipolar junction transistors (BJTs) as noise generating components.

An NPN BJT has two n-type and one p-type semiconducting regions. Thus, it can be expressed as two diodes connected back to back. This leads that in order to generate noise using an NPN transistor, emitter-base junction has to be reverse biased, because base-emitter is a pn junction diode. This idea of reverse biasing an emitter-base junction of an NPN BJT to generate noise can also be extended to PNP BJTs as seen in the part a of Figure 2.1.

A typical noise generating circuit employs a reverse-biased Zener or a reverse-biased junction of an NPN or PNP BJT, in series with a resistive load which is shown in part b of Figure 2.1. The noise voltage is taken from a coupling capacitor which blocks DC. A high gain RF amplifier is usually needed to increase the strength of the noise signal.

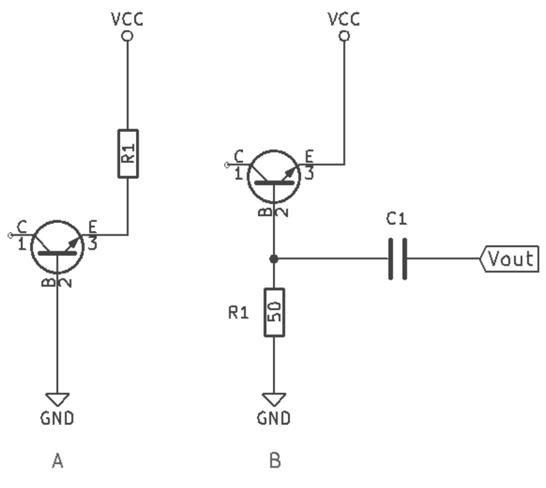


Figure 2.1. a) Technique of biasing an NPN BJT transistor as a reverse biased diode, b) reverse biasing an NPN BJT transistor and obtaining the generated noise through a coupling capacitor.

The aim of the research presented in this thesis is to generate noise signals in VHF and UHF bands using various noise sources. VHF band is from 30 MHz to 300 MHz, whereas the UHF band is from 300 MHz and 3 GHz. Since frequencies up to about 3

GHz are involved, high-frequency circuit design techniques have been implemented during the design of noise generating circuits. High-frequency effects of interest are parasitic inductances and capacitances on the printed circuit board (PCB), self-resonance frequency (SRF) of passive components, transmission line effects, and skin effect.

Susans (1968) was the first who performed research about noise properties of Si and GaAs diodes as noise sources within VHF and UHF bands. Susans found that all types of Si and GaAs diodes generate high levels of noise in the reverse breakdown region. He suggested biasing the diode by a current source instead of a voltage source because of the negative temperature effects on the noise characteristics at high frequencies. By using this principle Maxim Integrated company designed low-cost white noise generators in 2005 (Maxim, 2005). A reverse biased avalanche Zener diode as the source of noise, up to several hundred megahertz, and two cascaded low-noise amplifiers (LNA) are used to amplify the generated noise signal. Maxim also tested several Zener diodes with different breakdown voltages (i.e. 4V, 5.1V, 7.5V and 12V). In this thesis, noise power of various noise generating components (Zener diodes, BJTs) for various biasing schemes have been investigated at VHF and UHF bands. For this reason, a universal circuit design which is applicable to test various noise generating components under different biasing schemes has been developed.

2.2. Design of a Prototype Noise Generator Circuit

In this thesis, a universal current source circuit has been designed to test different types of noise sources having different voltage and current characteristics shown in Figure 2.2. The core of the circuit is a current source that uses a BD140 PNP transistor. Current can be adjusted from about 1.9 mA to 86 mA by using a potentiometer under a fixed reference voltage set by a Zener reference D1. A capacitor C3, 100 nF, is placed to reduce voltage fluctuations on the Vcc line. R2, a 22 Ω resistor, is connected in series to a 5 KΩ potentiometer to limit the maximum value of the current. RF choke inductor L, 15 μH, is placed between the noise generating section of the circuit and the transistor to prevent noise to pass through the transistor. Capacitor C2, 22 nF, is placed to eliminate voltage fluctuations in the DC part of the circuit by directing them to flow to ground. Reverse biased Zener diode D1 is used to ensure stable reference voltage drop for the current source circuit. The resistor R1, 5.6 KΩ, is used to provide a current return path for the base of the transistor and Zener D1. The resistor R3, 51 Ω, is used for impedance matching. The capacitor C1, 10 nF, is used to block DC at the output if any, and couple RF signal with minimal loss to SMA port.

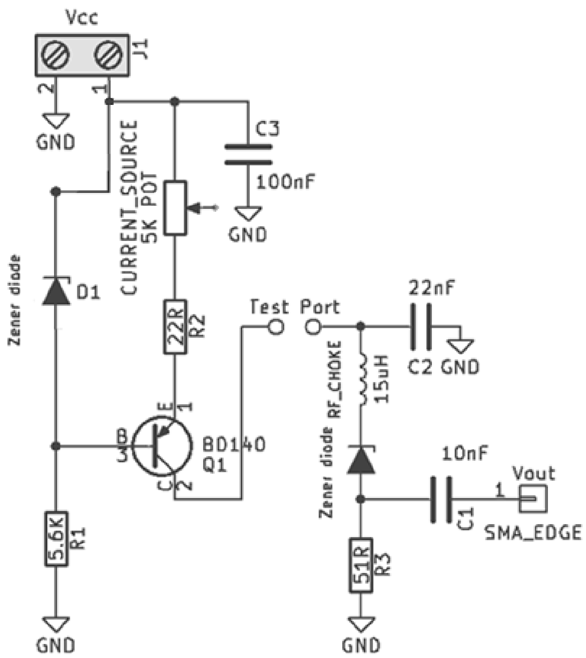


Figure 2.2 Schematic of the noise generator circuit.

By using an open source CAD (Computer Aided Design) program KiCAD version 4.0.6, a PCB has been drawn as shown in Figure 2.3. For impedance matching, besides the 51 Ω resistor, microstrips are used at the RF section of the circuit. To calculate the width of a 50 Ω microstrip line, Ansoft Designer has been used. Ansoft Designer calculated the width of the microstrips about 3 mm. 3D simulation of the designed and assembled PCB is shown in Figure 2.4.

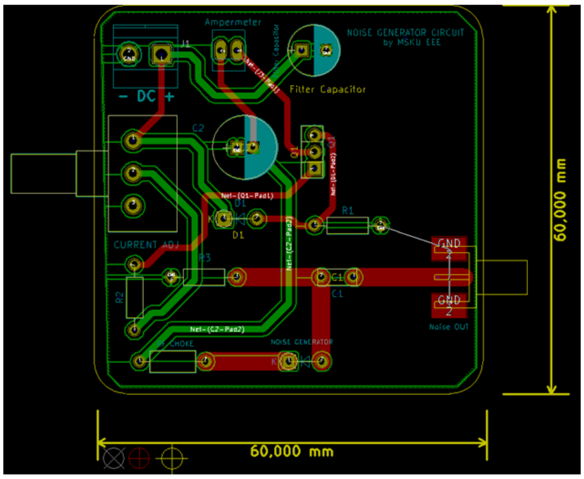


Figure 2.3. PCB drawing of the noise generator circuit using the CAD program KiCAD 4.0.6.

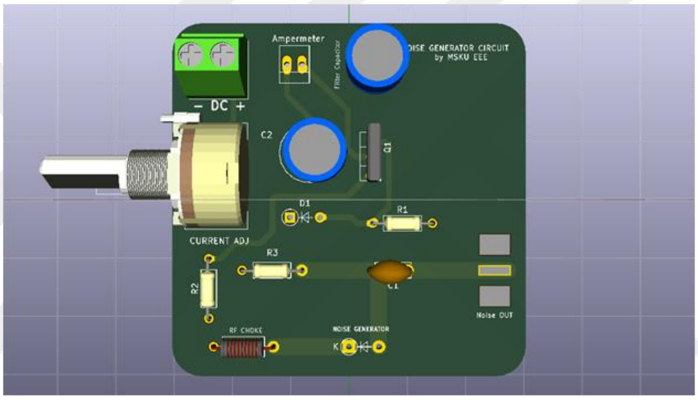
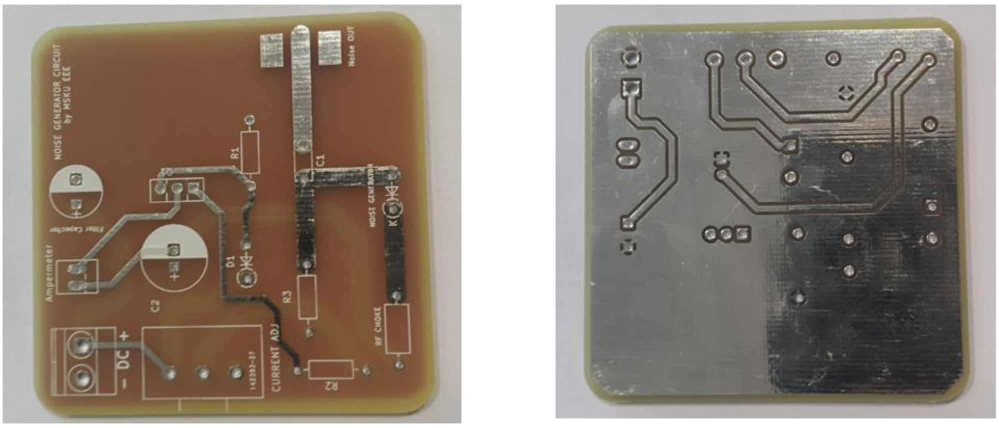


Figure 2.4. 3D view of the noise generator circuit PCB in KiCAD.



(a) (b)

Figure 2.5. Fabricated PCB a) front view, b) back view.

The front and back views of produced PCB are shown in Figure 2.5. After assembling the components on to the PCB, the prototype noise generator circuit became ready for measurements. A Siglent SSA3032X Spectrum Analyzer is used for noise power measurements. Spectrum analyzer is set to full span from 0 Hz to 3.2 GHz. No internal attenuation is used, and the internal preamplifier is set as OFF. Resolution bandwidth (RBW) and video bandwidth (VBW) are set to 300 KHz. For the first measurements, 18V-1W and 24V-1W Zener diodes are used as noise sources for 2 mA, 6 mA, 10 mA, 14 mA, and 20 mA bias currents. The results are taken from spectrum analyzer as .csv files and Sigma Plot is used to plot the noise responses. The generated noise by 18V and 24V Zener diodes is shown in Figure 2.6 and Figure 2.7, respectively.

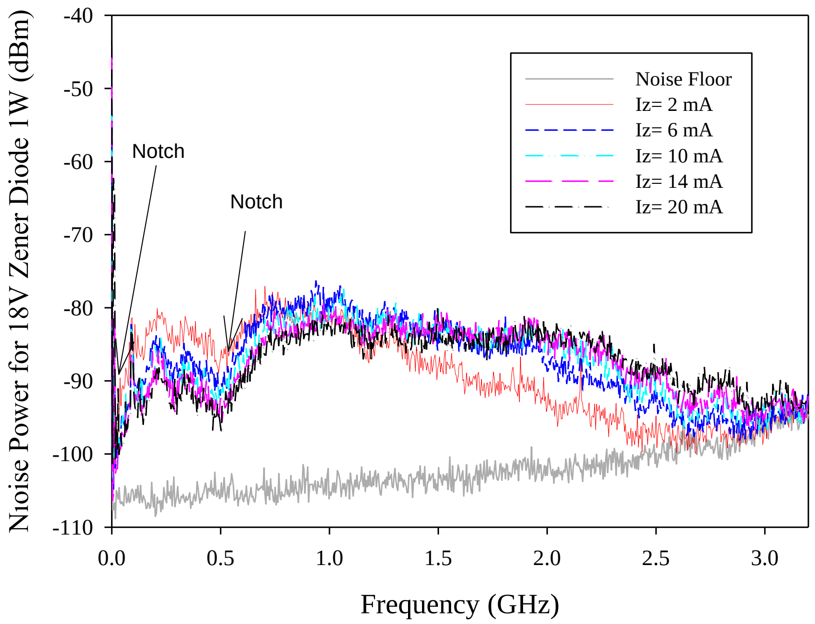


Figure 2.6. Noise power for 18V-1W Zener diode.

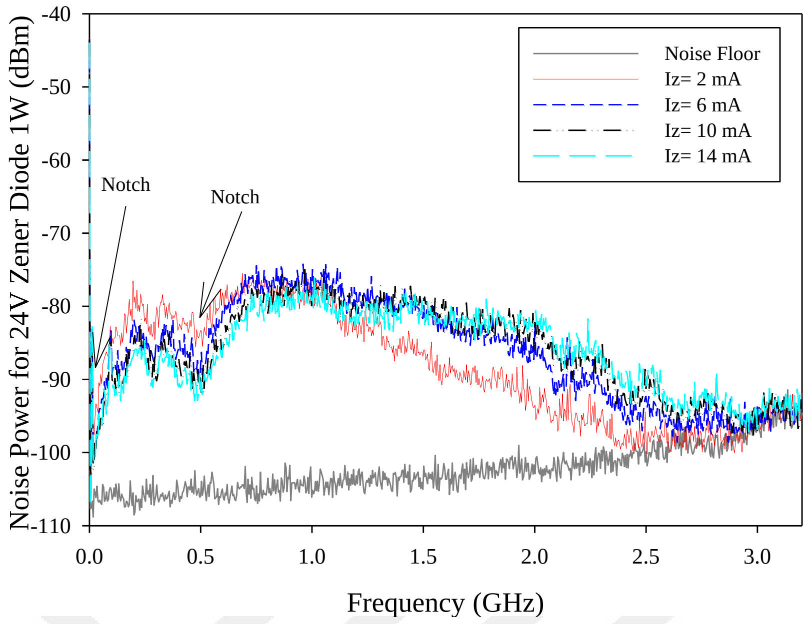


Figure 2.7. Noise power for 24V-1W Zener diode.

By analyzing the noise power from Figure 2.6 and Figure 2.7, following remarks can be made;

- Spectrum of the generated noise is not white noise due to notches and high-frequency cut-off.
- High noise power up to 1 GHz is generated for lower bias currents (i.e. 2 mA, 6 mA, and 10 mA).
- Noise in UHF region is generated by increasing the bias current. At higher bias currents, noise is generated up to about 2.9 GHz. However, noise power decreases with increasing frequency, and beyond 2.9 GHz, no noise is generated.

2.3. Improved Noise Generator Circuit Using TL431 Voltage Reference for the Current Source and Use of SMD Components in the RF Section

If the figures are analyzed carefully, it's seen that noise power distribution is not flat all over the frequency spectrum and both noise generators have common deep notches at some frequencies. This is a serious disadvantage of the noise generator circuit that is designed. The reason of the notches is the self-resonance frequency of PTH-type (Plated Through Hole) inductors, capacitors, and resistors used in the design. To overcome this problem, SMD components have been used in the improved design. Another problem with the old design was the voltage drop on reference Zener D1 that controls the current. This voltage drop is not stable, decreased with increasing current due to increasing voltage drop on the noise source Zener. In order to stabilize this reference voltage, Zener diode D1 is replaced by TL431 voltage regulator. TL 431 has a 2.5 V reference when the input and the ADJ ports are shorted and is very stable under designated current levels. The modified circuit schematic and board are shown in Figure 2.8. and Figure 2.9. respectively.

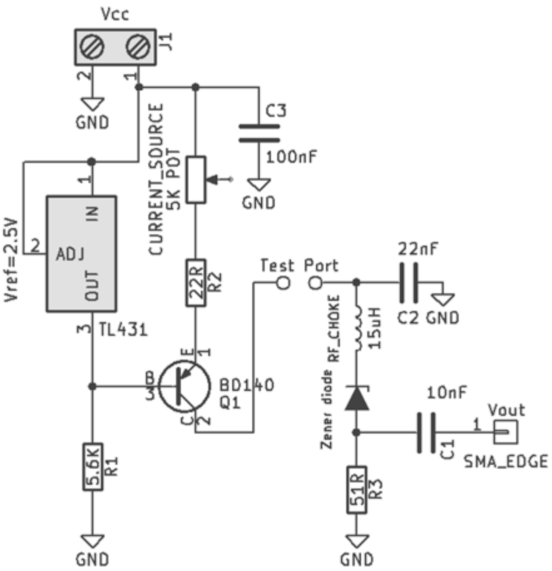


Figure 2.8. The schematic for the modified noise generator circuit. TL431 is used as reference voltage for the constant current source.

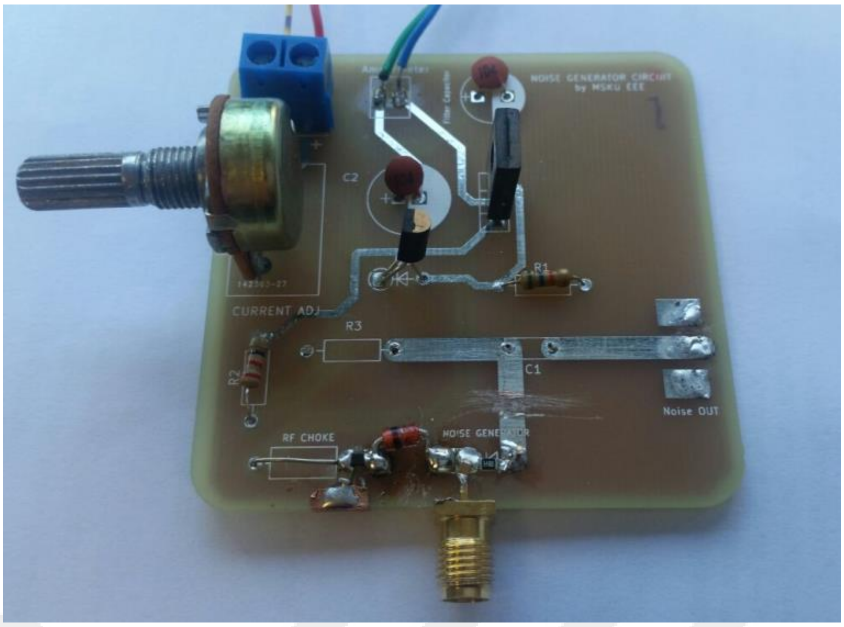


Figure 2.9. Photograph of the modified board. Note that components in the RF generating block of the noise generator are replaced by 0805-type SMD components.

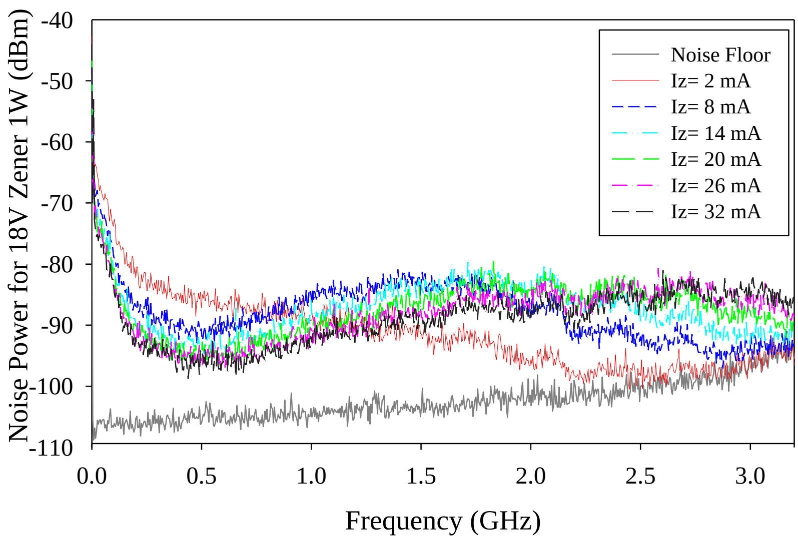


Figure 2.10. Noise power measurement for 18V Zener diode.

Measurements of the improved noise circuit show that notches are eliminated by using SMD components as seen in Figure 2.10 and Figure 2.11. Besides, by using SMD components higher noise power at higher frequencies has been obtained. The maximum frequency range of the spectrum analyzer is 3.2 GHz, but as can be seen from the graphs, the noise power generated extends well beyond this range. And with increasing current, noise power density increases at the higher-end of the spectrum.

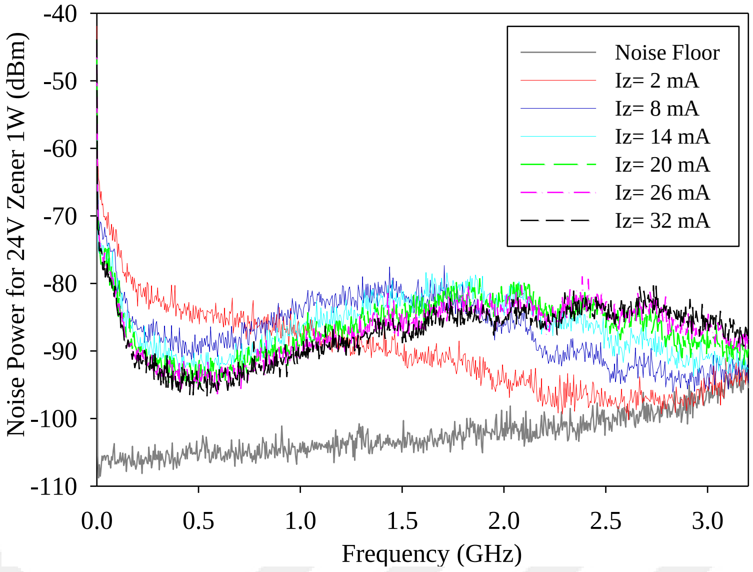


Figure 2.11. Noise power measurements for 24V Zener diode.

2.4. Measurement of Noise Power of Various Zener Diodes

After the latest revision, improved noise generator circuit is ready for testing various noise generators. If Zener diodes are biased at threshold avalanche region, they generate excess noise (Somlo, 1975). By using this principle, Zener diodes are tested under different reverse bias currents. Test processes are held in accordance to the following steps;

- The improved noise generator circuit was constructed using two different PCBs to verify board level modifications.
- Measurement of various Zener diodes for different reverse bias current values and deciding higher noise generating ones. 1W Zeners were used in this process.
- Measurement of the decided Zener diodes that have different power ratings (0.5W and 1W Zeners have been compared)
- Decision between two high noise power generating noise Zeners (22V vs 24V)

Before starting the measurements of Zener diode noise characteristics, it's needed to verify that the noise generator circuit is very stable and gives the same measurement results for the same Zener diodes. The noise generator circuit is constructed using two different boards, named as Board #1 and Board #2. Noise characteristics of identical Zener diodes are measured and compared by using Sigma Plot software.

22V Zener diode is selected randomly, and generated noise characteristics measured for 2 mA, 14 mA and 32 mA reverse biased currents for both boards and shown in Figure 2.12., Figure 2.13. and 2.14. respectively. It's seen that measurements of *both boards are nearly identical*. Since PTH components are replaced by SMD components manually, slight differences are seen between the boards. Board#1 is chosen for the next step in measurements.

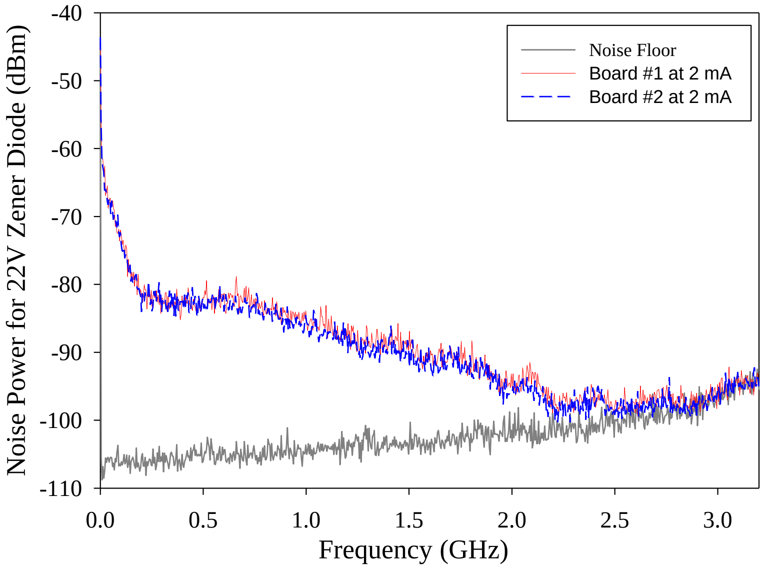


Figure 2.12. Noise power for 22V Zener diode for Board #1 vs Board #2 at 2 mA.

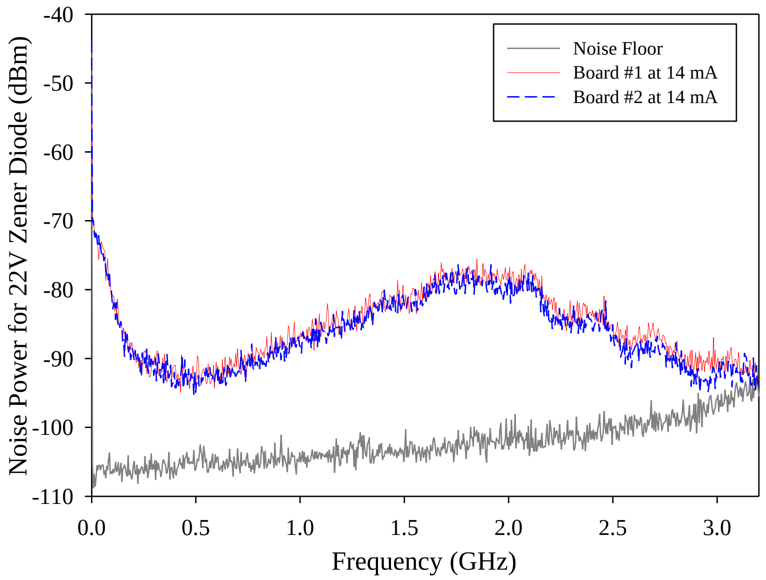


Figure 2.13. Noise power for 22V Zener diode for Board #1 vs Board #2 at 14 mA.

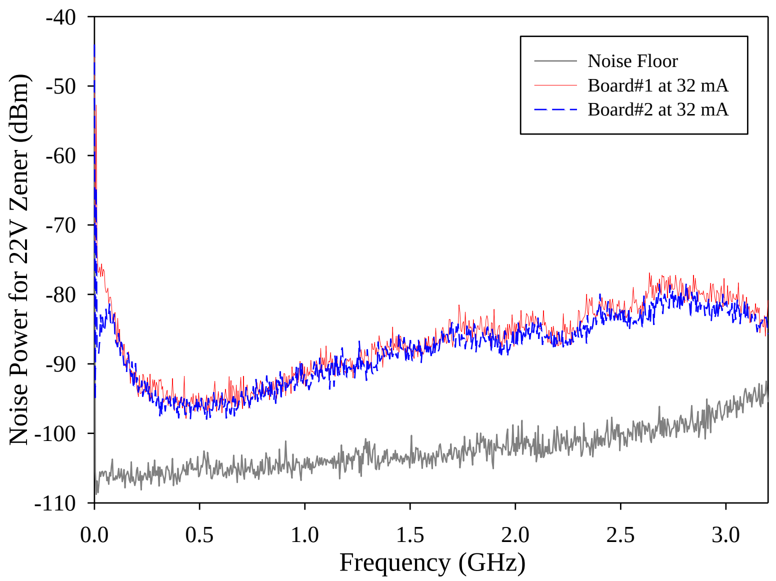


Figure 2.14. Noise power for 22V Zener diode for Board #1 vs Board #2 at 32 mA.

By using Board#1, 15V, 18V, 22V, and 24V Zener diodes are measured under the bias currents of 2 mA, 8mA, 14 mA, 20 mA, 26 mA, and 32 mA. The results are shown in Figure 2.15., Figure 2.16., Figure 2.17. and Figure 2.18. Its observed that general behavior of Zener diodes is about the same. That is when the bias current is low, low frequency noise power is high. When the bias current increases to some medium current that is 8-14 mA, noise power increases in the range of 1 GHz - 2.5 GHz. And for the high current biasing, i.e. 26 mA and 32 mA, noise power fills the spectrum beyond the region of 2.5 GHz.

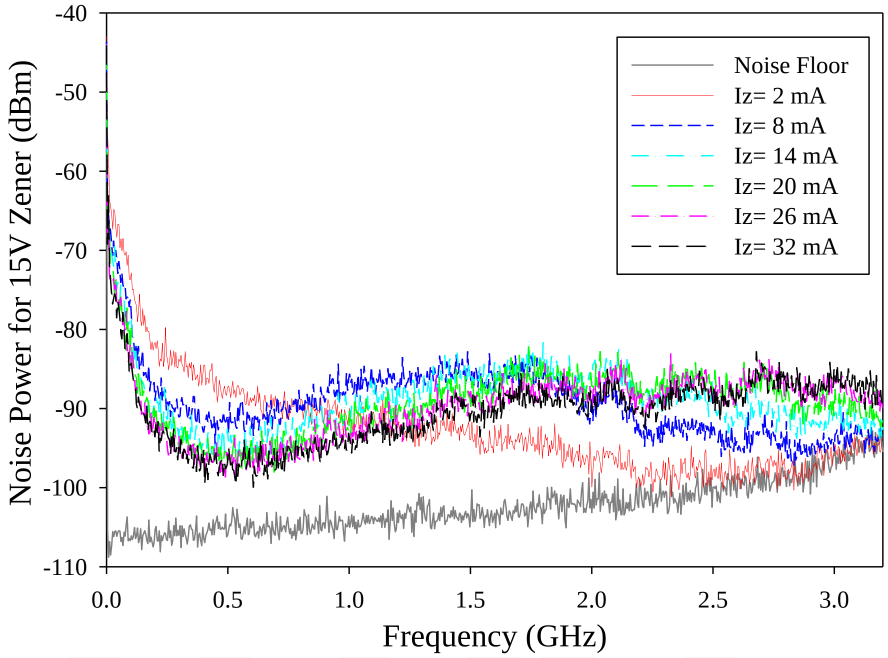


Figure 2.15. Noise power for 15V Zener diode under different biasing currents.

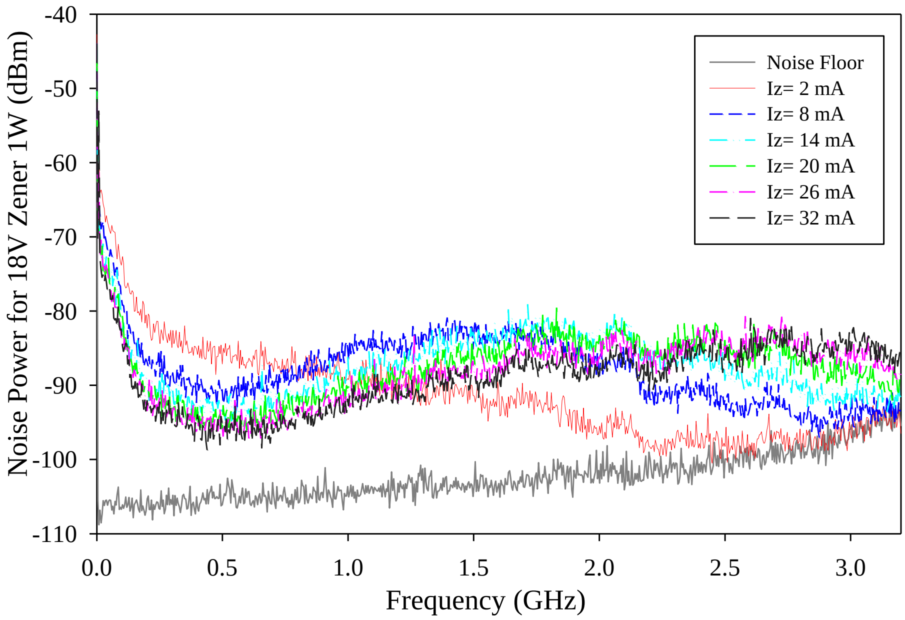


Figure 2.16. Noise power for 18V Zener diode under different biasing currents.

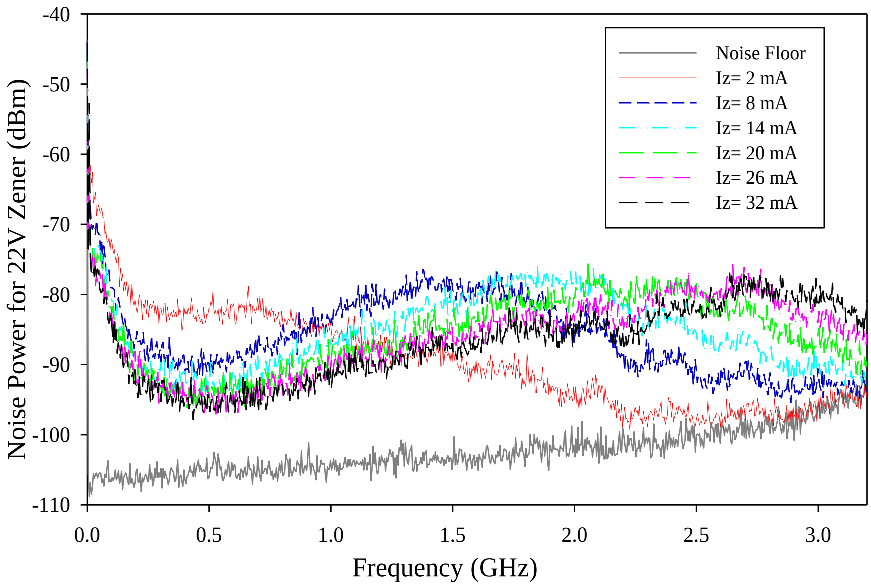


Figure 2.17. Noise power for 22V Zener diode under different biasing currents.

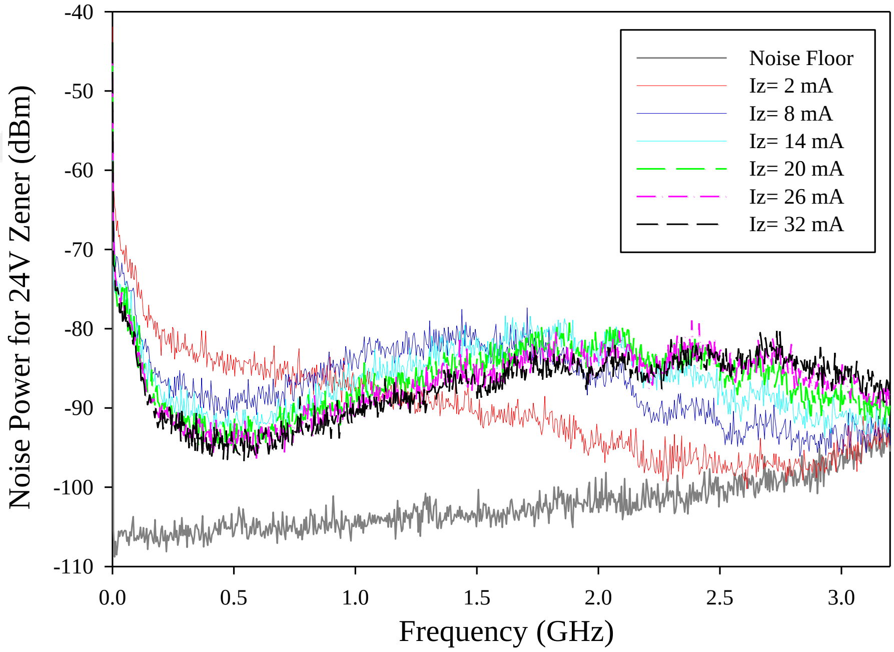


Figure 2.18. Noise power for 24V Zener diode under different biasing currents.

22V Zener diodes have 1W and 1/2W power rated versions and this difference also needs to be taken into account. These two versions of the Zener diodes are measured for low (2 mA), medium (14 mA), and high (32 mA) bias currents. The results are shown in Figs. 2.19, 2.20, and 2.21.

For low current biasing, both Zener diodes' behavior is almost the same. Noise power is not observed beyond 2.5 GHz as shown in Fig. 2.19.

For medium current biasing shown in Fig. 2.20, both Zener diodes generate almost the same noise power up to about 1.7 GHz. The generated noise power makes a dip at about 500 MHz and makes a peak at about 1.7 GHz. 1W Zener diode generates about 5 dB more noise power from about 1.7 GHz to 2.5 GHz. But at 3.2 GHz, noise power is not observed. On the other hand, generated noise power below 750 MHz for 14 mA bias current is less than that of the 2 mA bias current.

For high current bias condition, shown in Fig. 2.21, both Zener diodes generate high noise powers which are almost the same up to about 2.6 GHz. Just like the medium bias current condition, noise power output for high bias current makes a dip at 500 MHz. However, peak noise power occurs at about 2.6 GHz. Beyond 2.6 GHz, 1W Zener diode generates more noise power than the 1/2W Zener diode.

For Zener diodes, low bias currents generate higher noise power from 10 MHz to 750 MHz. When the biasing current is increased, the noise is observed at high frequencies starting from 2.5 GHz and the peak point of noise power shifting to higher frequencies starting from 250 MHz to 3 GHz. It's observed that 1W Zener diode generates higher noise power at higher frequencies than the 1/2W Zener diode. Hence, 1W Zener diode is chosen for the next steps of the thesis.

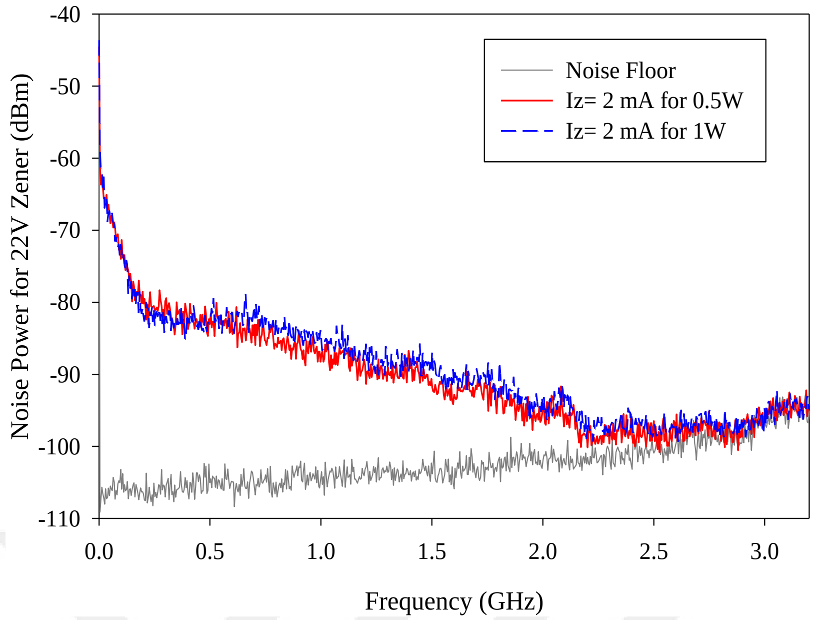


Figure 2.19. Noise power for two different 22V Zener diodes which are 0.5 W and 1 W under 2 mA current biasing.

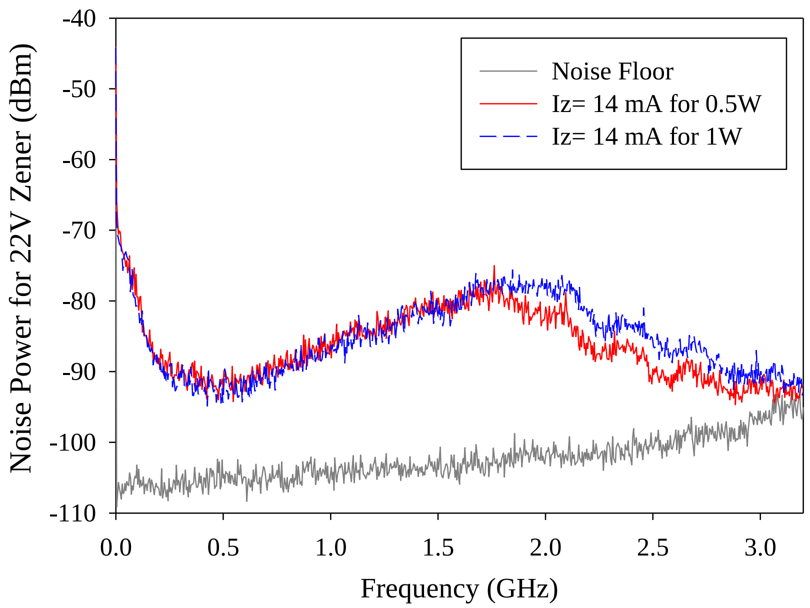


Figure 2.20. Noise power for two different 22V Zener diodes which are 0.5 W and 1 W under 14 mA current biasing.

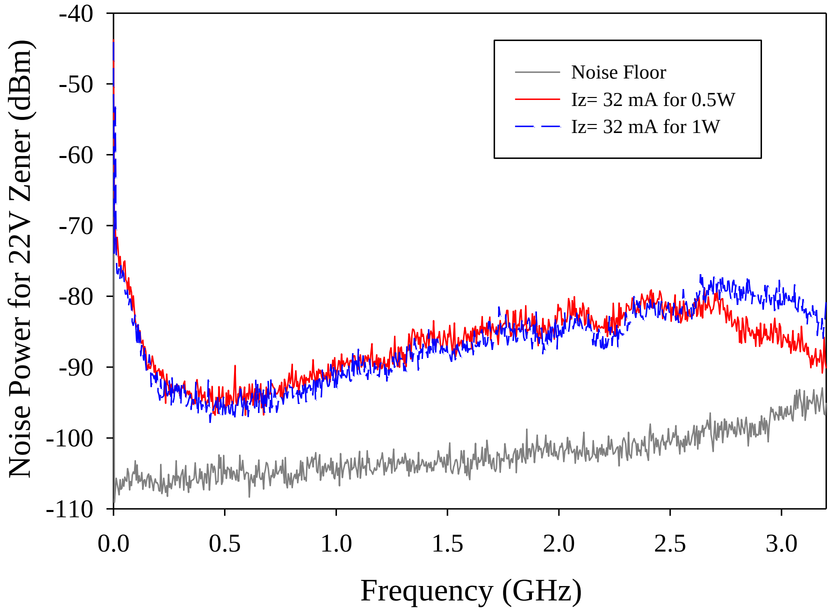


Figure 2.21. Noise power for two different 22V Zener diodes which are 0.5 W and 1 W under 32 mA current biasing.

In the first part of the thesis it can be seen that 22V and 24V Zener diodes generate much more noise power in contrast to 15V and 18V Zener diodes.

For the purpose of using the noise generator in specific applications such as for use as a tracking generator, RF amplifier stages will be designed and used for amplification of the generated noise. Since the gain of an RF amplifier decreases as the frequency increases, in order to achieve an almost flat noise power at the output of the amplifier, the noise characteristics of the chosen Zener diode must be reciprocal of the RF amplifier. From reciprocity it's meant that the Zener noise power should increase with increasing frequency. In order to choose the most suitable Zener diode for the thesis, 22V and 24V Zener diodes have to be compared. Figures 2.22, 2.23 and 2.24 show the generated noise by 22V and 24V Zener diodes under 2mA, 14mA and 32 mA biasing currents. At high bias currents 22V Zener diodes' low frequency noise power is lower than high frequency noise as seen in Figure 2.24. By combining the 22V Zener diode noise generator with an RF amplifier, flat noise power distribution can be obtained. That's why 22V Zener diodes are chosen and it's very promising for the future chapters of the thesis especially 1W 22V Zener diode.

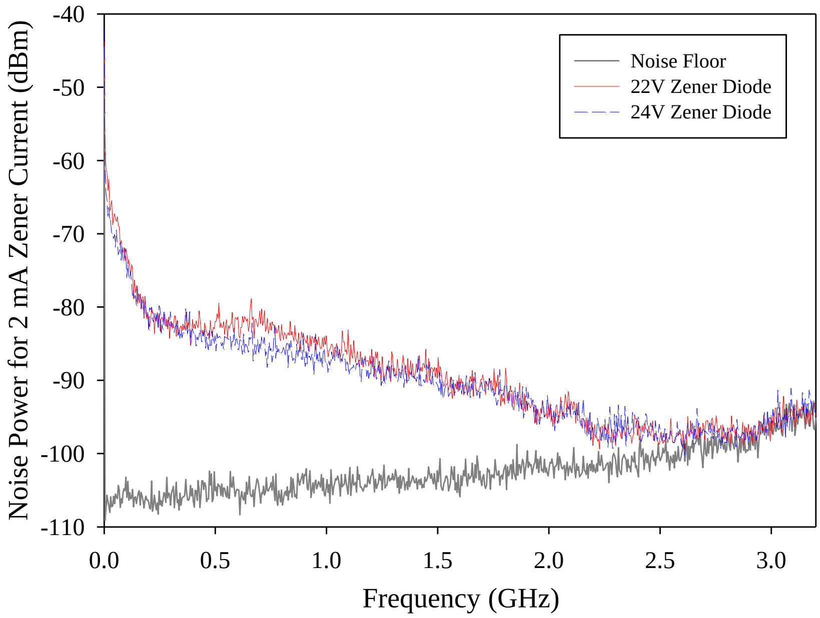


Figure 2.22. Noise power for two different 22V and 24V Zener diodes under 2 mA current biasing.

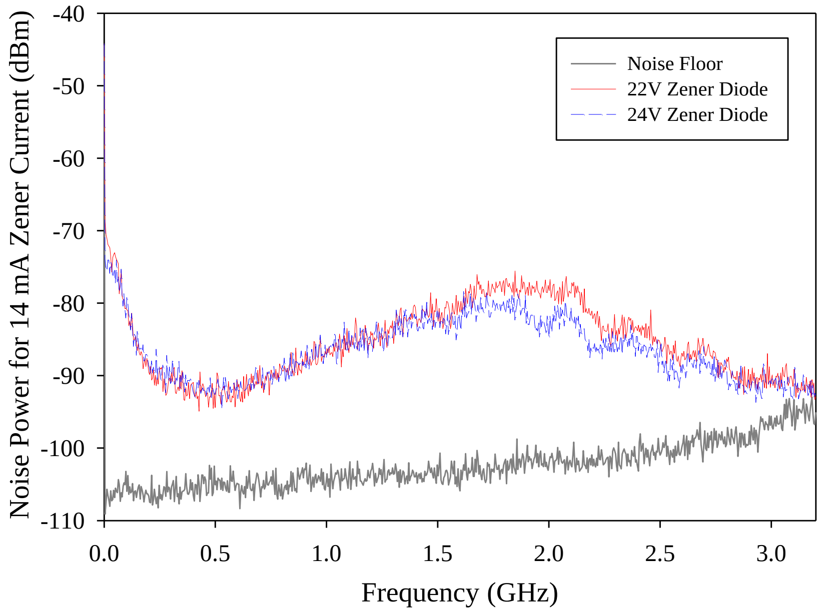


Figure 2.23. Noise power of two different 22V and 24V Zener diodes under 14 mA current biasing.

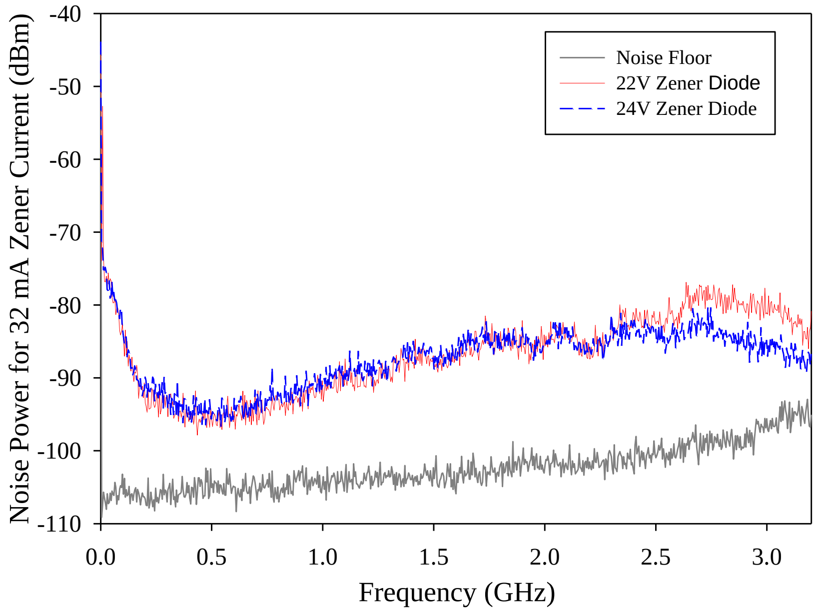


Figure 2.24. Noise power of two different 22V and 24V Zener diodes under 32 mA current biasing.

2.5. Transistors as Noise Sources

Transistors can also be used for noise generating components. In order to generate noise from transistors, it's needed to reverse bias emitter-base leads while the collector lead is open circuit as shown in Fig. 2.25(a). Also one more connection type which is reverse biasing emitter-base and at the same time reverse biasing collector-emitter junctions is investigated. This is achieved by shorting collector to emitter while the emitter-base junction is under reverse bias. This type of connection is shown in Fig. 2.25(b). In the thesis three types of transistors are tested. These are BFG35, 2N2222, and 2N3904. While testing a transistor it's observed that under low biasing current, generated noise power is high. When the biasing currents are reached to 14-20 mA level, noise power begins to decrease. Therefore 2 mA, 8 mA, 14 mA, and 20 mA testing currents are decided for biasing transistors.

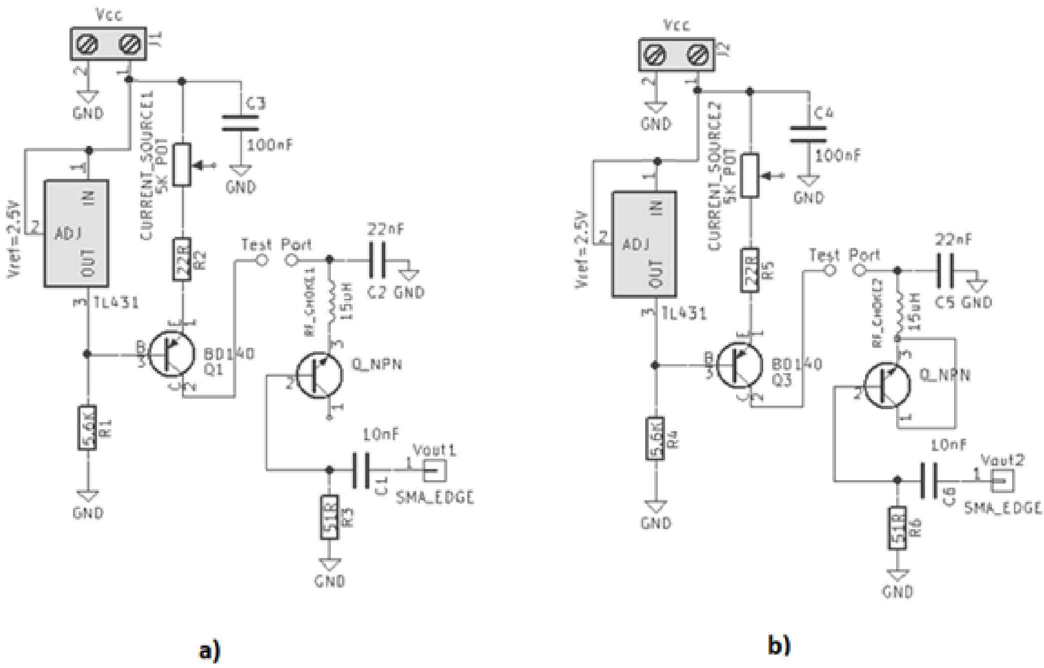


Figure 2.25. Transistor is connected as the noise source, a) emitter-base junction is reverse biased and the collector lead is open, b) emitter-base junction is reverse biased when the collector is shorted to emitter.

BFG35 is a 10V, 150 mA, 4 GHz, RF bipolar NPN transistor and used for wideband amplifier applications (Philips Semiconductors, 1999). BFG35 is tested with collector lead is open. As seen in Figure 2.26, noise is generated up to about 2.6 GHz, but noise power is very low. For 8 mA bias current, noise power has the highest value. Also under all biasing currents, noise power is lowest at about 400 MHz. It can be said that since BFG35 is a low-noise device used for low-noise amplifiers, a low noise power is observed for BFG35.

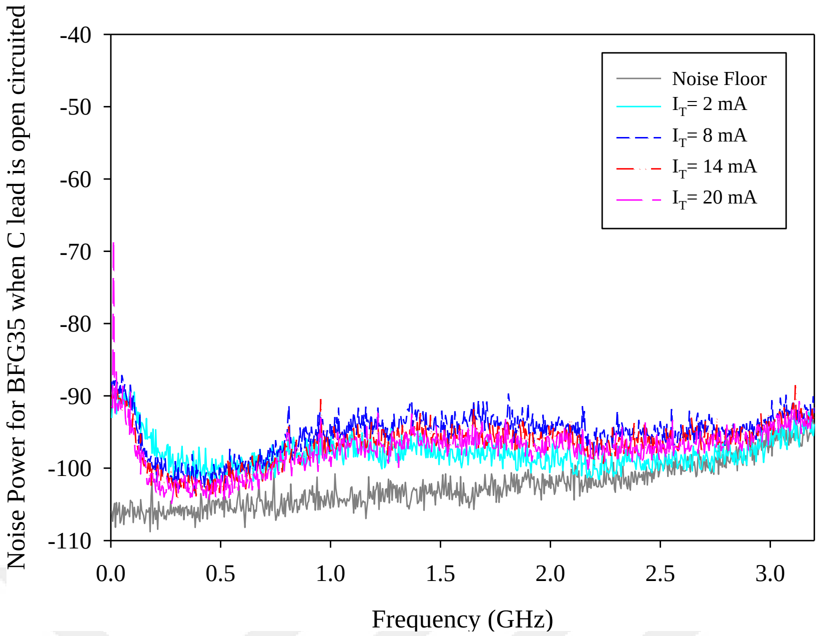


Figure 2.26. Noise power graph for BFG35.

2N2222 is a 30 V, 800 mA, 250 MHz, NPN bipolar transistor and used for signal processing, power management, portable devices, consumer electronics (ON Semiconductor, 2013). 2N2222 is tested under both configurations that is collector is open circuit and collector-emitter junction is short circuited. Figure 2.27. shows the generated noise power distribution when the circuit is tested with collector open configuration. General noise characteristic is as same as BFG35, however 2N2222 generates about 10 dB more noise power than BFG35. Noise response is highest under 2 mA biasing.

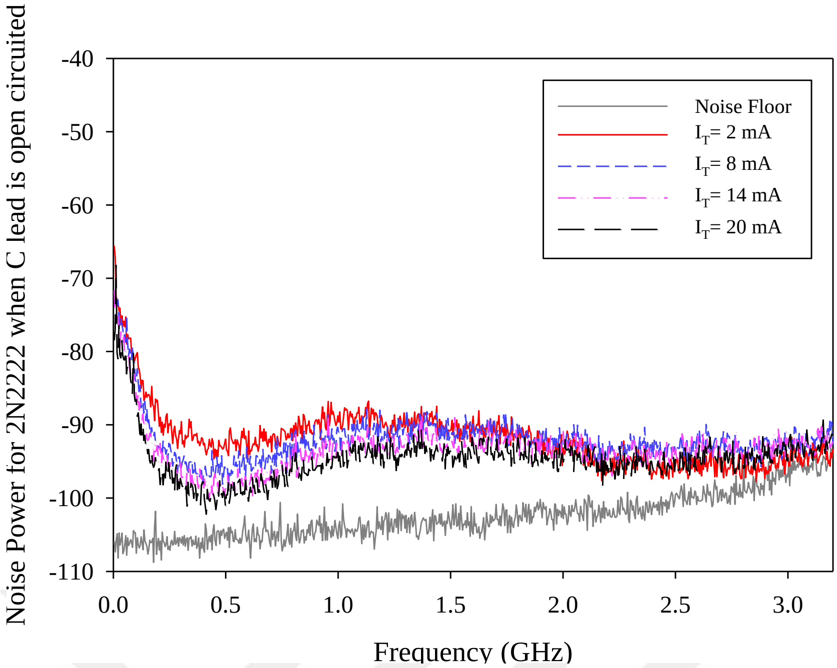


Figure 2.27. Noise power distribution for 2N2222 when the collector lead is open circuit.

Figure 2.28. shows the generated noise power distribution when the circuit is tested with collector-emitter junction is short circuited. Under this configuration, no noise power output is observed at about 1.5 GHz. The reason of this noiseless region will be investigated as a future study. The peak values of noise power under different biasing current occur at 1.2 GHz. The generated noise power distribution has the same trend under all bias currents. On the other hand, under 2 mA current biasing generated noise power is slightly higher than generated currents by other current bi-asings. Over 2.8 GHz no noise is generated.

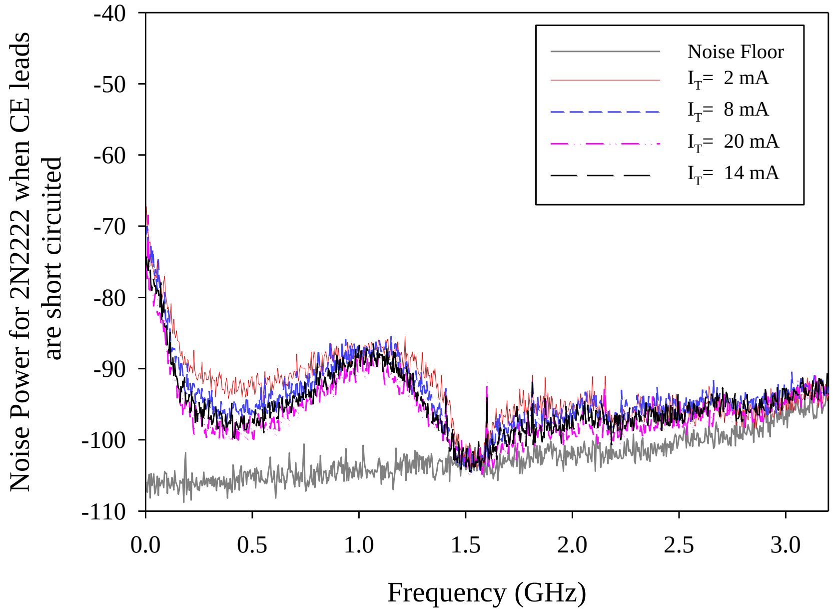


Figure 2.28. Noise power distribution for 2N2222 when the collector and emitter leads are short circuited.

2N3904 is a 40V, 200 mA, 100 MHz NPN bipolar transistor used for general-purpose low-power amplifier or switching applications (ON Semiconductor, 2012). For open collector configuration, noise characteristics for 2N3904 are about the same as 2N2222 transistor but 2N3904 generates about 5 dB more noise power as shown in Figure 2.29. 2N3904 has the highest noise power for 2 mA biasing current.

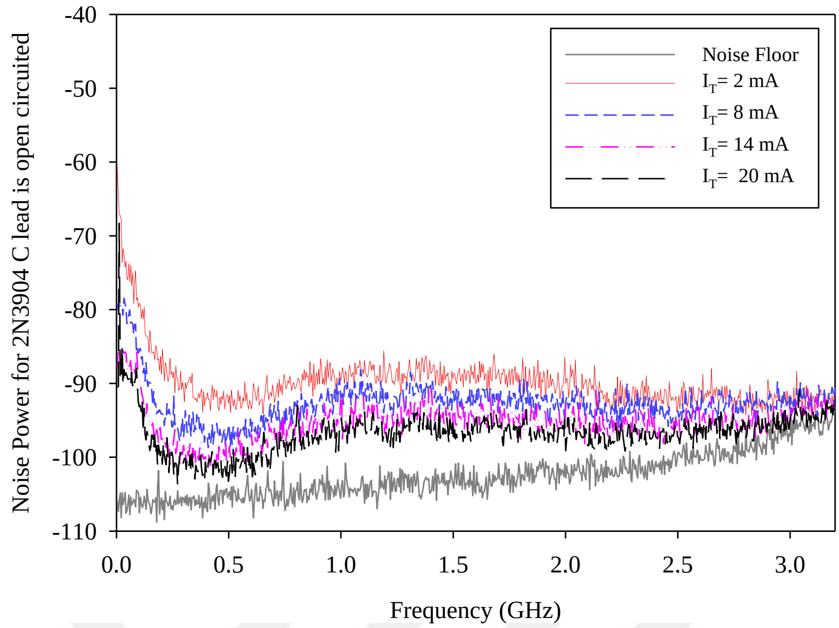


Figure 2.29. Noise power distribution for 2N3904 when the collector is open.

Figure 2.30 shows the generated noise power distribution when the circuit is tested with shorted collector-emitter configuration. For this transistor, no noise power output is observed at about 1.8 GHz. Also under 2 mA biasing conditions, 2N3904 produces the highest noise power all over the frequency spectrum.

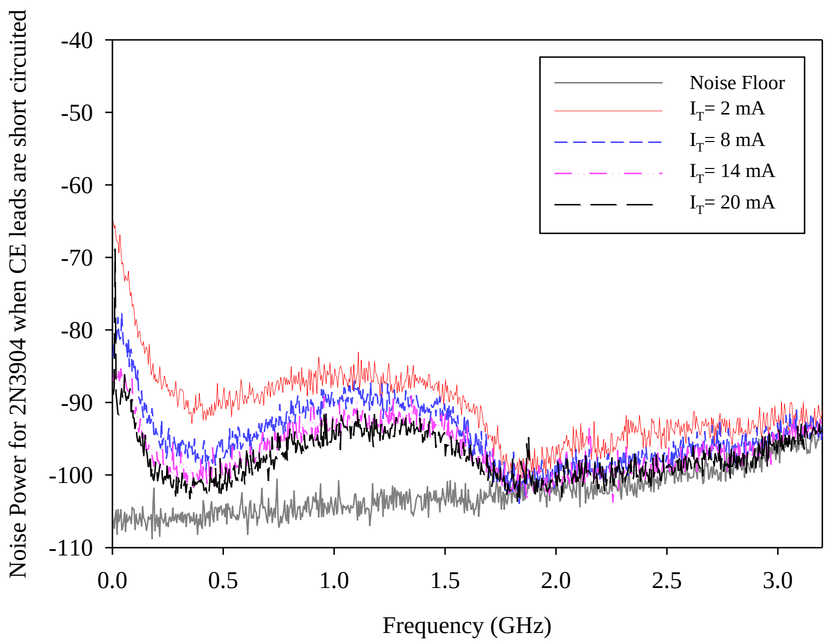


Figure 2.30. Noise power distribution for 2N3904 when the collector and emitter leads are short circuited.

In Figure 2.31. the highest noise power generating components within Zener diodes and transistors are selected and compared. 22V Zener diode under 32mA biasing current and 2N3904 BJT NPN transistor with 2 mA are generating highest zener powers within their class. Figure also shows that higher frequency noise response of Zener diode is 13-15 dB more than 2N3904.

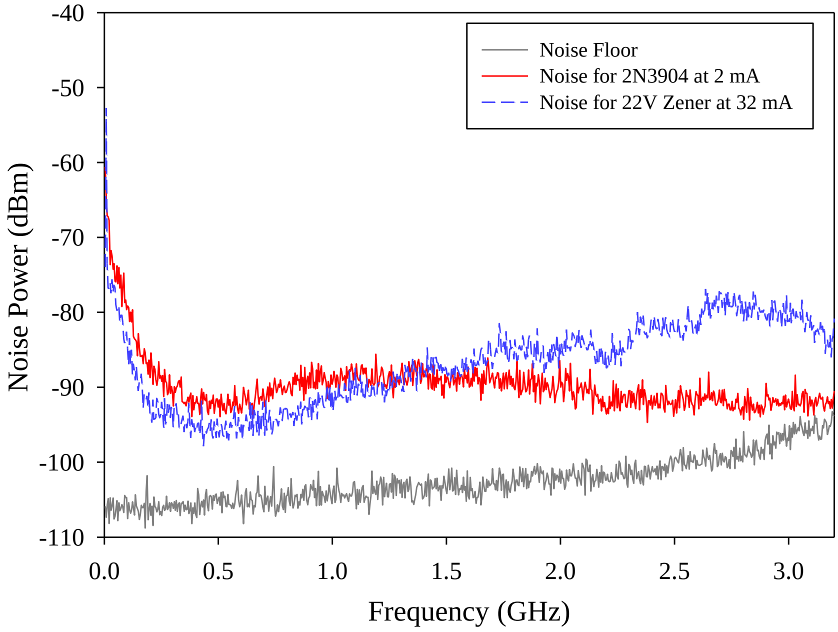


Figure 2.31. Comparison of noise powers generated by 2N3904 at 2 mA biasing current and 22V Zener diode at 32 mA biasing current.

2.6. New Technique in Noise Generation: Two Independent Current Sources to Achieve Flat Noise Power

Various measurements of Zener diodes noise characteristics under different bias currents show for low current biasing conditions, noise power in low frequencies is higher. On the contrary, for high current biasing conditions noise power is higher at high frequencies. Briefly, by the increasing current, noise power density shifts to the higher frequency regions.

Theoretically, if these two generated noises for low and high current biasing are combined together; flat noise spectrum density is needed to be obtained.

Two identical noise generator boards are prepared separately. 22V Zener diodes are chosen for their noise characteristics. 2 mA noise response of Zener diode show that noise power is higher at low frequencies as shown in Figure 2.32.

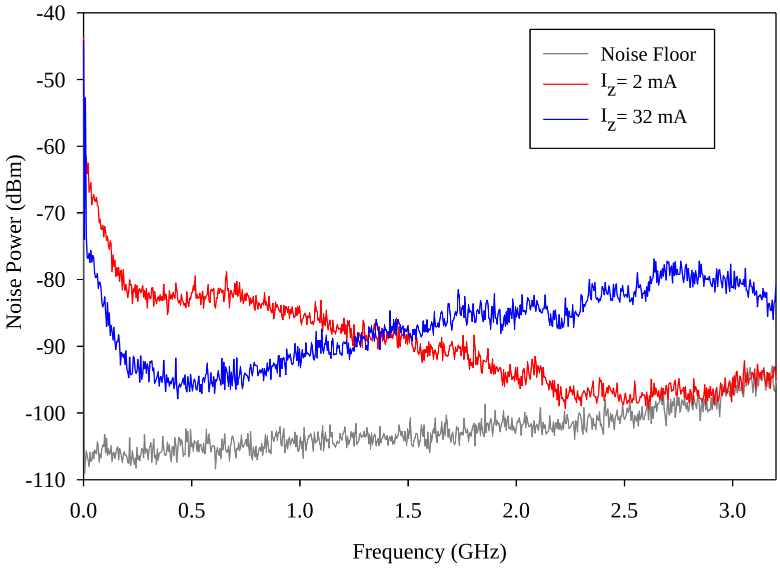


Figure 2.32. Noise power for 22V Zener diode under 2 mA and 32 mA current bias. Red line shows the noise response of 2 mA and it's higher at lower frequencies. Blue line shows the noise response of 32 mA and it's higher at higher frequencies.

As shown in Figure 2.33, two independent constant current sources are designed and each of the current sources provides a constant current biasing for a 22V Zener diode. 22V Zener diode on Board#1 is biased by 2 mA and the 22V Zener diode on Board#2 is biased by 32 mA. Boards are connected together by shorting the cathodes of the Zener diodes, and the output is taken from the 51 Ω load resistor.

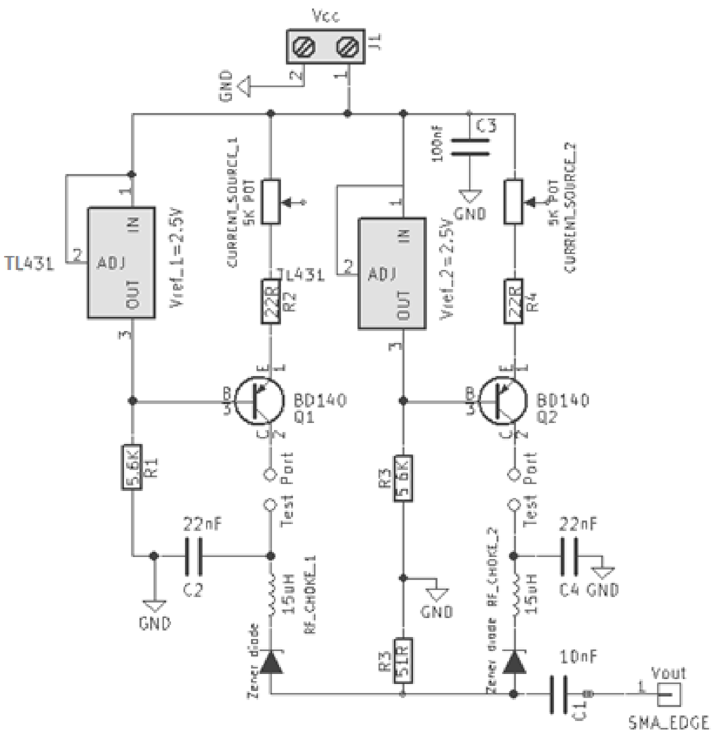


Figure 2.33. Schematic of the noise generator having two independent constant current sources.

The resultant output noise power output is almost flat when 2 mA and 32 mA current sources are used as shown in Figure 2.34.

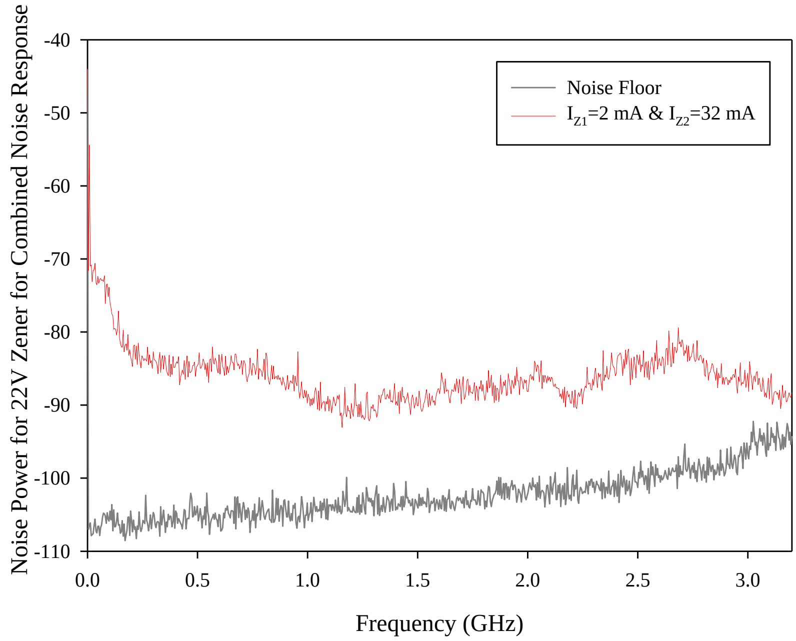


Figure 2.34. The output noise response of the dual constant current source noise generator. The combined response is nearly flat over the band of interest.

Using two different current sources has an important advantage. By adjusting the bias currents separately; it's possible to change the flatness of the output noise power. Fine tuning has been done and a more smooth noise response is obtained at the currents 4.3 mA for Board#1 and 40.5 mA for the Board#2 as shown in Figure 2.35. Also .bmp image of the tuned noise response taken from spectrum analyzer is shown in Figure 2.36.

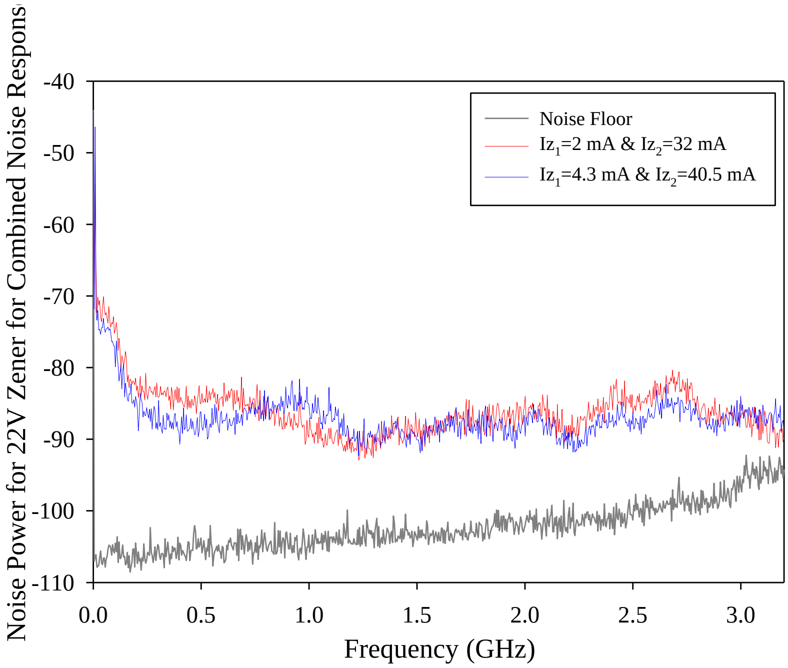


Figure 2.35. The output noise response of the dual constant current source noise generator after fine tuning of bias currents. At 4.3 mA and 40.5 mA, the combined response is better over the band of interest.

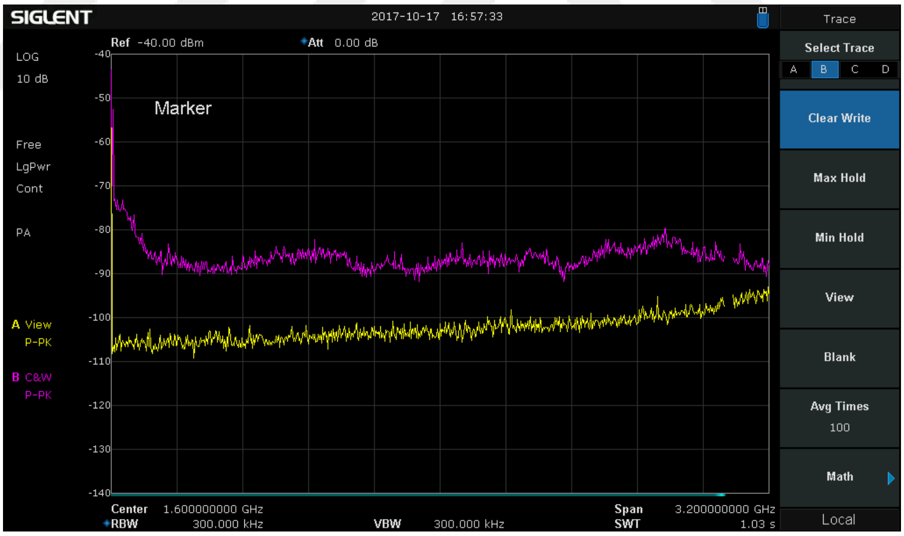


Figure 2.36. Picture of the output noise response of the dual constant current source noise generator after fine tuning.

3. DESIGN OF A MULTI-STAGE MMIC AMPLIFIER

3.1. Design of a Single-Stage MMIC Amplifier

In order to use the generated noise for specific applications, the noise signal has to be amplified by using an RF amplification stage which may include a single RF amplifier or multiple RF amplifiers connected in cascade. RF amplifiers for the gain needed can be designed using discrete transistors, or can be purchased commercially as a ready-to-use blocks. In this thesis, ERA-1SM MMIC amplifier is used for amplification of the noise signal for testing of a filter.

ERA-1SM MMIC amplifier is a wideband amplifier whose operating bandwidth is specified from 100 MHz to 8 GHz. It uses Darlington configuration and enclosed in a Micro-X package (Mini Circuits MMIC, 2012). It's used in microwave radio and test equipment, cable TV, and cellular/3G base stations etc. ERA-1SM provides typically 12 dB gain at 100 MHz and 10.9 dB at 3 GHz.

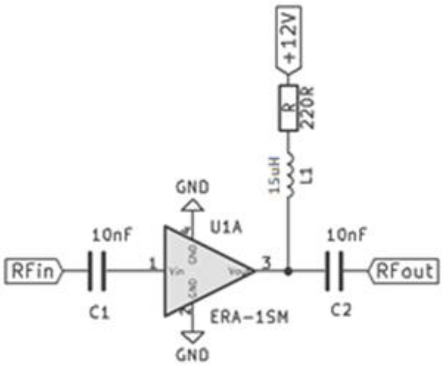


Figure 3.1. Single-stage MMIC amplifier circuit.

First, a single-stage MMIC amplifier shown in Figure 3.1 is constructed. Vcc value of ERA-1SM can be adjusted from 7 V to 20 V. In this thesis, Vcc is chosen as 12 V and a current-limiting resistor of 220 Ω is selected to supply about 40 mA bias current for ERA-1SM. Capacitors C1 and C2 are used to block DC and their value is 10 nF. Inductor L1 is used as an RF choke and its value is 15 µH. For ERA-1SM, RF signal is injected at terminal 1 and the amplified signal is taken out from terminal 3.

Terminals 2 and 4 are used as the ground of the MMIC. The constructed circuit is shown in Figure 3.2.

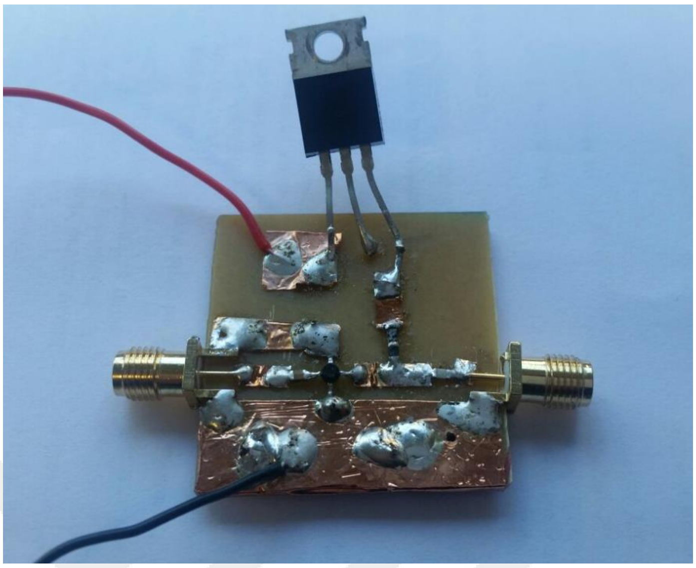


Figure 3.2. Single-stage MMIC amplifier circuit board.

3.2. Design of a 6-Stage MMIC Amplifier

To use the designed noise source for intended applications, a signal level of -50 dBm (at least) is required especially at 3 GHz. For this purpose, a 6-stage MMIC amplifier circuit is designed which consists of cascaded six single-stage MMIC amplifiers. The 6-stage MMIC amplifier is powered by 12V DC, and its schematic is shown in Figure 3.3. SMA-type edge-mount connectors are used for RF input and RF output. Resistors R10, R11, R12, R13, R14, and R15 in Fig. 3.3 are all 220 Ω resistors. The constructed 6-stage MMIC amplifier is shown in Figure 3.4.

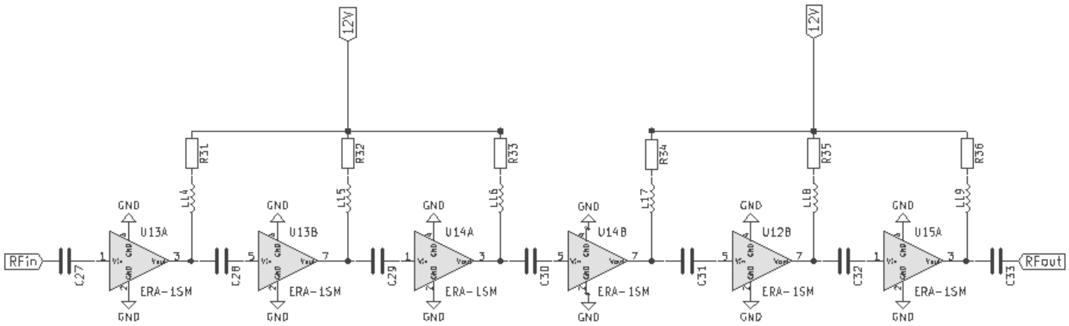


Figure 3.3. Schematic of 6-stage MMIC amplifier circuit.

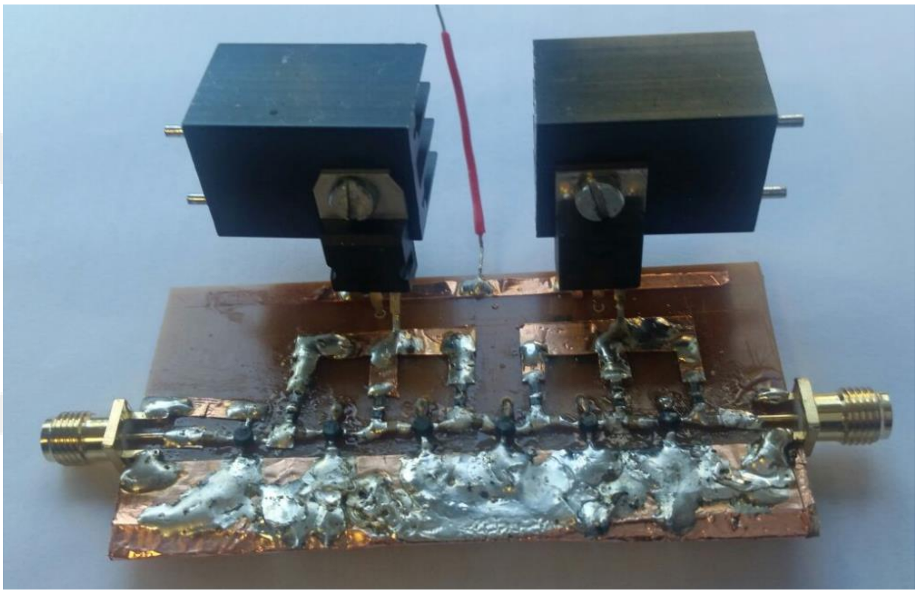


Figure 3.4. 6-stage MMIC amplifier board. Note that black iron cases mounted to 7812 ICs are heat sinks.

3.3. Integrated Noise Source and Amplifier

The next step in the design is to integrate the noise source and the amplifier, and measure its performance using the spectrum analyzer. As it's explained before, a 22V Zener diode at 32 mA bias current is chosen for the source of noise. Note that, Vcc is set to 32 V for the noise generator. However, since ERA-1SM requires 12 V Vcc, 7812 IC is used to transform 32 VDC to 12 VDC for the MMIC. A single-stage MMIC amplifier is expected to yield about 10-dB amplification. Schematic of the integrated unit (noise generator + single-stage amplifier) is shown in Figure 3.5. The resulting noise power distribution is shown in Figure 3.6.

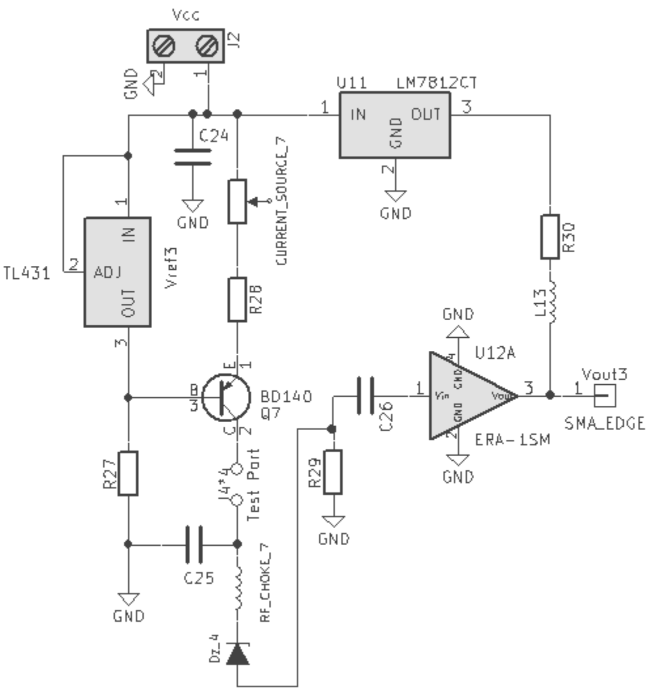


Figure 3.5. Circuit schematic of the noise generator with a single-stage MMIC amplifier.

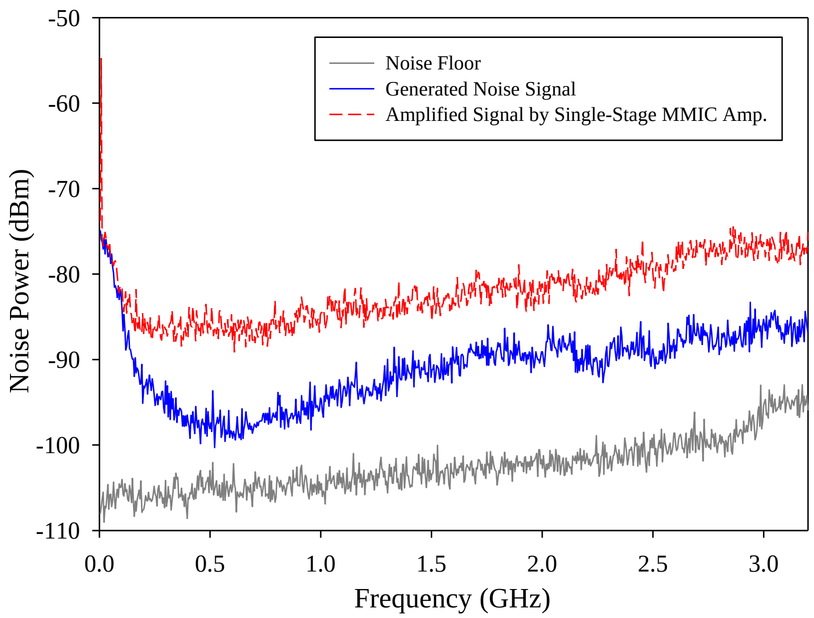


Figure 3.6. Noise power of the noise floor, generated noise signal by a 22V Zener diode under 32 mA bias current, and the amplified signal by a single-stage MMIC amplifier.

Noise generator is then integrated with the 6-stage MMIC amplifier circuit. This time, to protect 7812 ICs from overheating, the array of 6 ERA-1SMs is shared by two 7812s. Therefore, each 7812 supplies about 120mA at 12VDC to feed three ERA-1SM MMICs. The circuit schematic is shown in Figure 3.7. Inductors L7, L8, L9, L10, L11, and L12 are 15 μH RF chokes.

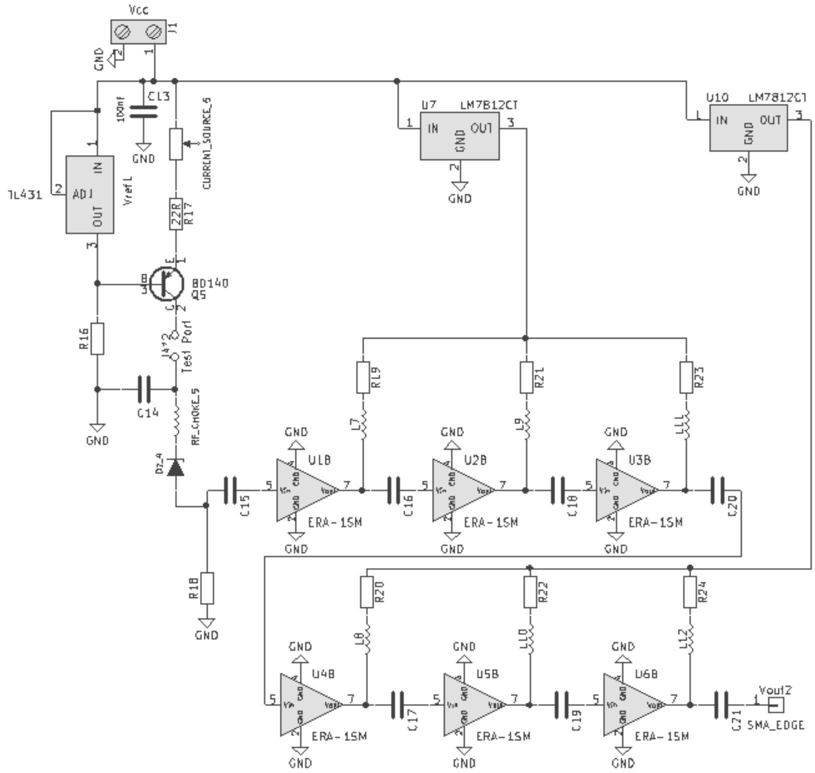


Figure 3.7. Schematic of the noise generator circuit using a 6-stage MMIC amplifier.

The resulting noise power distribution is shown in Figure 3.8. Note that the total gain of the amplifier array is at least 50 dB, and the amplified noise signal power is about -45 dBm from about 500 MHz to 3.2 GHz.

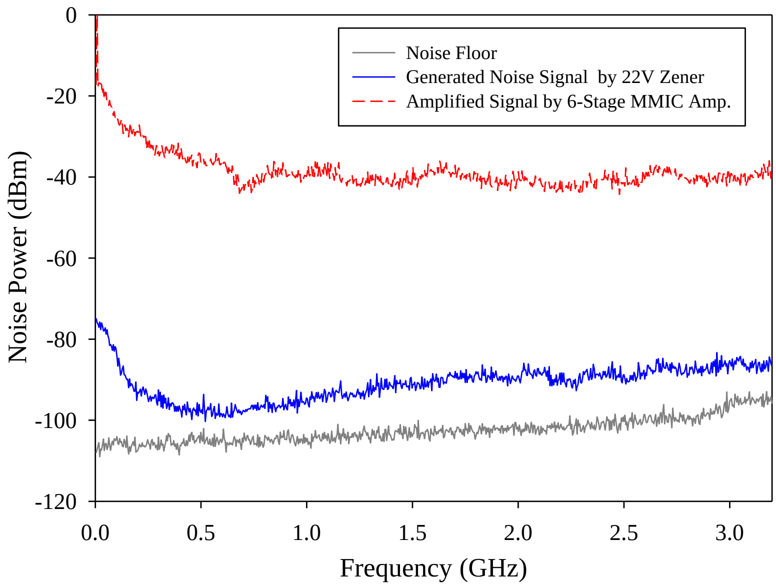


Figure 3.8. Noise power of the noise floor, generated noise signal by 22V Zener diode under 32 mA current biasing, and the amplified signal by a 6-stage MMIC amplifier.

Dual-current source noise generator is designed to achieve a flat noise power over the spectrum of interest. The first current source is set to 40.5 mA and the second current source is set to 4.3 mA. This design is integrated with a 6-stage MMIC amplifier as shown in Figure 3.9. The resulting noise power distribution is shown in Figure 3.10.

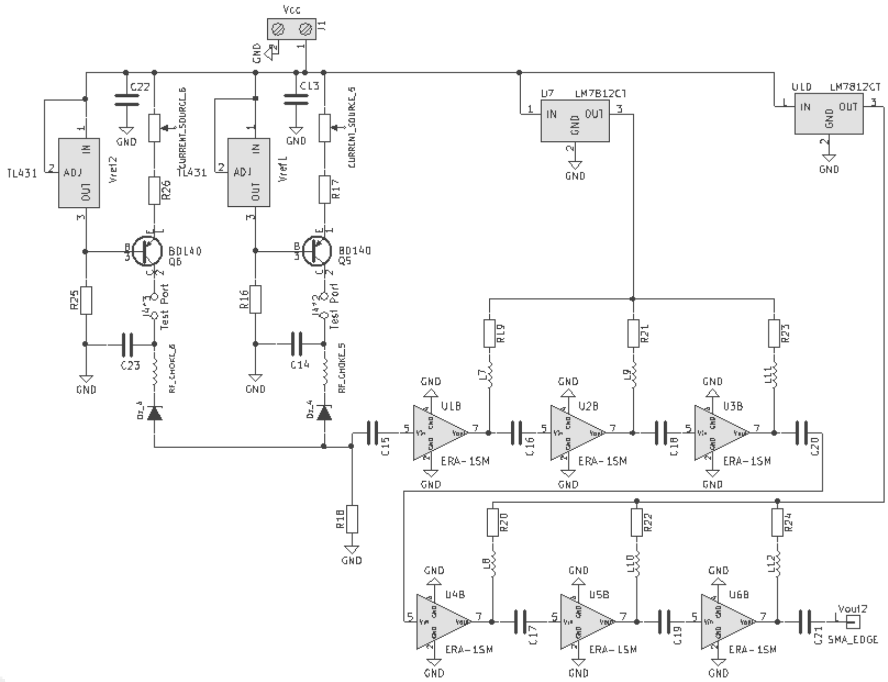


Figure 3.9. Schematic of the dual-current source noise generator circuit using a cascaded 6-stage MMIC amplifier.

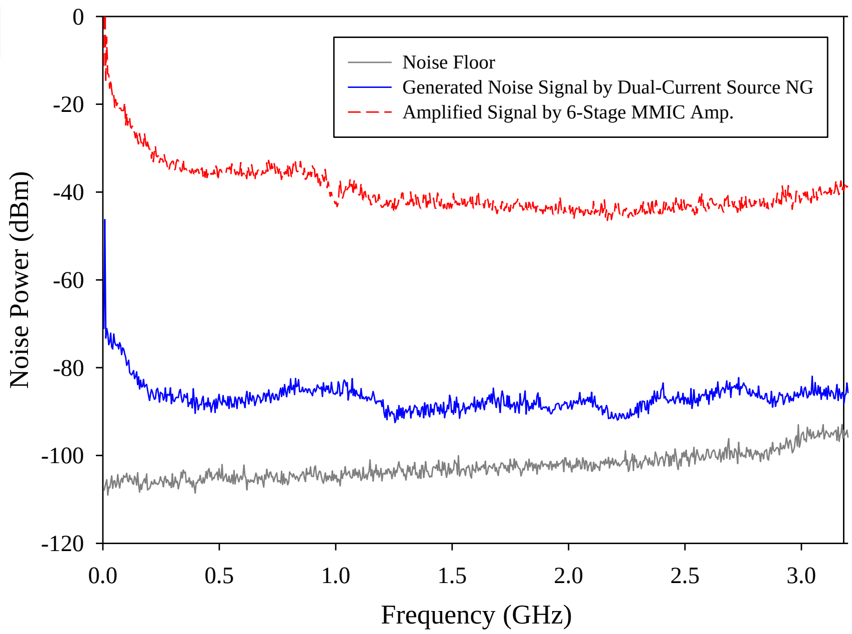


Figure 3.10. Noise power of the noise floor, generated noise signal by dual-current source noise generator, and the amplified signal after 6-stage MMIC amplifier.

4. APPLICATIONS OF NOISE GENERATOR

4.1. Testing of a 2.45-GHz Band-pass Filter

Generated broadband noise can be used in various applications such as filter testing, antenna testing, jamming, noise figure testing etc. In this thesis, the designed noise generator is used for testing a commercially manufactured 2.4-GHz micro strip band-pass filter shown in Figure 4.1. In this application, the noise signal generated by the noise generator is used as a Tracking Generator (TG). The same testing is also performed using a Spectrum Analyzer with Tracking Generator, and the results are compared.

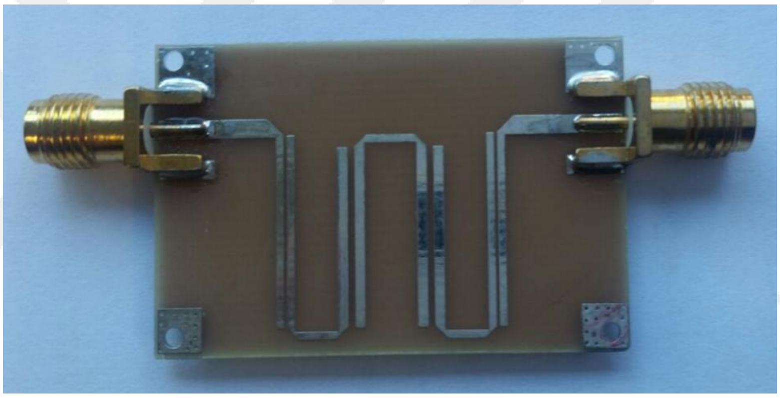


Figure 4.1. A 2.4-GHz band-pass filter used for filter testing.

For the filter test, a noise generator having a single 22V Zener diode driven by 32 mA biasing current is used. The output of the noise generator is fed to a 6-stage MMIC amplifier, and the amplified noise signal is shown in Figure 4.2.

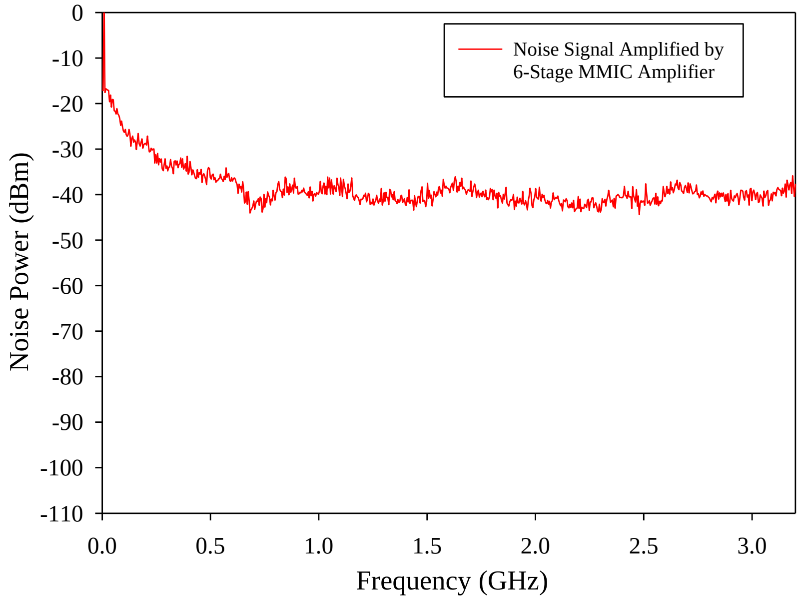


Figure 4.2. Noise signal used for band-pass filter testing (the noise signal is amplified by a 6-stage MMIC amplifier).

The block diagram of the test setup is shown in Figure 4.3. The first block on the left is the noise generator circuit which generates the noise signal. This stage is followed by a 6-stage MMIC amplifier. The amplified noise signal is about -45 dBm. First, this signal is applied directly to the RF input of the spectrum analyzer. After a normalization procedure to set the normalized noise signal level to about 0 dBm, the 2.4 GHz band-pass filter is placed between the noise generator and the RF input of the spectrum analyzer.

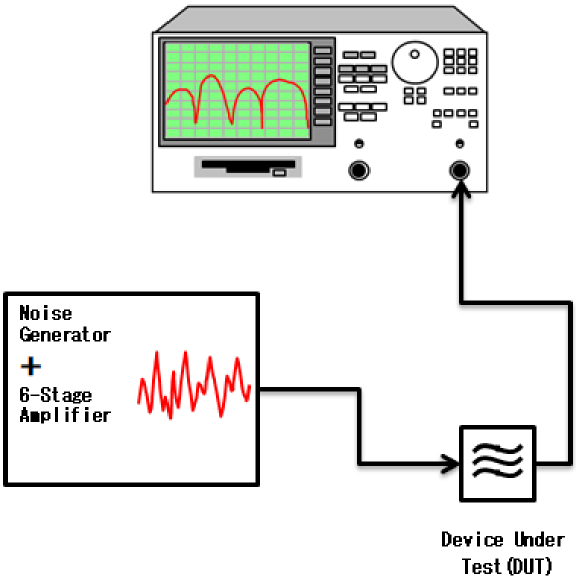


Figure 4.3. Block diagram of testing a band-pass filter using the noise generator as tracking generator.

Filter response is observed on the spectrum analyzer as shown in Figure 4.4.

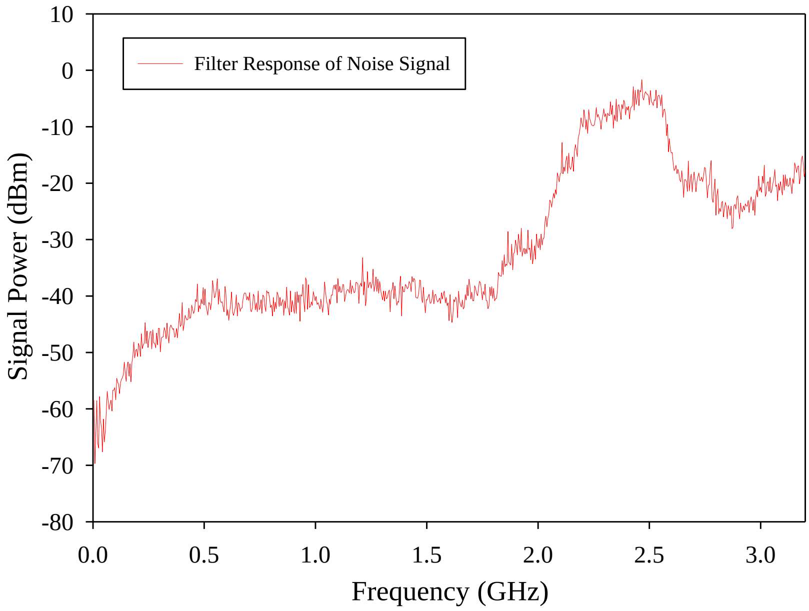


Figure 4.4. Band-pass filter response of the noise signal.

The same filter was tested using the internal TG of the spectrum analyzer. For a fair comparison, average power levels of the signals have to be equalized. For this purpose, the default power level of the TG was reduced from 0 dBm to -45 dBm by first reducing the TG power level to -5 dBm, then using two 20-dB attenuators in cascade. So the overall attenuation is now -45 dB, and the TG power level is -45 dBm. The block diagram in Figure 4.5 shows the test setup of testing a filter using internal TG of the spectrum analyzer.

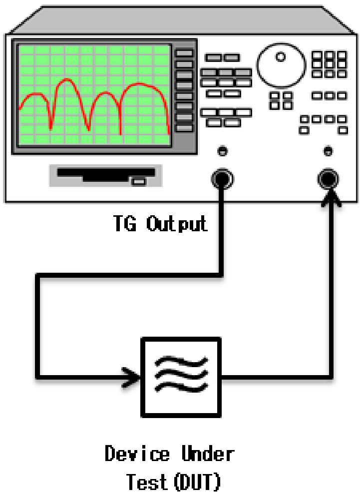


Figure 4.5. Block diagram of testing a band-pass filter using the internal tracking generator of the spectrum analyzer.

After obtaining the -45 dBm TG signal, it's normalized using some settings of the spectrum analyzer. The normalized signal is then applied to the band-pass filter and the filter response is observed on the screen of the spectrum analyzer. The filter response due to -45 dBm TG signal is shown in Figure 4.6.

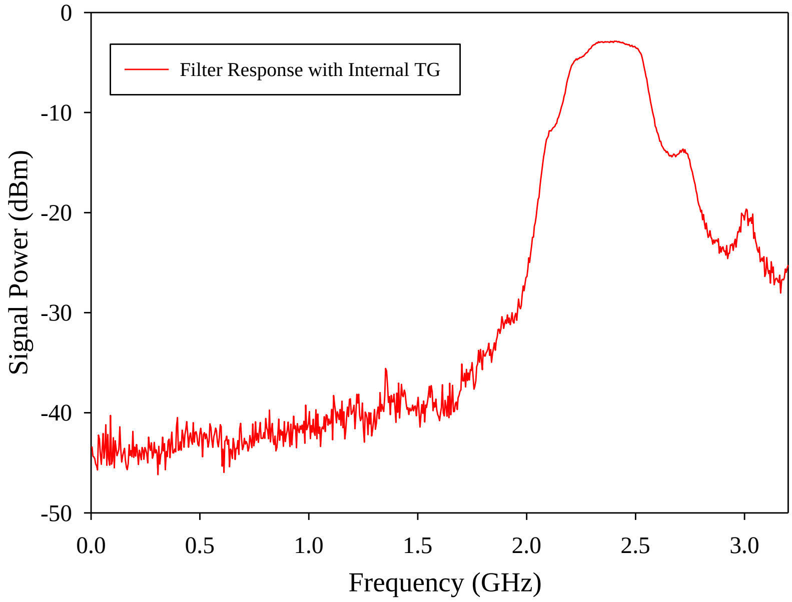


Figure 4.6. Band-pass filter response due to internal TG signal of the spectrum analyzer.

To compare both signal responses, both of them are plotted on the same graph in Figure 4.7. Consequently, it's observed that band-pass filter responses due to the noise generator and the internal TG of the spectrum analyzer are in excellent agreement. These measurements prove that the designed noise generator in this thesis can be used as a TG. Conventional TGs are frequency-swept sinusoidal oscillators. The designed noise generator is compact, easy-to-build, and is a low-cost alternative to conventional TGs.

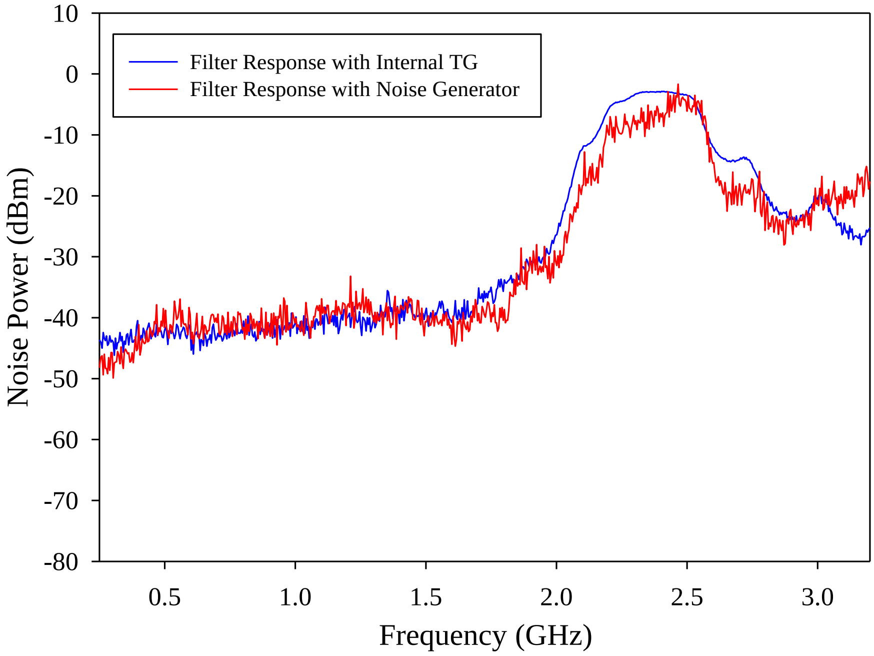


Figure 4.7. The comparison of filter responses due to the internal TG signal of the spectrum analyzer and the noise signal generated by the noise generator circuit.

5. CONCLUSION

A broadband white noise generator is designed by using Zener diodes. In order to bias Zener diodes, a stable constant current source is designed and a TL431 shunt voltage regulator is used for voltage reference. Noise response of different voltage rated Zener diodes are obtained and investigated. 22V Zener diodes give better noise performance than the other Zener diodes subjected to the test. A novel technique of two independent constant current sources with two identical Zener diodes is designed to obtain an almost flat noise power distribution similar to white noise. The advantage of adjusting the bias currents separately gives the chance to obtain different noise power distribution characteristics over the spectrum of interest. The generated noise signal is used for filter testing as the tracking generator signal, and the result is compared with the filter response obtained when using the internal tracking generator of the spectrum analyzer. It's observed that both filter responses are almost the same proving that the designed noise generator presented in this thesis is an excellent cost-effective alternative to conventional and expensive frequency-swept sinusoidal tracking generators.

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Russian	X		
Kazakh		X	