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A REPORT

ON

DESIGN & DEVELOPMENT OF RF BROADBAND SOLID STATE NOISE SOURCE FOR PRECISION NOISE FIGURE MEASUREMENTS

[redacted]

BY

A. RAMU 1996A8PS914

AT

GIANT METREWAVE RADIO TELESCOPE, KHODAD
NATIONAL CENTRE FOR RADIO ASTRONOMY, PUNE

A Practice School II station of

BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE, PILANI

(December, 2001)

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A.Ramu 1996A8PS914 B.E (Hons.) Electronics & Instrumentation

Prepared in partial fulfillment of the
Practice School- II Course

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BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE PILANI (RAJASTHAN)

Practice School Division

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Centre: Pune
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Design and Development of RF Broadband Solid State Noise Source for Precision Noise Figure Measurements

ID No./Name/Discipline of the Student:
1996A8PS914
A. Ramu
B.E (Hons.) Electronics & Instrumentation

Name and Designation of the Expert:
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Head, Front End Electronics Lab

Name of the PS Faculty:
Mr. Bipin Kumar

Key Words:
GMRT, Solid State Noise Source, Noise Diode, Noise Figure, Y-Factor, ENR, Noise Temperature, Bulk Avalanche Mechanism, Constant Current Source, Voltage Regulator, Attenuator, PCB, Plated Through Holes, Etching.

Project Areas:
Solid-State Electronics, Radio Frequency Circuit Design

Abstract:
The solid-state noise source is a noise diode that generates known levels of noise through a controlled bulk avalanche mechanism to measure the noise figure of electronics devices like amplifiers, mixers and local oscillators. This is a broadband noise source that works in the frequency range of 10 MHz to 3GHz. The output of this is typically 15 dB of Excess Noise Ratio.

Signature of Student

Signature of PS Faculty

Date

Date

BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE

PILANI (RAJASTHAN)

PRACTICE SCHOOL DIVISION

Response Option Sheet

Station: National Centre for Radio Astronomy **Centre:** Pune

ID No. & Name: 19996A8PS914 A. Ramu

Title of the Project: Design & Development of RF Broadband Solid State Noise Source for Precision Noise Figure Measurements.

Usefulness of the project to the on-campus courses of study in various disciplines. Project should be scrutinized keeping in view the following response options. Write Course No. and Course Name against the option under which the project comes.

Code No.	Response Options	Course No. (s) & Name
1.	A new course can be designed out of this project	No
2.	The project can help modification of the course content of some of the existing courses	ES C252 Electronics
3.	The project can be used directly in some of the existing Compulsory Discipline Courses (CDC)/ Discipline Courses Other than Compulsory (DCOC)/ Emerging Areas (EA) etc. Courses	EEE C382 Communication Systems
4.	The project can be used in preparatory courses like Analysis and Application Oriented Courses (AAOC)/ engineering Science (ES)/ Technical Art (TA) and Core Courses	TA C222 Measurement Techniques-II
5.	This project cannot come under any of the above mentioned options as it relates to the professional work of the host organization	–

Signature of Student Signature of Faculty

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1. INTRODUCTION

The Giant Metrewave Radio Telescope (GMRT) is a unique facility for radio astronomical research using the metre-wave lengths range of the radio spectrum. GMRT is the world's most powerful radio telescope operating in the frequency range of about 50 to 1500 MHz. GMRT is an indigenous project and a technological breakthrough achieved by Indian Scientists and Engineers in the design of lightweight, low-cost dishes. The design is based on what is being called the `**SMART**' concept - for **S**tretch **M**esh **A**ttached to **R**ope **T**russes. This consists of 30 fully steerable gigantic parabolic dishes of 45m diameters each spread over distances of upto 25 km. The number and configuration of the dishes was optimized to meet the principal astrophysical objectives which requires sensitivity at high angular resolution as well as ability to image radio emission from diffused extended regions. Fourteen of the thirty dishes are located in a compact central array in a region of about 1 sq km. The remaining sixteen dishes are spread out along the 3 arms of an approximately `Y'-shaped configuration over a much larger region, with the longest interferometric baseline of about 25 km. The multiplication or correlation of radio signals from all the 435 possible pairs of antennas or interferometers over several hours will thus enable radio images of celestial objects to be synthesized with a resolution equivalent to that obtainable with a single gigantic dish 25 kilometer in diameter. The array will operate in six frequency bands centered around 50, 153, 233, 325, 610 and 1420 MHz. All these feeds provide dual polarization outputs and also possible for dual-frequency observations. The instrument has state-of-the-art electronics systems developed indigenously and consisting of antenna feeds at six different frequency bands between 50 MHz and 1500 MHz, having good polarization characteristics as well as simultaneous multiband operation. Low-noise amplifiers, local oscillator synthesizers, mixers, IF amplifiers are the important electronic devices that are crucial for the operation of GMRT antennas. The present project deals with the design of solid-state noise source to measure the noise figures of the above devices in determining the performance characteristics of the receiver system.

1.1 OVERVIEW

Noise is a natural phenomenon that affects most microwave and RF systems. Thermal noise is an important consideration for microwave designers because it greatly affects the linear microwave and RF systems. Noise plays a very crucial role in the performance of receiving systems. The receiving systems often processes very weak signals, but the noise added by the system components tends to obscure those very weak signals. Sensitivity and Noise Figure are the system parameters that characterize the ability to process low-level signals. Noise figure is a unique measure that provides a means of evaluating the internal noisiness of receiver systems and the sub-elements like the pre-amplifiers, mixers and IF amplifiers that make up the system.

1.2 SCOPE

The solid-state noise source is a noise diode. This noise source generates excess noise under controlled bulk avalanche mechanism, operating at recommended reverse bias potential applied to the diode. Also for stability of the noise power it is recommended to operate the noise diode maintaining a constant current source. The noise source is calibrated using standard Y-factor Excess Noise Ratio technique in which the power is measured in the receiver system with the diode alternately turned on and then off. The noise source is designed to our range of frequencies with a view to use in GMRT Front End Lab to measure the noise figures of various devices.

1.3 SPECIFICATIONS

SOLID STATE NOISE SOURCE

Frequency Range:	10MHz – 1600MHz
Supply Voltage:	+28V (DC) or Pulsed Mode of Operation
Output Excess Noise Ratio(ENR):	Around 14dB

Biasing Voltage, V_B :	8 - 12 volts
Load Resistance, R_L:	50-ohm
Operating Current, I_{OP}:	6mA
Input Connector:	BNC –Female
Output Connector:	N-Type – Male

Dimensions

Length:	89mm
Width:	32mm
Height:	35mm

2. NOISE IN RECEIVER SYSTEMS

The Receiver noise is generated primarily within the input stages of the receiver called Johnson noise. The noise performance of a receiver is described by a figure of merit called the noise figure (NF). The noise figure is defined as:

$$NF = \frac{\text{Noise output of Actual Receiver}}{\text{Noise Output of Ideal Receiver}} \qquad \textbf{(2-1)}$$

The Noise Figure is applied to both individual components such as a single transistor amplifier or to a complete receiver system. The overall noise figure of the system is calculated if the individual noise figures and gains of the system components are known. The noise figure of each component is found when the internal noise, Na, is added along with the gain of the device.

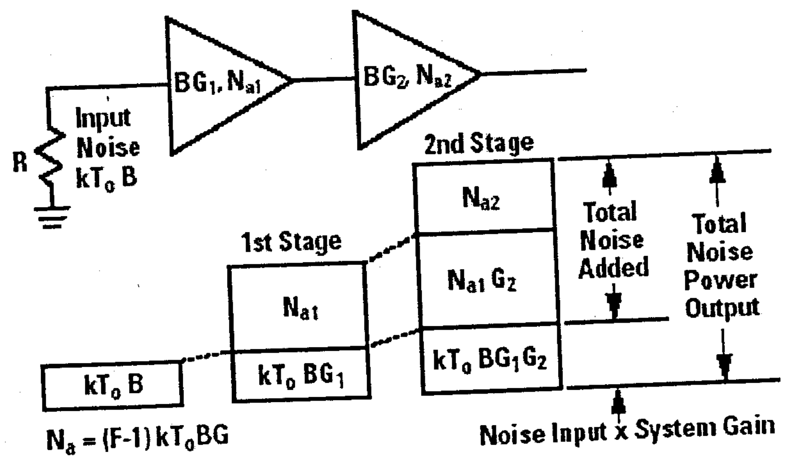


Figure 2.1: The Effect of Second Stage Contribution

From Figure 2.1, the output noise will consist of source noise, kToB amplified by both gains, G1G2, plus the first amplifier output noise, Na1, amplified by the second gain, G2, plus the second amplifiers output noise, Na2. The output noise can be expressed in terms of Noise Factor, F as

$$N_o = kT_oBG_1G_2\left[F_1 + \frac{F_2 - 1}{G_1}\right]$$

(2-2)

As the output noise is known, the noise factor of the combination of both amplifiers is the overall system noise figure of the two-stage network

$$F_{sys} = F_1 + \frac{F_2 - 1}{G_1}$$

(2-3)

The quantity (F2-1)/G1 is called the second stage contribution. The first stage gain is always high than the second stage contribution. And hence the pre-amplifier gain is an important parameter in receiver design.

The noise figure of an n-stage cascade of devices is expressed as

$$F_{sys} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1G_2} + \cdots \frac{F_n - 1}{G_1G_2 \ldots G_{n-1}}$$

(2-4)

4. MEASUREMENT OF NOISE

Noise in receiving systems is normally characterized in terms of available noise power from a thermal source, say, a resistive termination. The available noise power from a given resistor is given by the expression

$$P_N = kTB \tag{4-1}$$

Where

P_N = Available noise power at the output of a resistor terminals

k = Boltzmann's constant = $1.38*10^{-23}$ Joules/K

T = Absolute temperature in °K

B = Bandwidth of the measuring system in Hz

4.1 CONCEPT OF NOISE FIGURE

The Noise Figure F of a network is defined as the ratio of the signal-to-noise power ratio at the input to the signal-to-noise power ratio at the output. Thus the noise figure of a network is the degradation in the signal-to-noise ratio as the signal goes through the network. An ideal amplifier amplifies both the noise at its input along with the signal, maintaining the same signal-to-noise ratio at its input and output. A realistic amplifier however, adds some extra noise from its own components and degrades the signal-to-noise ratio at the output. The noise figure F of a network is given by

$$F = \frac{S_i/N_i}{S_o/N_o}$$

$$= \frac{S_i/N_i}{GS_i/(N_a + GN_i)}$$

$$= \frac{N_a + GN_i}{GN_i} \tag{4-2}$$

S_i and N_i represents the signal and noise levels available at the input to the device under test (DUT), S_o and N_o represent the signal and noise levels available at the output, N_a is the noise added by the DUT, and G is the gain of the DUT. Figure 4.1 is the symbolic representation of the Noise Figure.

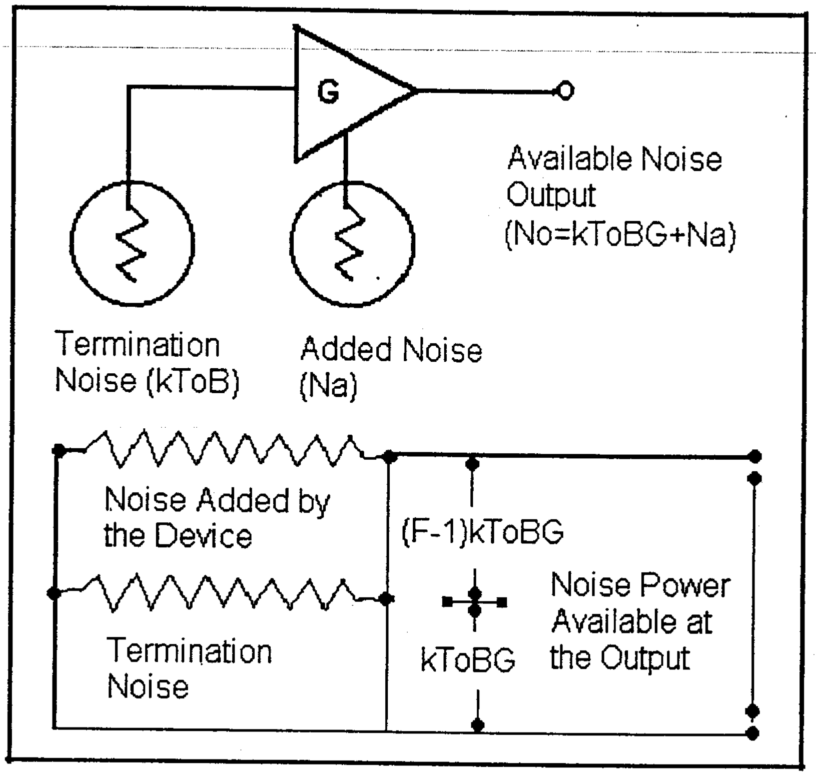


Figure 4.1: The symbolic representation of Noise Figure

When the input is terminated with the matched load, the thermal noise available from the input termination is kT_oB.

The above equation 4-2, can be written as

$$F = \frac{N_a + kT_oBG}{kT_oBG}$$

Noise Added by the device N_a is therefore given by

$$N_a = (F-1)\ kT_oBG \qquad \textbf{(4-3)}$$

4.2 NOISE TEMPERATURE

Thermal noise power that generates at any temperature above absolute zero in a conductor is proportional to its physical temperature. Sometimes, especially when the noise figures are very low it is convenient to quantify the amount of noise generated by the device in terms of Noise Temperature, T_e instead of Noise Figure. Noise temperature T_e is the effective input noise temperature and is the equivalent temperature of the source impedance that would produce the same added noise, N_a with a perfect (noise free) device. It is defined as

$$T_e = \frac{N_a}{kGB}$$

It is related to the noise figure F by the expression

$$T_e = (F-1)\, T_o \qquad (4\text{-}4)$$

Where T_o is the ambient temperature (approximately 300 °K)

4.3 THE MEASUREMENT OF NOISE FIGURE

The basis of most noise figure measurements depends on a fundamental characteristic of linear two-port devices, noise linearity. The noise power out of a device is linearly dependent on the input noise power or temperature. If we know the slope of the characteristic and a reference point, the output power corresponding to a noiseless input power, N_a can be calculated from the Figure 4.2.

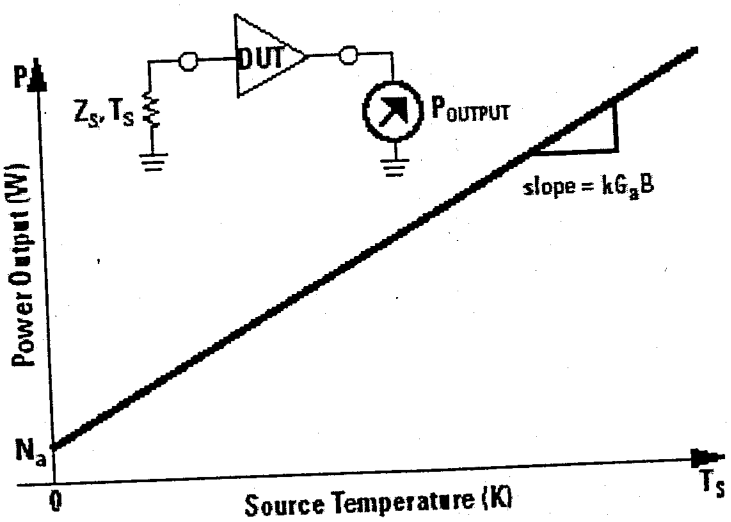


Figure 4.2: Noise Power vs Source Temperature Characteristic of Linear two port Devices

For source impedance with a temperature of absolute zero, the power output consists solely of added noise N_a from the device under test (DUT). For other source temperatures the power output is increased by thermal noise from the source amplified by the gain characteristic of the DUT. Noise figure measurements for various devices are made with a noise source which has a calibrated output noise level, represented by excess noise ratio (ENR). ENR dB is the ratio, expressed in dB of the difference between T_h and T_c, divided by T_o.

$$ENR_{dB} = 10\log\left(\frac{T_h - T_c}{T_o}\right) \qquad (4\text{-}5)$$

where T_h is the noise temperature of the noise source when it is on

T_c is the noise temperature when the noise source is off

T_o is the ambient temperature

In most of the cases T_c is maintained at T_o.

4.4 Y-FACTOR METHOD OF MEASUREMENT

The Y-Factor method is the basis of most noise figure measurements automatically performed internally in a noise figure analyzer. This uses noise source and determines the internal noise in the DUT and also the noise figure or effective input noise temperature. When the noise source is connected to the DUT, the output power N_2 measured corresponds to the noise source on and N_1 is the noise power output when the source is off. The ratio of these two powers is called the Y-factor.

$$Y = \frac{N_2}{N_1} \quad \textbf{(4-6)}$$

The calibrated ENR of the noise source represents a reference level for input noise and determines the DUT internal noise, N_a. The measurement concept involves the measurement of the two powers N_2 and N_1 by switching the calibrated noise source on and off and then N_a is calculated as

$$N_a = kT_oBG\left(\frac{ENR}{Y-1} - 1\right) \quad \textbf{(4-7)}$$

From equation (4-3), Na = (F-1) kT_oBG. Substituting for N_a in equation (4-7), the Noise Figure F is given by

$$F = \frac{ENR}{Y-1} \quad \textbf{(4-8)}$$

The above equation is modified when the noise source cold temperature, Tc, is not at the reference temperature, To.

$$F = \frac{ENR - Y\left(\frac{T_c}{T_o} - 1\right)}{Y-1} \quad \textbf{(4-9)}$$

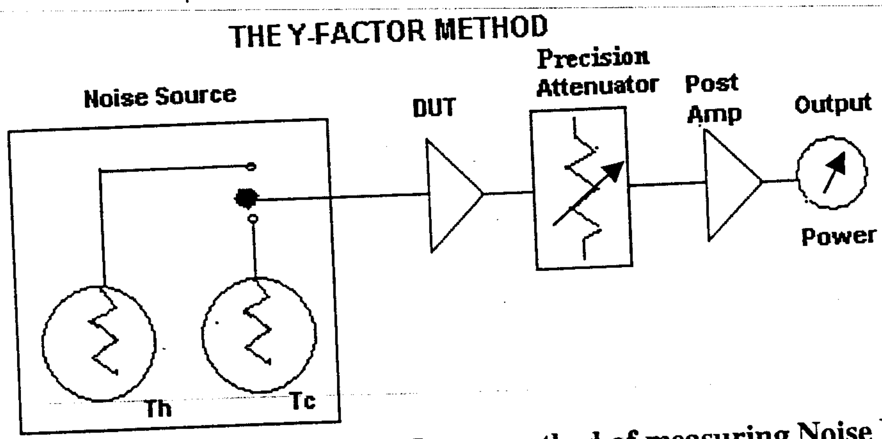


Figure 4.3: The schematic of the Y-Factor method of measuring Noise Figure

A precision attenuator is kept between the DUT and the post amplifier to maintain the linearity in the amplitude measurement of the system while measuring very low noise figures. When measuring N_h the precision attenuator keeps increasing the attenuation till it gets the same reading on the NFA as in the case of N_c. The reading indicated on the precision attenuator is the Y factor in dB.

5. NOISE SOURCES

The prime function of a noise source is to establish a reference noise power level for noise figure measurements. The most popular noise generators or sources fall into three categories based on the noise generating mechanism: thermal, gas-discharge, and solid-state. The thermal noise generator implies a transmission line terminated with a resistive load, held in a constant thermal environment. This operation principle makes it the most accurate and often used as a calibration standards for gas-discharge and solid-state generators. Several companies manufacture calibrated random noise sources, but the following commonly available devices can also serve as noise generators:

- Hot/Cold Body Noise Source
- Zener diode
- Gas-discharge device
- Any reverse-biased semiconductor junction driven into avalanche mode

5.1 HOT/COLD BODY NOISE SOURCE

The system consists of two (one hot and one cold) or three (one hot, one ambient and one cold) thermal noise sources whose outputs are easily switched on into a common calibrated output port. The units use liquid helium/nitrogen as the medium for commercially available cold noise source. With a cold source temperature at 78 kelvin, the measurements are made using a room temperature termination as a hot noise source. In order to increase the Y-Factor to a more measurable magnitude, the hotter source can be preferred. The hot termination is inserted into an oven that controlled temperature is calibrated against boiling water.

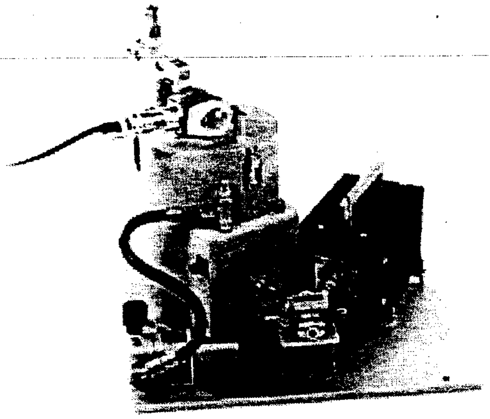


Figure 5.1: Hot/Cold Noise Source

The hot/cold noise source junctions are held at one in the boiling point of water, Th=373.2 °k, and other at the boiling point of liquid nitrogen, Tc=77.3 °k at standard pressure. This is potentially the most accurate standard noise source. This has low excess-noise ratio, which makes this suit for low-noise measurements. But this complicates the need for liquid nitrogen and other cryogenic fluid to use in the field. It is used for stationary applications and as the best available noise reference source.

5.2 GAS-DISCHARGE NOISE SOURCE

The gas-discharge noise generating tube has progressed to mechanically precise argon filled quartz tube with radioactive trace elements to ease ignition. The most common is cold cathode and hot filament. This device emits noise of uniform spectral density over a wide band of frequencies in the positive column of a low-pressure gaseous discharge tube. When the gas-discharge lamp is energized, the ionized gas becomes a good microwave absorber. The plasma represents very hot termination. This behaves as thermal noise from a fictitious resistance at a very high temperature, typically in excess of 11,000k, which is nearly 15.7dB ENR. The apparent temperature is due to electrons of high average energy contained in the plasma column of the tube. When the lamp is de-energized, the passive load at the opposite end of the guide terminates the UUT. The gas-discharge tube is not a primary noise standard because its noise temperature, and hence the actual noise output, depend on variables such as the gas pressure, the type of gas used, and the diameter of the plasma column. The principle asset of gas discharge tube is their high noise output when compared to hot/cold sources. The dis-advantages of this are it needs typically 1000-5000 volts peak to initiate the discharge and the current required is 100 to 200 mA, with a voltage drop of

100volts. So the power supply requires is somewhat special. These are preferred particularly above 18GHz because of their proven repeatability. One of the models is shown below

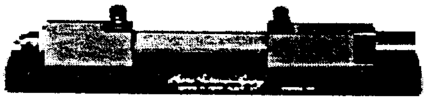


Figure 5.2: Gas-Discharge Noise Source

5.3 SOLID-STATE NOISE SOURCE

The most popular noise source in RF works is the solid-state diode source. Its advantages are such that it has completely taken over the 10MHz to 18GHz frequency range. This has started out as a zener diode, but special diodes, called noise diodes are developed to yield the very broadband, high noise output that characterizes this device. The diode is reverse biased at the breakdown. The basic diodes can provide excess-noise ratios of 32-38 dB, but this cannot always be utilized directly because the impedance of the diode varies from approximately 20ohms when turned off and nearly 400ohms when turned on. Under certain conditions the semiconductor diode operated in the avalanche mode will generate a relatively large amount of RF and Microwave noise, which is 10^6 kelvin equivalent noise temperature. The high level of available noise power generated by the diode permits attenuation to be inserted between the device and the input of the UUT. The attenuator masks the rather severe source impedance change that would normally be seen as the diode is switched from the on to the off. In order to provide constant output impedance, the unit must be padded. The final ENR is thereby lowered to the customary value of around 14dB. Advantages of this are its small size and light weight, and operates on +28 volts at less than 15mA. No ignition pulse is required eliminating a potential EMI and temperature rise due to power dissipation is negligible.

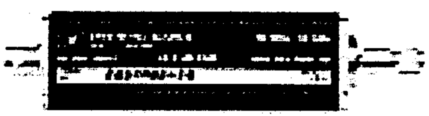


Figure 5.3: Model of Solid State Noise Source

6. SOLID STATE NOISE SOURCE

The solid-state noise source generates a precise amount of electrical conducted noise equivalent to the thermal noise from a resistor with a physical temperature, T_{hot}. The primary function of a noise source is to establish a reference noise power level for noise figure measurements. The solid-state noise source output is maintained at constant and independent of temperature if a current regulator controls the current through the noise diode.

The five basic parameters of a solid-state noise sources are

1. Output Level

The output level is normally specified as Excess Noise Ratio, as dBm/Hz or in terms of the actual noise temperature, T_{hot}.

2. Output Characteristics

Impedance: Nominally 50ohms.

Frequency: Bandwidth over which specified ENR is maintained.

3. Input Power

Voltage: Amount of DC voltages/currents to supply bias to activate the noise source.

4. Accuracy/Stability

Temperature coefficient: The rate at which the output power changes over temperature.

Input sensitivity: The amount of output power changes with variations in input DC voltage.

6.1 THEORY OF OPERATION

A solid-state noise source is a noise diode. The noise diode operates in bulk avalanche mechanism under reversed biased condition. A noise source is a device that provides two known levels of noise to determine the noise slope in measuring the output power change. A typical solid-state noise source is a special low-capacitance diode that generates noise with a constant current. When the diode is biased, the output noise will be greater than KT_cB due to avalanche noise generation in the diode, when unbiased the output will be the thermal noise produced in the attenuator, KT_cB. These levels are sometimes called Th and Tc corresponding to the terms hot and cold.

The noise diode has a very low flicker noise effect and creates a uniform level of truly Gaussian noise over a wide band. The bandwidth is maximized when the diode has very low junction capacitance and lead inductance.

6.2 ZENER VS AVALANCHE BREAKDOWN

Avalanche Breakdown

* The impurities are lightly doped in the pn junction
* Breakdown voltage increases with increase in temperature
* Breakdown is sharp
* Breakdown voltage decreases with increase in doping concentration of the lightly doped side
* Usually occurs above 5V

Zener Breakdown

* The impurities are doped highly in the pn junction
* Breakdown voltage decreases with increase in temperature
* Breakdown tends to be soft
* Breakdown voltage decreases with increase in doping concentration
* Occurs below 5V

6.3 BULK AVALANCHE MECHANISM

The dynamic resistance in a forward-biased junction does not adds excess noise to the system. But when a diode is reverse biased an electric field is formed between the cathode and anode specifically across the depletion region. However, if the electric field becomes too strong by creating an electric field that adds to the existing electric field in the junction, 'avalanche breakdown' occurs.

When a PN-junction diode is reverse biased, the majority carriers, holes in the P-material and electrons in the N-material, move away from the junction. The barrier or depletion region becomes wider and majority carrier current flow becomes very difficult across the high resistance of the wide depletion region. The presence of minority carriers causes a small leakage current that remains nearly constant for all reverse voltages up to a certain value. Once this value has been exceeded, there is a sudden increase in the reverse current. The voltage at which the sudden increase in current occurs is called the BREAKDOWN VOLTAGE. At breakdown, the reverse current increases very rapidly with a slight increase in the reverse voltage.

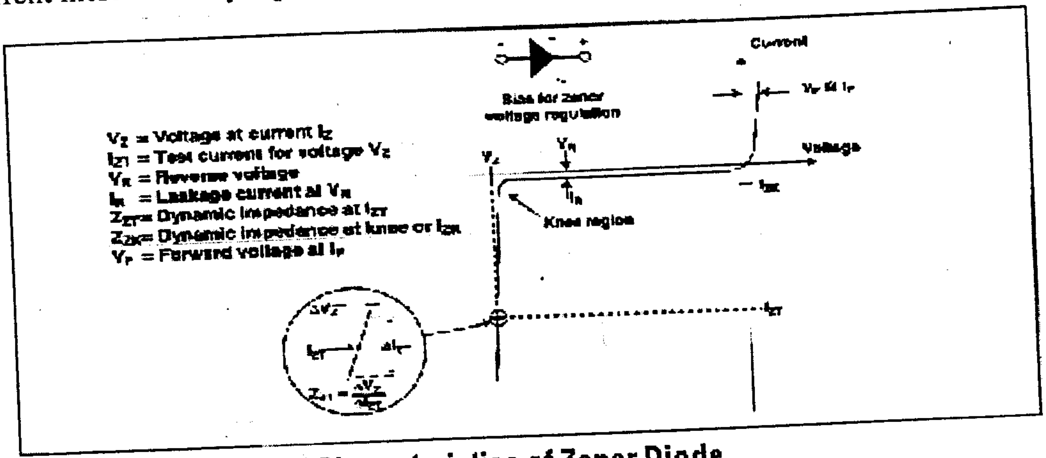


Figure 6.1: I-V Characteristics of Zener Diode

The two distinct theories used to explain the behavior of PN junctions during breakdown are the zener effect and the avalanche effect.

Zener breakdown occurs in heavily doped pn junction regions. If a reverse voltage is applied, the electric field intensity increases at the junction and excites valence electrons from its covalent bond thus resulting in a very high current. Before the field becomes high enough to cause avalanching, the junction will breakdown by another mechanism, called band-to-band tunneling, or Zener breakdown. In this case, the depletion layer is thin because of the much heavier doping levels. The zener breakdown voltage is dependent upon the doping. When this voltage is reached the electrons cross over the tunnel through the barrier and appears on the other side of the junction, as the depletion layer is thin. This is called tunneling.

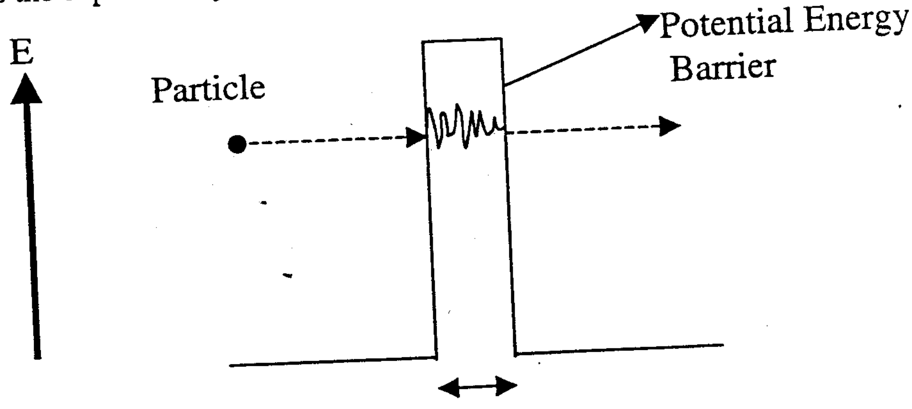


Figure 6.2: Zener Breakdown

AVALANCHE BREAKDOWN

This type of breakdown diode has a depletion region that is deliberately made narrower than the depletion region in the normal PN-junction diode, but thicker than that in the Zener-effect diode. The thicker depletion region is achieved by decreasing the doping level from the level used in Zener-effect diodes. The temperature coefficient of the avalanche mechanism is positive. That is, as the temperature increases, the reverse breakdown voltage increases. Avalanche breakdown occurs when a high reverse voltage is applied to a diode and large electric field is created across the depletion region.

The field accelerates minority carriers in the depletion region associated with small leakage currents to high enough energies so that they ionize silicon atoms when they collide with them. In this process one electron (1e) loses its energy by creating a new hole-electron pair (2e+1h) are created which accelerate in opposite directions causing further collisions and resulting in large current, referred to as avalanche breakdown.

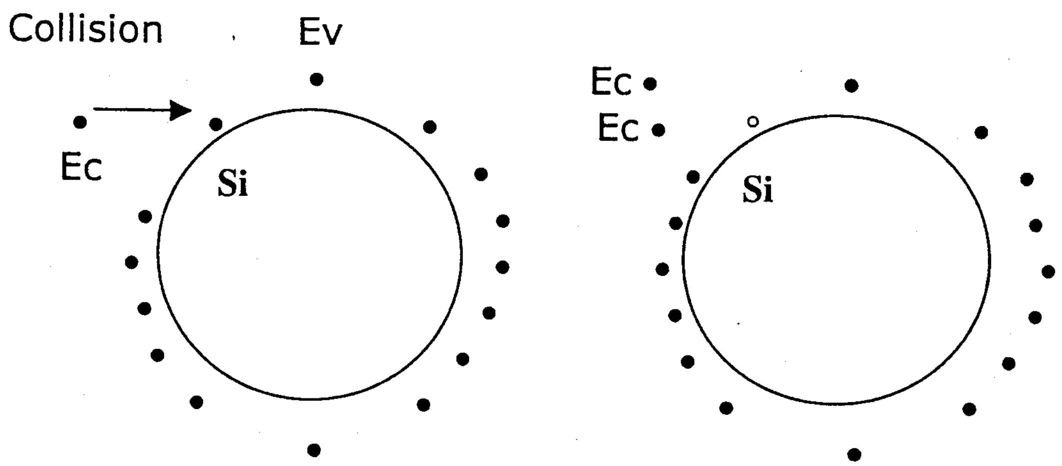


Figure 6.3: Avalanche Multiplication

For reverse voltage slightly higher than breakdown, the avalanche effect releases an almost unlimited number of carriers so that the diode essentially becomes a short circuit. Only an external series current-limiting resistor limits the current flow in this region. Removing the reverse voltage permits all carriers to return to their normal energy values and velocities. If the breakdown voltage is higher, the avalanche process dominates, and if lower, the tunneling or Zener mechanism dominates. At low doping levels and higher voltages the avalanche mechanism dominates while at heavy doping levels and lower voltages the Zener mechanism dominates.

7. DESIGN OF NOISE SOURCE

The purpose of RF broadband solid state noise source is to provide known noise output within the frequencies of our range at various intervals in measuring noise figures of electronic devices like amplifiers, mixers, oscillators.

7.1 DESIGN CONSIDERATIONS

There are three components of a noise source: a noise generator, an attenuator and the calibration data of Excess Noise Ratio (ENR) at each frequency. The primary component is a special purpose low capacitance diode that generates noise when reverse biased into avalanche breakdown with a constant current source. Under this condition the noise diodes generate a relatively large amount of RF and microwave noise, which is 10^6 kelvin equivalent noise temperature. The typical ENR of noise diodes is 30-35 dB. The most critical one is the attenuator, which reduces the output noise to usable form of nearly 15 dB by allowing larger loss between the diode and the output of the noise source. The larger amount of attenuation also results in constant output impedance thus controls the mismatch uncertainties when the unit is switched from the cold to the hot condition.

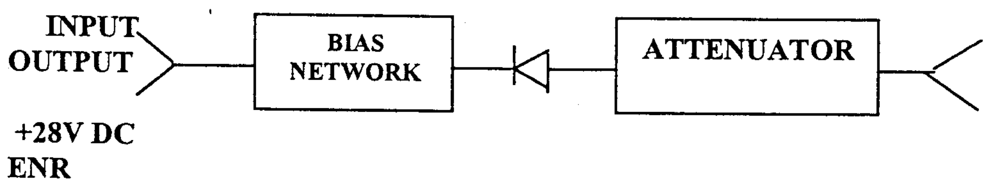


Figure 7.1: Block diagram of a typical Solid-State Noise Source

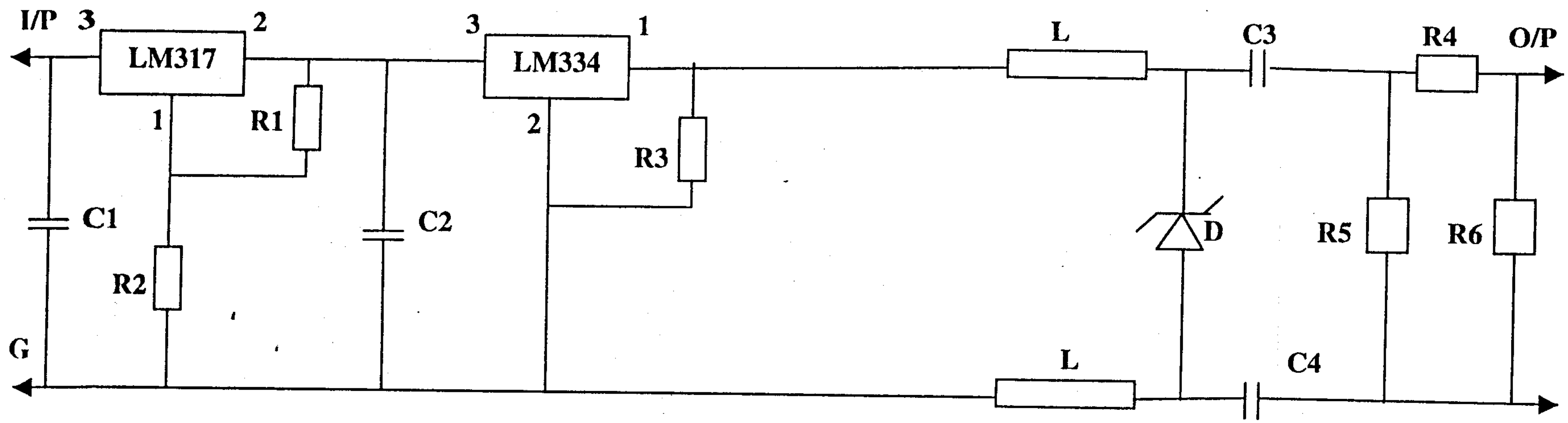
The ENR of a noise source varies with temperature and supply voltage. The ENR is defined as

$$\mathbf{ENR = (T_{hot} / T_c) - 1} \qquad \mathbf{(7\text{-}1)}$$

T(hot) is constant when the ENR is constant. It is therefore important to keep the ENR constant during changing environments. The DC current through the noise diode is varied internally to obtain temperature compensation of the RF noise power generated by the diode.

The bias network facilitates the circuit with the operating conditions to noise diode through voltage regulation and constant current. The impedance mismatch caused during diode on and off is reduced by adding high value of the attenuator at the output. The attenuator consisting of pi resistive network will give broadband match at the output. Since the stability requirement of ENR is very high, precautions have to be taken in the ground plane management. DC and RF ground portions were isolated using inductors and capacitors in a proper configuration.

7.2 CIRCUIT DIAGRAM FOR SOLID STATE NOISE SOURCE



LM317 : VOLTAGE REGULATOR
LM334 : CONSTANT CURRENT SOURCE

RESISTORS

R1 = 220-ohm R2 = 1.8K R3 = 12-ohm R4 = 153-ohm R5 = 68-ohm R6 = 68-ohm

TYPE

R1, R2, R3 (METAL FILM) *R4, R5, R6 (CHIP)*

CAPACITORS

C1 = 120pF C2 = 120pF C3, C4 = 4700pF

TYPE

C1, C2 (CERAMIC) C3, C4 (CHIP)

INDUCTORS

L = 100nH

DIODES

D = NC 302 (NOISE DIODE)

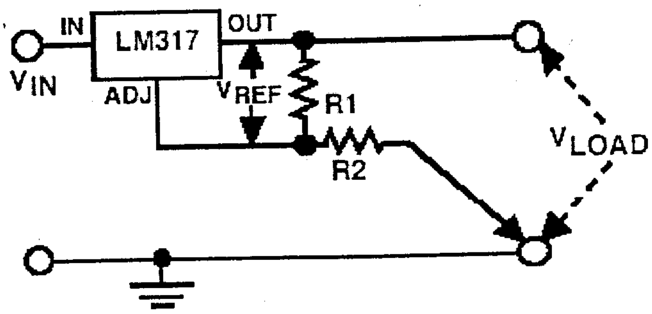
I/P = +28 Volts **O/P** = Noise Output (ENR) **G** = Ground

7.3 CONSTRUCTION DETAILS

The circuit consists of mainly a voltage regulator, constant current source and noise diode.

7.3.1 VOLTAGE REGULATOR

Every electronic circuit is designed to operate at some supply voltage, which is usually assumed to be constant. A voltage regulator provides this constant DC output voltage and contains circuitry that continuously holds the output voltage at the design value regardless of changes in load current or input voltage. All IC regulators have within them a voltage reference, which serves as an electrical yardstick against which to measure the output voltage. Voltage regulators are used in a wide range of applications where stable output voltages are required. The voltage regulator LM317 of National Semiconductors that we are using provides the necessary operating voltage to the noise diode. The LM317 develops a nominal 1.25 volts reference voltage, VREF, between the output and the adjustment terminal. Since the reference voltage is constant between these two terminals across R1, a constant current flows through R1 and R2, thus giving an output/load voltage of



$$V_{LOAD} = V_{REF}\frac{(R1+R2)}{R1}$$

Figure 7.2: Voltage Regulator

LM317 is designed to minimize IADJ and makes it constant with line and load voltages. C1 and C2, in the circuit diagram of solid-state noise source, are the input and output bypass capacitors. These capacitors make the circuit less sensitive to the adjustments, thus eliminating the stability problems. The adjustment terminal is bypassed to ground to improve ripple rejection. In this circuit we have used ceramic capacitors that are good at high frequencies. The input voltage is normal +28 volts from the power supply and delivers the output of 10 Volts by calculation of external resistances R1 and R2 that came as 220 and 1.8K ohms respectively. This IC is designed for minimal power dissipation and also to minimize the number of external components required at all interfaces.

The package that is used is TO-39 with rated power dissipation of 2W and designed for 0.5A load current.

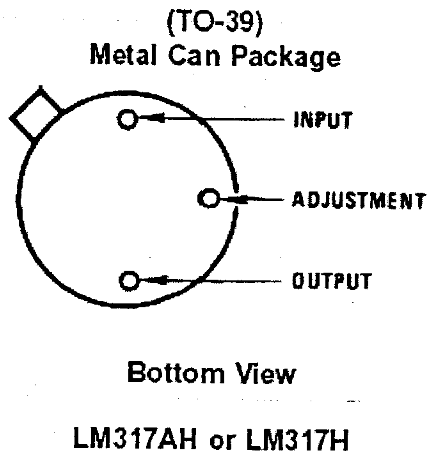


Figure 7.3: LM317 Connection Diagram

7.3.2 CONSTANT CURRENT SOURCE

Noise generator circuit requires a precision constant current source, which automatically maintains a constant current flow through the noise diode. The simple constant current source is a LM334 regulator IC. The LM334 is a three-terminal current source designed to operate at current levels from 1μA to 10mA, as set by an external resistor. The device operates as a true two-terminal current source and requires no extra power connections or input signals. Its regulation is typically 0.02%/V and terminal-to-terminal voltage ranges from 800mV to 30V. This current source is made independent of temperature i.e., zero temperature coefficient current source by adding a diode and a resistor.

The package used in our circuit is TO-92. This device works over a range of 1 to 30 V. The output current of LM334 is by a resistor that is connected between the set terminal (R) and the output terminal (V-). The current is about 68 mV/R. The LM334 constant-current source is programmed for a cathode current by the selection of R1 (67mV/R1 = Icathode). A 6mA current is produced with a 22ohm resistor. The voltage stated here as 68 mV is directly proportional to the absolute temperature, varying from about 58 mV at 0°C to 79 mV at 100°C, so the set current varies with temperature.

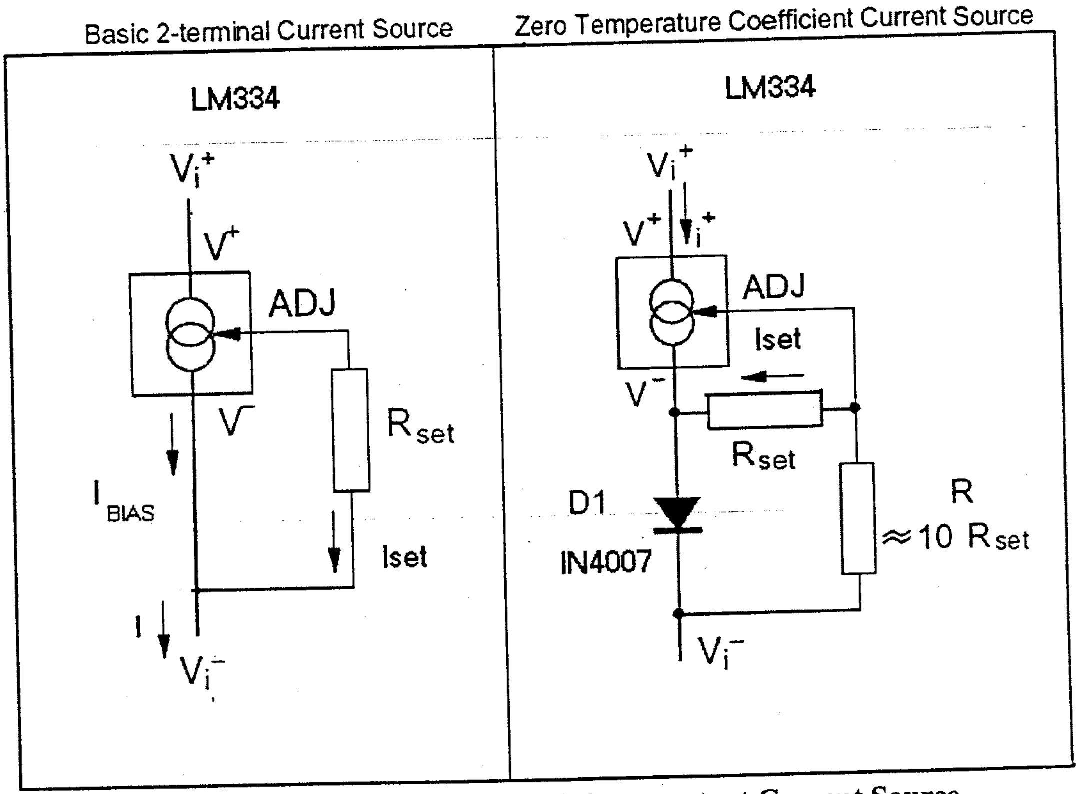


Figure 7.4: Zero Temperature Co-efficient constant Current Source

The total current through the LM334 (I) is the sum of the current going through the set resistor and LM334's bias current. Vset determines the current flowing through Rset, which is approximately 214uV/K (equals to 64mV/300K). The ratio (n) of these two currents, set and bias is 14, from the characteristic table. Since I_{BIAS} is simply a percentage of I, the equation can be written as

$$I = I_{BIAS} + Iset = (Vset / Rset) + I_{BIAS}$$

$$I = (Vset / Rset)(n/(n-1))$$

$$I = (Vset / Rset)\,(1.076) = (230.46uV/K)/ Rset$$

Keeping in view the importance of constant output current, a diode (IN4007) and a resistor is added to the standard LM334 configuration to cancel the temperature dependent characteristics. Now the output current is the sum of all the three currents that are coming from two terminals and one junction.

$$I = Iset + I_{BIAS} + IR$$

$$Iset = (Vset / Rset) \qquad IR = (Vset + VD) / R$$

From the characteristic data sheets we can calculate the ratio of R to Rset is approximately 10. And VD is taken as 0.6 V in forward bias. The voltage across Rset is 67.7mV along with 5.9 % of I_{BIAS}.

$$I = (67.7mV/Rset) + (67.7mV + 0.6V) / 10Rset$$

$$I \approx (0.134V) / Rset$$

For 6mA of output current Rset should be 22-ohm and R is 220-ohm. The package used in noise source is of TO-92 Plastic Package as shown below.

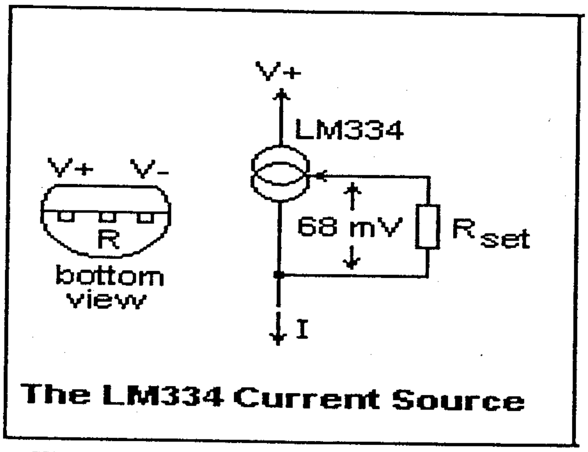


Figure 7.5: LM334 Connection Diagram

In the final implementation the temperature compensation is not used because the temperature compensating diode could give rise to problem while using the noise diode in pulsed mode applications. So therefore with 68mV as the reference voltage, the R_{SET} is calculated to be 12-ohm in order to set a constant current of approximately 6mA.

7.3.3 NOISE DIODE

Noise Com's noise diodes are the fundamental building blocks of all noise systems. Their performance characteristics have made them ideally suited to broadband noise generation with flat response. These diodes deliver symmetrical white gaussian noise and flat output power versus frequency. The noise diodes are available in a wide variety of package styles. The NC 100 and NC 200 series diodes are designed for audio and RF applications. The NC 300 and NC 400 series are designed for microwave applications with required 50-ohm impedance. The small signal impedance of the NC300 and NC400 Series is 10-20 ohms when a diode is turned on and the output level is higher at low frequencies with low currents. Driving the diodes with more current results in more output at higher frequencies. The diode that is being used in our noise source is NC 302 with a frequency range of 10 Hz to 3 GHz.

NOISE/COM recommends an operating current of 6mA for the NC302 noise diode with bias voltage of 8 - 12 Volts and load impedance of 50-ohm. The ENR output range is 30-35 dB. The NC302 diode generates the noise signal through a controlled bulk avalanche mechanism, resulting in a uniform level of Gaussian noise over a wide band of frequencies. We can measure the noise figure at any arbitrary frequency, as this covers a wide range of frequencies and its power output is accurately known. These noise diodes are characterized by accurately known and stable values of Excess Noise Ratio (ENR), and with a good source match. The typical value of ENR is about 15dB. This source looks like a 50-ohm resistor operating at a temperature Th given by the relation

$$ENR = 10Log_{10}\left(\frac{T_h}{T_0} \quad 1\right)$$

(7-2)

The output of this noise diode is given to the input of the DUT. And the measured output is Nh. The theoretically expected expression for Nh is

$$N_k = kT_k G + (F-1)kTG \qquad (7\text{-}3)$$

The output of the noise diode is attenuated to bring the level of the noise source signal down to a level comparable with the noise power output of the receiver with attenuators. Attenuator in a network introduces a known amount of loss when functioning between two resistive impedances. The basic fixed attenuator is shown in Figure 7.6. Shunt resistors R1 and the series resistor R3 are set to achieve some desired value of attenuation.

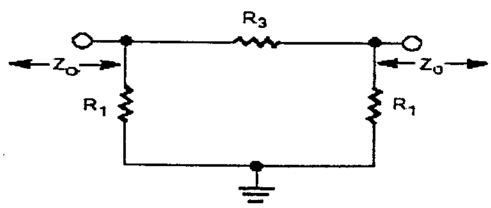


Figure 7.6: Attenuator

The choke inductors are used for cutting the voltage fluctuations mainly the ac part of it in entering the RF portion of the circuit. Ceramic capacitor uses titanium acid barium as dielectric to bypass high frequency signals to the ground. Some of the capacitors used are multilayer with good temperature and frequency characteristics. Metal film resistors are used in this circuit, as it requires high tolerance i.e., more accurate value. Every real resistor, inductor and capacitor contains unwanted parasitic elements, which degrade its electrical performance, if operating in high frequency circuits.

There are some special considerations that have been taken in the RF portion. As we know the wire is the simplest element, which has zero resistance that makes it short circuit at DC and low frequencies. But in RF/MW frequencies it behaves as a complex element deserving special attention. This depends to a large extent on the wire's diameter and length. As frequency increases, the electrical signals propagate less and less in the inside of the conductor. The current density increases near the outside perimeter of the wire and causes a higher impedance to be seen by the signal. Also the magnetic field exits in the medium surrounding any current carrying conductor opposes the current flow and exhibits the property of inductance. To reduse this parasitic reactance in the RF portion thin film chip resisters and capacitors are used in the noise circuit and also to block the DC components from appearing at the noise output.

8. DEVELOPMENT OF NOISE SOURCE

The electronic components in a device are mounted on a PCB. Besides keeping the components in place, its purpose is to provide electrical connections between the components mounted on it. Printed circuit board design starts with specifying the electronic components that perform the required functions for a product, followed by determining the most efficient and effective way to electrically connect these components.

The substrate of the board is an insulating and non-flexible material. The thin wires that are visible on the surface of the board are part of a copper foil that initially covered the whole board. In the manufacturing process this copper foil is partly etched away, and the remaining copper forms a network of thin wires. These wires are referred to as the *conductor pattern* and provide the electrical connections between the components mounted on the PCB.

The components leads are soldered to the conductor pattern of the PCB. On the most basic PCBs, the components are located on one side of the board and the conductor pattern on the opposite side. This requires holes in the PCB for the component leads to penetrate the board. Hence, the leads are soldered to the PCB on the opposite side of where the components are mounted. The top and bottom side of a PCB is therefore respectively referred to as the 'Component Side' and 'Solder Side as shown in Figures 8.2 and 8.1.

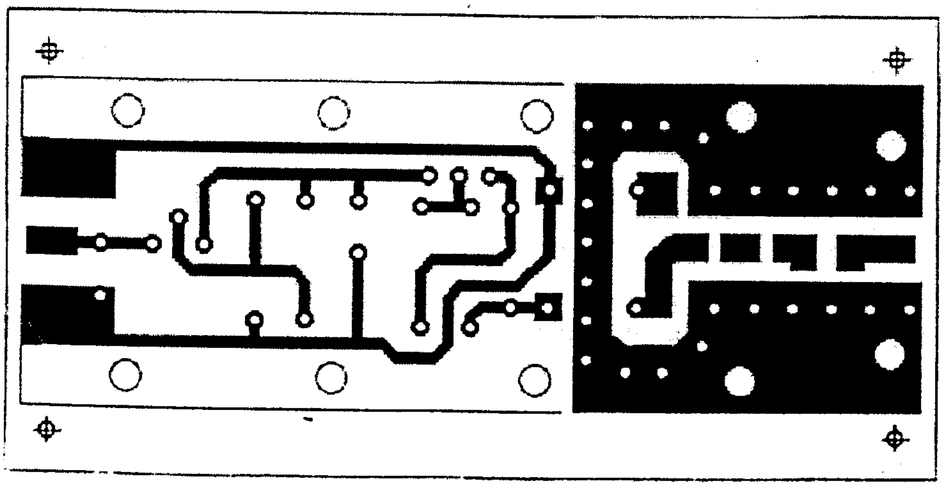


Figure 8.1: PCB Layout Viewing Solder Side

This PCB layout was generated in a EZROUTE software tool directly from the schematic. The layout is printed on high-quality film using a standard inkjet printer, which is then used to produce the PCB from Rogers Ultralum 2000 material for the prototype.

DESIGN PROCESS

The design process of a PCB starts with a schematic of a detailed drawing of all connections between the components in a circuit. This was done using EZROUTE software. This layout describes the board's template, which includes interconnections between various devices on the board and a mechanical drawing of the board's shape and locating all the devices for optimal electrical and mechanical performance. The PCB Size was determined by taking a graph sheet, drawing the sketch of the placement of components in the graph sheet such that it occupies less PCB Size. The size of our PCB is 3.5 inches length and 1.25 in width. The Size of track for Power supplies is about 1mm.

MANUFACTURING FILES

A set of files being sent to the PCB manufacture as inputs to the machines that produce boards that produces the boards. The standards and the most common is a Gerber file. A set of Gerber files includes photo plots for all signal, power and ground layers, photo plots for the solder mask and the silk screen, drill files. The Gerber file is an instruction set, extracted from the board design, which directs the plotter to produce the image of the board on paper, film; resist coated substrate, or other media. To prevent stray electromagnetic energy from entering or leaving a device, the PCB is placed inside a metal box.

The components are mounted and soldered using both PTH (Plated Through Hole Technology) and SMT (Surface Mount Technology). In PTH the legs are first cut near the board and slightly bent over to keep the component in place. The solder attaches the solder pads and component legs. After some time of cooling the PCB is enclosed in electronic housings called chassis and are connected to peripheral devices for final testing

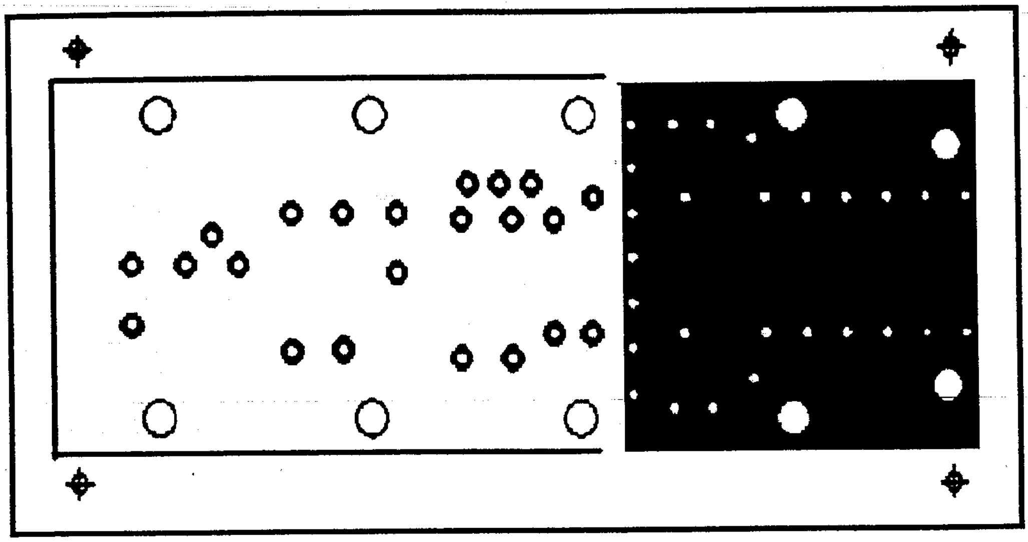


Figure 8.2: PCB Layout Viewing Component Side

The insulating and protective coat on solder mask that protects the thin copper wires and prevents solder from attaching outside the connection points for the components. On top of this brown colored mask a *silk screen* is printed which was shown in Figure 8.3. This is text and symbols printed on the board to label the locations for the different components that are mounted.

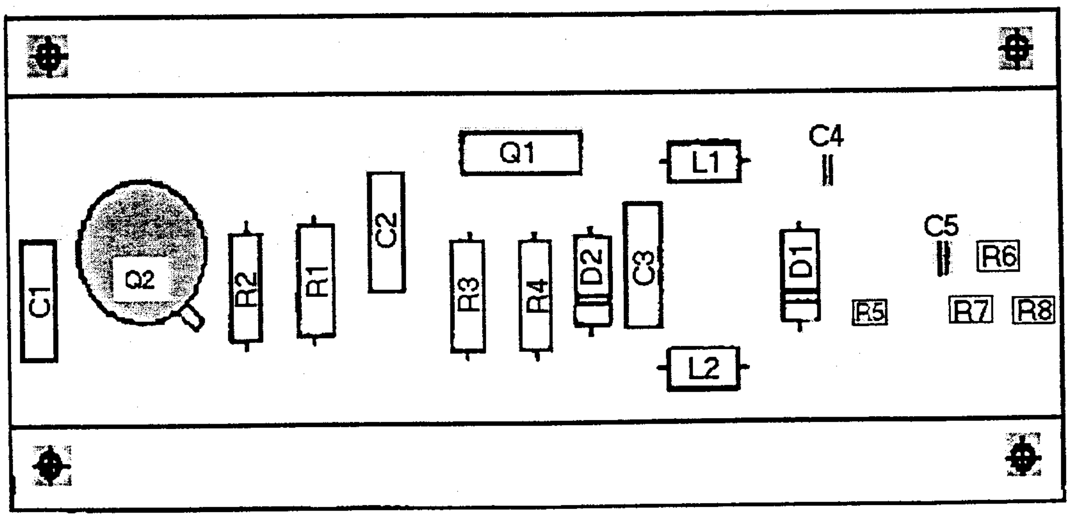


Figure 8.3: PCB Layout Viewing Silk Screen

The chassis is shown as below with BNC connector on left and N-type connector on right.

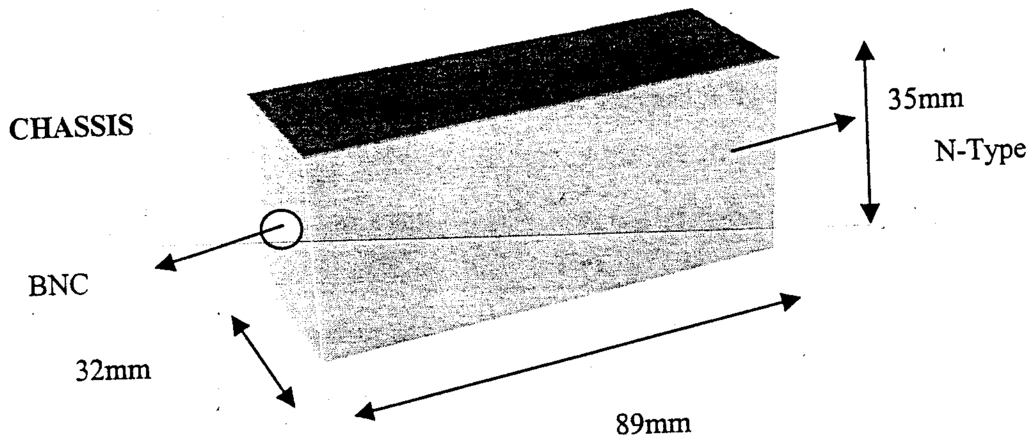


Figure 8.4: Chassis

9. CALIBRATION OF NOISE SOURCE

The calibration of noise source is designed for highly accurate noise figure and effective input noise temperature measurements. ENR is a measure of how much the noise increases in the output when the source is turned on from off position and the noise generator is calibrated in terms of its ENR.

The calibration has been performed at a period of 100MHz with reference to standard noise sources of Agilent Technologies and NoiseComs. The calibration setup is shown in Figure 9.1.

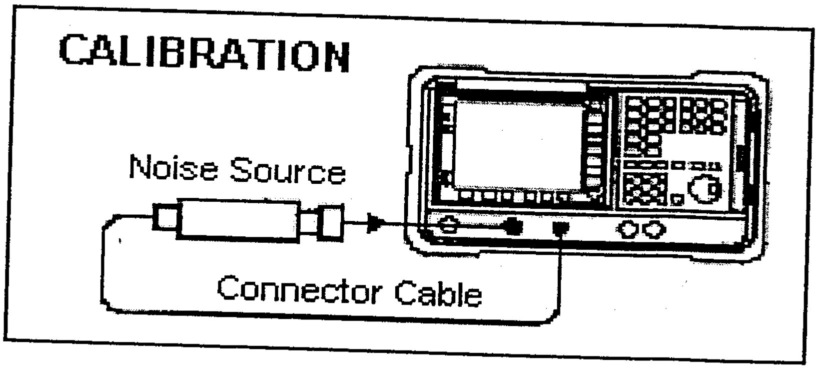


Figure 9.1: Noise Source Calibration Setup

Noise Figure is calculated

$$NF = ENR - 10 \log (Y-1) \qquad (9\text{-}1)$$

Where NF = Noise Figure in dB

ENR = Excess Noise Ratio in dB

Y = Ratio of levels with noise source on/off

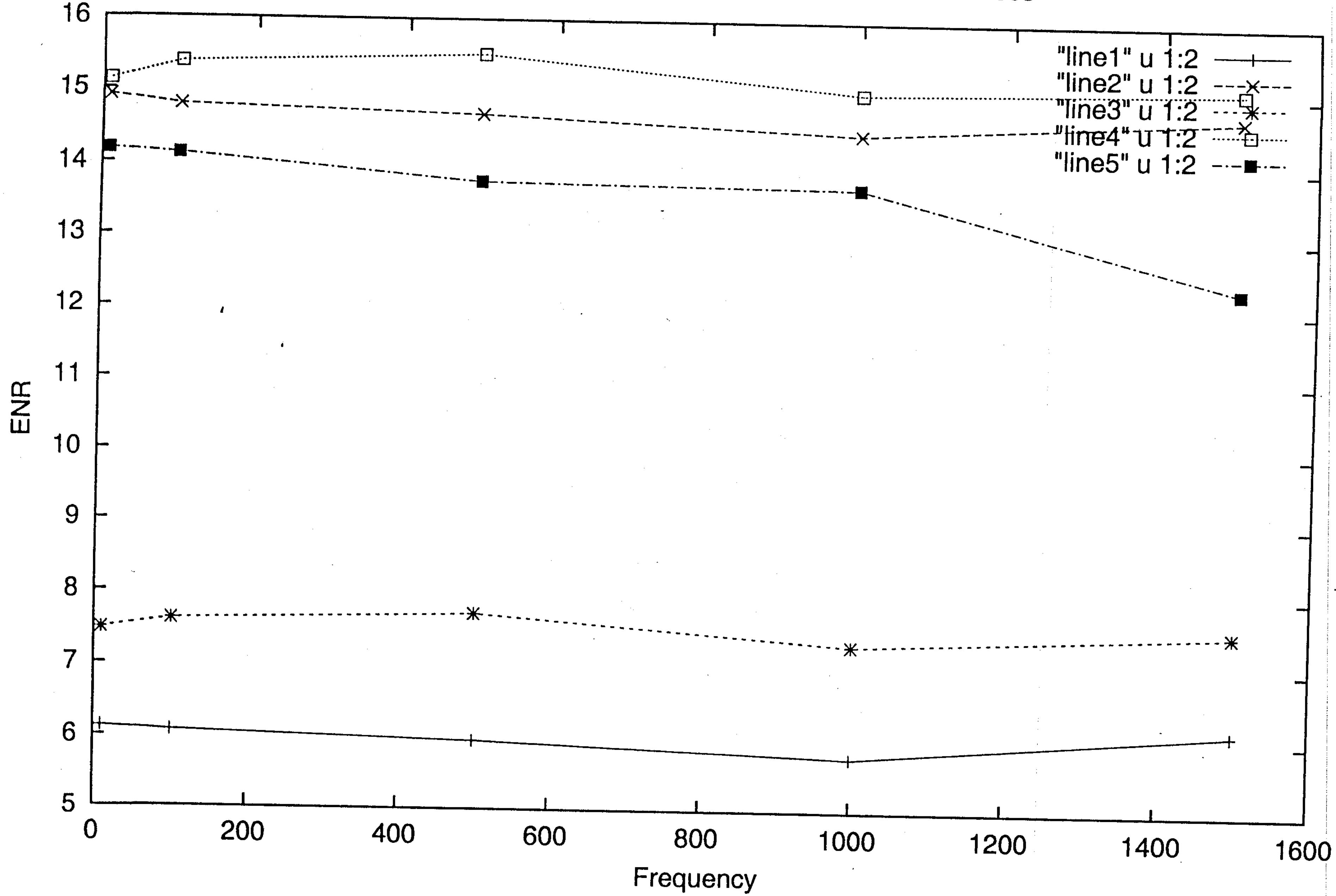
Figure 9.2: The measured ENR of our Solid State Noise Source is given in the following table:

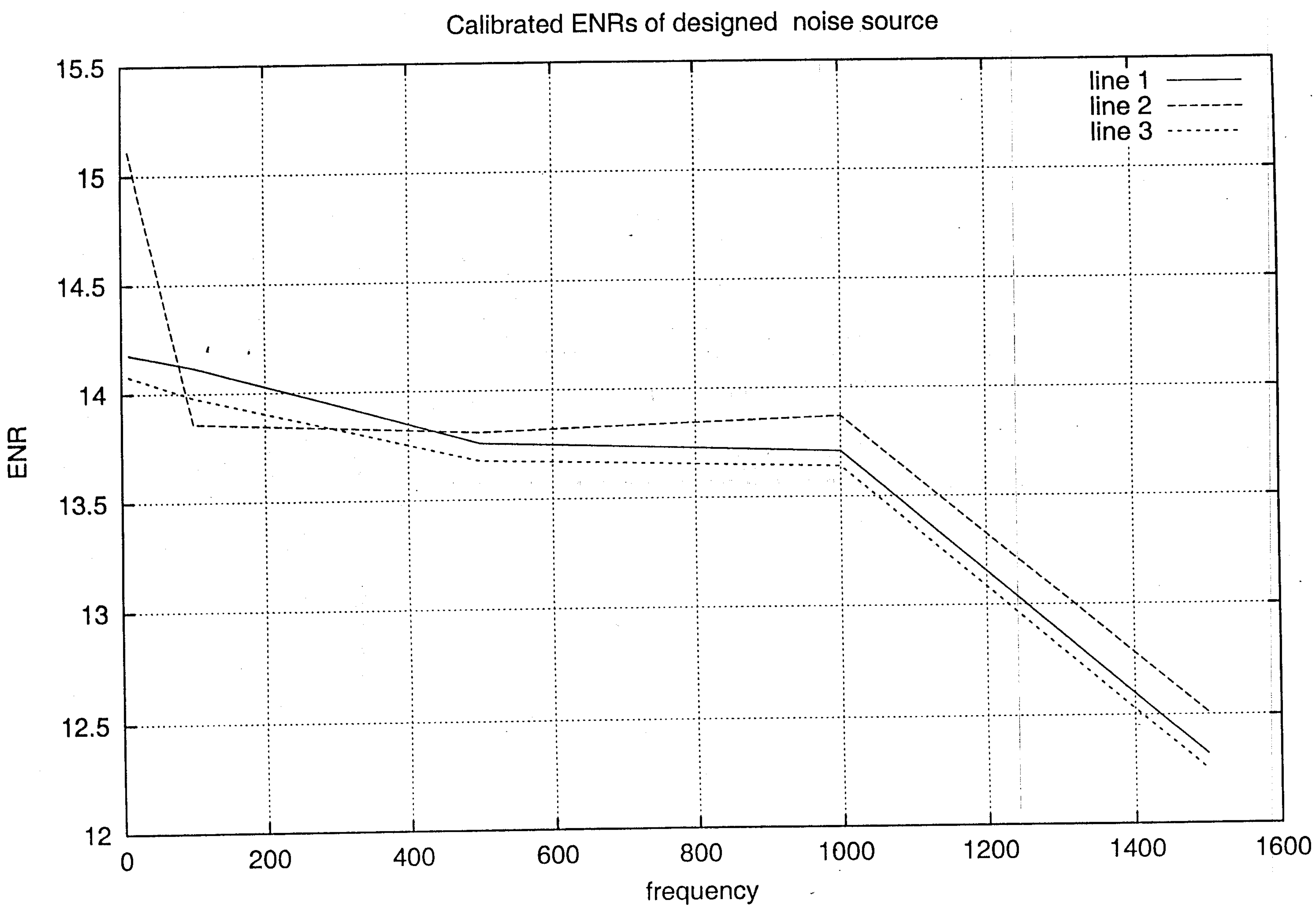
S.No	FREQUENCY (MHz)	ENR in dB
1	10	14.18
2	50	13.72
3	100	14.12
4	200	14.31
5	300	13.38
6	500	13.76
7	600	13.60
8	800	13.68
9	900	13.80
10	1000	13.71
11	1100	13.40
12	1200	13.54
13	1300	13.10
14	1400	12.78
15	1500	12.32
16	1600	11.42

In Figure 9.3
Line1 : 346A
Line2: 346B
Line3: L150
Line4: L151
Line5: Designed Noise Source

In Figure 9.4
The ENR of the designed noise source is measured at three different times.

Figure 9.3 : Calibrated ENRs of various Noise Sources




Calibrated ENRs of designed noise source
ENR
15.5
15
14.5
14
13.5
13
12.5
12
0
200
400
600
800
1000
1200
1400
1600
frequency
line 1
line 2
line 3

10. AMPLIFIER NOISE FIGURE MEASUREMENT

The amplifier whose noise figure has to be measured is been called as DUT. Its characteristics includes gain G and noise figure F, which is to be measured. The DUT works in a 50-ohm environment and the room temperature is T. The input of the DUT is terminated with 50 ohms, and the output displays on Noise Figure Meter

To measure the noise figure at any arbitrary frequency we use a power source whose output is accurately known. For this we are using a wideband noise source, which have spectral content over a wide frequency range. The noise diode is characterized by accurately known and stable values of EXCESS NOISE RATIO (ENR), and which has a good source match. This source looks like a 50-ohm resistor operating at a temperature Th given by the relation

$$ENR = 10Log_{10}\left(\frac{T_h}{T_0} - 1\right)$$

The Noise Figure, F

$$F = \frac{\text{ENR}}{Y - 1}$$

The entire measurement process is shown in the schematic as below.

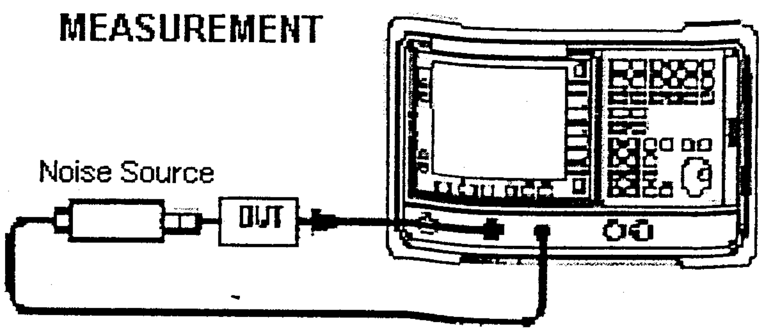


Figure 10.1: Amplifier Measurement Setup

The noise source can be switched on and off. When off, the equivalent noise temperature of the noise diode is the room temperature and the noise diode looks like an ordinary 50-ohm resistance at room temperature. All the calculations are carried out inside the microprocessor based Noise Figure Meter and the NF of Low Noise Amplifier is displayed on its screen.

The Effective Noise temperature of a Low Noise Amplifier at 610MHz from the measurements are

	346B(Agilent NS)	TIFR
Noise Temperature =	53 °K	57 °K

11. SOURCE AND MEASUREMENT ERRORS

The noise figure test equipment and noise figure devices under test are sensitive to the impedance presented at their input. Small changes in output impedances are caused when the noise source is switched on and off affecting the measurement accuracy.

The accuracy and stability of a noise source is influenced by the sensitivity of the ENR to variations in temperature and supply voltage. In contrast to hot and cold systems, solid-state noise sources are insensitive to common variations in the barometric pressure and the humidity. The residual noise exists in the off condition of a solid state noise source is due to thermal heating of the noise diode. The increased junction temperature of the diode generates excessive noise in the off state when the noise source acts as a resistor at ambient temperature. The effect of the residual noise decreases as the attenuation in the noise source in increased and as the junction temperature of the diode is reduced.

Many factors that affects the uncertainty of NF measurements includes

- Extraneous signals
- Nonlinearity
- Instrumentation uncertainty
- ENR uncertainty
- Mismatch
- Measurement architecture
- Instrument NF
- Unwanted in-band power

The uncertainity of the measurement resulting from errors in T(hot), T(cold) and Y are evaluated as

$$D(NF) = |\partial NF/\partial T(hot)| * D(T(hot)) + |\partial NF/\partial T(cold)| * D(T(cold)) + |\partial NF/\partial Y| * D(Y) \quad \textbf{(11-1)}$$

Where D is delta, which is change in respective variable.

A correction figure 10 logA can be added to Noise Figure to compensate for ambient temperature deviations of the output noise power

$$A = 1 - [(T_a/T_o) - 1] * [\, Y/10^{(ENR/10)}] \quad \textbf{(11-2)}$$

The following equation can be used to estimate overall NF measurement uncertainty

$$\{[(F_{12} / F_1) \delta NF_{12}]^2 + [(F_{12} / F_1G_1) \delta NF_2]^2 + [((F_2-1)/ F_1G_1) \delta G_{1(dB)}]^2 + [((F_{12} / F_1)-(F_{12} / F_1G_1) \delta ENR]^2\}^{0.5} \qquad (11\text{-}3)$$

F_1 is the linear noise figure of the DUT, F_2 is the linear noise figure of the noise figure instrument, F_{12} is the linear noise figure of the complete system (DUT and instrument), and G_1 is the linear gain of the DUT. The various other uncertainty components are

11.1 EXTRANEOUS SIGNALS

Pagers, security communication systems, wireless phones, and cordless LANs are all common sources of intermittent and potentially disruptive signals at rather high power levels. If the DUT is connected directly to an instrument that does not incorporate adequate internal screening, any spurious signals emanating from the instrument increase the uncertainty of the measured results.

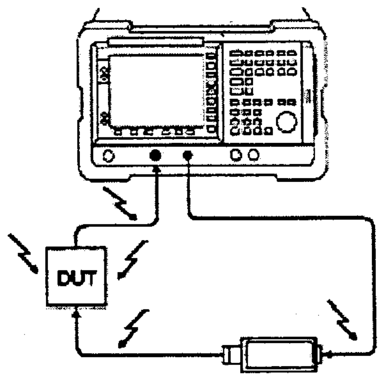


Figure11.1: Spurious noise entering the test setup from external devices or connected components. Choosing a measurement instrument with good sheilding is critical for NF measurements, since DUTs are often connected directly to the instrument. Well-designed instruments will exhibit very low emissions in the near field.

11.2 NONLINEARITIES

It is impossible to measure the NF of a nonlinear device. Noise measurement can only be accomplished when both the hot and cold powers from the noise source are constrained to straight lines. If the DUT behavior is nonlinear, Y-factor is distorted and NF cannot be accurately measured. The below figure shows a plot of a device with a degree of compression, results in a NF measurement that is too high. Elements such as AGC (automatic gain control), regenerative circuits, and limiters (e.g., frequency- or phase-locked loops) add nonlinear behavior to equipment that makes noise characterization virtually impossible. Thus, the NF of sub-systems should be measured before these elements are added.

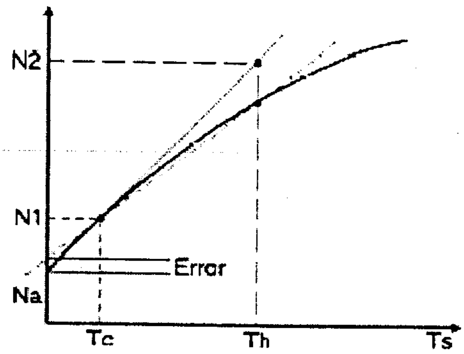


Figure 11.2: Noise power Non-linearity

11.3 INSTRUMENTATION UNCERTAINTY

The primary component of instrumentation uncertainty is the linearity of the noise power detector. An ideal power detector response would be along the horizontal axis of the graph in figure below, which illustrates the behavior of a representative noise figure meter. The nonlinear effects of the power detector are present in every calibration and measurement regardless of the DUT's characteristics. Choosing a noise source with a lower ENR, which exercises less of the detector's dynamic range and yields behavior that is more linear, can minimize this effect. Instrumentation uncertainty is a key measure of the raw performance of NF measurement equipment, differences between instruments as little as 50mdB can have a significant effect on overall measurement uncertainty. This feature is a primary concern while choosing equipment.

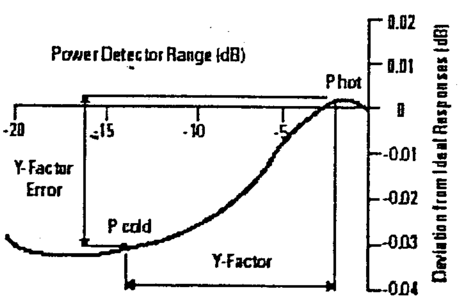


Figure 11.3: Non-Linear Behavior of Noise figure Meter

11.4 EXCESS NOISE RATIO (ENR) UNCERTAINTY

The ENR uncertainty of the noise source can be an especially large component of measurement uncertainty. Any ENR error transfers directly to the NF, since NF=ENR-10Log (Y-1). Typical ENR uncertainty specifications for noise sources are currently around 0.1dB. The plot of a representative noise source is shown below. The care should be taken to ensure that noise sources are routinely calibrated and that the proper calibration tables are used..

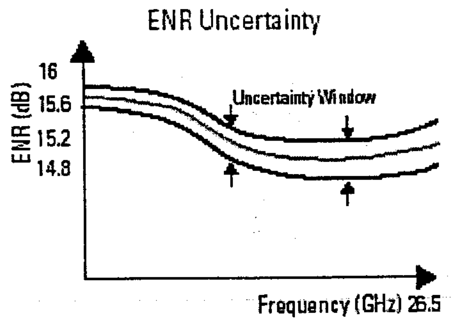


Figure 11.4: ENR Uncertainity

11.5 MISMATCH UNCERTAINTY

Noise-power reflections from noise sources and attached devices produce extremely complex effects. The VSWR of the noise source represents a potentially large source of error. Low ENR sources, 5dB, with higher internal attenuation provide the best accuracy. This is due to lower VSWR and better consistency between on and off impedances. By placing isolators on the links between the DUT, the noise source, and

the instrument can provide relief from these effects, but the isolators add insertion loss and hence another uncertainty component gets added. DUTs with high gain are more immune to the effects of mismatch uncertainty, since higher gain reduces the relative contribution of second-stage NF from the instrument.

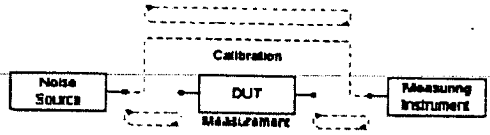


Figure 11.5: Noise-power reflections can come from external noise sources as well as attached devices, increasing mismatch uncertainty.

11.6 INSTRUMENT NF

The ratio of system, DUT and measurement instrument, linear noise factor to DUT noise factor is expressed as F12/F1 in the measurement uncertainty equation. This ratio is greater than one, but has a significant effect on overall uncertainty as the value increases above one. System NF (10logF12) is a function of the instrument's NF, plus the gain and NF of the DUT. Overall measurement uncertainty increases significantly as F12 increases. In this case, uncertainty can be improved by inserting a low-noise amplifier before the mixer during calibration and measurement. High gain DUTs also reduce F12, but as the DUT gain increases, the NF of the instrument also increases due to RF ranging.

OVERALL UNCERTAINTY

Many components make up measurement uncertainty, and each contributes differently to overall uncertainty depending on specific measurement conditions. Each isolated component provides little value. The real value is to be calculated from an aggregate estimate of overall uncertainty and simultaneously identifying the dominant components facilitates in the improvement of noise figure.

12. CONCLUSION

The solid-state broadband noise source have been designed and developed for measuring the noise figures of various frond end electronic devices. This broadband noise source covers all frequencies from 10MHz to 1600MHz and uses special purpose noise diode for the noise generation. The output of the source has been made for an ENR of 14dB. As noise figure measurements use the Y-factor ratio of method, the uncertainties of the measurements are cancelled and thus providing an accurate results. This noise source is going to be used in Front End Lab for measuring noise figures of amplifiers, mixers and other electronic networks.

The noise temperatures of a 610MHz LNA was measured using a HP Noise Figure Meter 8970A. The first measurement was done using the standard Agilent Technologies Noise Source 346B having an ENR of 15dB. After that the noise temperature of the same LNA was measured using the designed noise source and we found that the measured noise temperatures are close to the expected as shown below.

Noise Sourece	**Noise Temperature at 610MHz Center Frequency**
Agilent (346B)	53 ^{o}K
Designed Noise Source	57 ^{o}K

Appendix- A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Power Dissipation	Internally Limited
Input-Output Voltage Differential	+40V, −0.3V
Storage Temperature	−65°C to +150°C
Lead Temperature	
Metal Package (Soldering, 10 seconds)	300°C
Plastic Package (Soldering, 4 seconds)	260°C
ESD Tolerance (Note 5)	3 kV

Operating Temperature Range

LM117	$-55°C \le T_J \le +150°C$
LM317A	$-40°C \le T_J \le +125°C$
LM317	$0°C \le T_J \le +125°C$

Preconditioning

Thermal Limit Burn-In	All Devices 100%

Electrical Characteristics (Note 3)

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V, and I_{OUT} = 10 mA.

Parameter	Conditions	LM117 (Note 2)			Units
		Min	Typ	Max	
Reference Voltage					V
	$3V \le (V_{IN} - V_{OUT}) \le 40V$, $10 mA \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$	**1.20**	**1.25**	**1.30**	V
Line Regulation	$3V \le (V_{IN} - V_{OUT}) \le 40V$ (Note 4)		0.01	0.02	%/V
			0.02	**0.05**	%/V
Load Regulation	$10 mA \le I_{OUT} \le I_{MAX}$ (Note 4)		0.1	0.3	%
			0.3	**1**	%
Thermal Regulation	20 ms Pulse		0.03	0.07	%/W
Adjustment Pin Current			**50**	**100**	μA
Adjustment Pin Current Change	$10 mA \le I_{OUT} \le I_{MAX}$ $3V \le (V_{IN} - V_{OUT}) \le 40V$		**0.2**	**5**	μA
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		**1**		%
Minimum Load Current	$(V_{IN} - V_{OUT}) = 40V$		**3.5**	**5**	mA
Current Limit	$(V_{IN} - V_{OUT}) \le 15V$				
	K Package	**1.5**	**2.2**	**3.4**	A
	H Packages	**0.5**	**0.8**	**1.8**	A
	$(V_{IN} - V_{OUT}) = 40V$				
	K Package	0.3	0.4		A
	H Package	0.15	0.2		A
RMS Output Noise, % of V_{OUT}	$10 Hz \le f \le 10 kHz$		0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 μF		65		dB
	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 μF	**66**	**80**		dB
Long-Term Stability	T_J = 125°C, 1000 hrs		0.3	1	%
Thermal Resistance, Junction-to-Case	K Package		2.3	3	°C/W
	H Package		12	15	°C/W
	E Package				°C/W
Thermal Resistance, Junction-to-Ambient (No Heat Sink)	K Package		35		°C/W
	H Package		140		°C/W
	E Package				°C/W

Electrical Characteristics (Note 3)

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V, and I_{OUT} = 10 mA.

Parameter	Conditions	LM317A			LM317			Units
		Min	Typ	Max	Min	Typ	Max	
Reference Voltage		1.238	1.250	1.262				V
	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V, 10 mA ≤ I_{OUT} ≤ I_{MAX}, P ≤ P_{MAX}	**1.225**	**1.250**	**1.270**	**1.20**	**1.25**	**1.30**	V
Line Regulation	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V (Note 4)		0.005	0.01		0.01	0.04	%/V
			0.01	**0.02**		**0.02**	**0.07**	%/V
Load Regulation	10 mA ≤ I_{OUT} ≤ I_{MAX} (Note 4)		0.1	0.5		0.1	0.5	%
			0.3	**1**		**0.3**	**1.5**	%
Thermal Regulation	20 ms Pulse		0.04	0.07		0.04	0.07	%/W
Adjustment Pin Current			**50**	**100**		**50**	**100**	μA
Adjustment Pin Current Change	10 mA ≤ I_{OUT} ≤ I_{MAX} 3V ≤ ($V_{IN} - V_{OUT}$) ≤ 40V		**0.2**	**5**		**0.2**	**5**	μA
Temperature Stability	T_{MIN} ≤ T_J ≤ T_{MAX}		**1**			**1**		%
Minimum Load Current	($V_{IN} - V_{OUT}$) = 40V		**3.5**	**10**		**3.5**	**10**	mA
Current Limit	($V_{IN} - V_{OUT}$) ≤ 15V							
	K, T, S Packages	**1.5**	**2.2**	**3.4**	**1.5**	**2.2**	**3.4**	A
	H Package	**0.5**	**0.8**	**1.8**	**0.5**	**0.8**	**1.8**	A
	MP Package	**1.5**	**2.2**	**3.4**	**1.5**	**2.2**	**3.4**	A
	($V_{IN} - V_{OUT}$) = 40V							
	K, T, S Packages	0.15	0.4		0.15	0.4		A
	H Package	0.075	0.2		0.075	0.2		A
	MP Package	0.55	0.4		0.15	0.4		A
RMS Output Noise, % of V_{OUT}	10 Hz ≤ f ≤ 10 kHz		0.003			0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 μF		65			65		dB
	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 μF	66	80		66	80		dB
Long-Term Stability	T_J = 125°C, 1000 hrs		0.3	1		0.3	1	%
Thermal Resistance, Junction-to-Case	K Package					2.3	3	°C/W
	MDT Package					5		°C/W
	H Package		12	15		12	15	°C/W
	T Package		4	5		4		°C/W
	MP Package		23.5			23.5		°C/W
Thermal Resistance, Junction-to-Ambient (No Heat Sink)	K Package		35			35		°C/W
	MDT Package(Note 6)					92		°C/W
	H Package		140			140		°C/W
	T Package		50			50		°C/W
	S Package (Note 6)		50			50		°C/W

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed.

Note 2: Refer to RETS117H drawing for the LM117H, or the RETS117K for the LM117K military specifications.

Note 3: Although power dissipation is internally limited, these specifications are applicable for maximum power dissipations of 2W for the TO-39 and SOT-223 and 20W for the TO-3, TO-220, and TO-263. I_{MAX} is 1.5A for the TO-3, TO-220, and TO-263 packages, 0.5A for the TO-39 package and 1A for the SOT-223 Package. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 4: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

Note 5: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 6: If the TO-263 or TO-252 packages are used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W. If the SOT-223 package is used, the thermal resistance can be reduced by increasing the PC board copper area (see applications hints for heatsinking).

Appendix – B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

V^+ to V^- Forward Voltage	
LM134/LM234/LM334	40V
LM134-3/LM134-6/LM234-3/LM234-6	30V
V^+ to V^- Reverse Voltage	20V
R Pin to V^- Voltage	5V
Set Current	10 mA
Power Dissipation	400 mW
ESD Susceptibility (Note 6)	2000V
Operating Temperature Range (Note 5)	
LM134/LM134-3/LM134-6	−55°C to +125°C
LM234/LM234-3/LM234-6	−25°C to +100°C
LM334	0°C to +70°C
Soldering Information	
TO-92 Package (10 sec.)	260°C
TO-46 Package (10 sec.)	300°C
SO Package	
Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" (Appendix D) for other methods of soldering surface mount devices.

Electrical Characteristics (Note 2)

Parameter	Conditions	LM134/LM234			LM334			Units
		Min	Typ	Max	Min	Typ	Max	
Set Current Error, V^+=2.5V, (Note 3)	$10\ \mu A \le I_{SET} \le 1\ mA$			3			6	%
	$1\ mA < I_{SET} \le 5\ mA$			5			8	%
	$2\ \mu A \le I_{SET} < 10\ \mu A$			8			12	%
Ratio of Set Current to Bias Current	$100\ \mu A \le I_{SET} \le 1\ mA$	14	18	23	14	18	26	
	$1\ mA \le I_{SET} \le 5\ mA$		14			14		
	$2\ \mu A \le I_{SET} \le 100\ \mu A$		18	23		18	26	
Minimum Operating Voltage	$2\ \mu A \le I_{SET} \le 100\ \mu A$		0.8			0.8		V
	$100\ \mu A < I_{SET} \le 1\ mA$		0.9			0.9		V
	$1\ mA < I_{SET} \le 5\ mA$		1.0			1.0		V
Average Change in Set Current with Input Voltage	$2\ \mu A \le I_{SET} \le 1\ mA$							
	$1.5 \le V^+ \le 5V$		0.02	0.05		0.02	0.1	%/V
	$5V \le V^+ \le 40V$		0.01	0.03		0.01	0.05	%/V
	$1\ mA < I_{SET} \le 5\ mA$							
	$1.5V \le V \le 5V$		0.03			0.03		%/V
	$5V \le V \le 40V$		0.02			0.02		%/V
Temperature Dependence of Set Current (Note 4)	$25\ \mu A \le I_{SET} \le 1\ mA$	0.96T	T	1.04T	0.96T	T	1.04T	
Effective Shunt Capacitance			15			15		pF

Note 1: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

Note 2: Unless otherwise specified, tests are performed at T_j=25°C with pulse testing so that junction temperature does not change during test.

Note 3: Set current is the current flowing into the V^+ pin. For the Basic 2-Terminal Current Source circuit shown on the first page of this data sheet. I_{SET} is determined by the following formula: I_{SET}=67.7 mV/R_{SET} (@ 25°C). Set current error is expressed as a percent deviation from this amount. I_{SET} increases at 0.336%/°C @ T_j=25°C (227 μV/°C).

Note 4: I_{SET} is directly proportional to absolute temperature (°K). I_{SET} at any temperature can be calculated from: $I_{SET}=I_o\ (T/T_o)$ where I_o is I_{SET} measured at T_o (°K).

Note 5: For elevated temperature operation, T_j max is:

LM134	150°C
LM234	125°C
LM334	100°C

Thermal Resistance	TO-92	TO-46	SO-8
θ_{ja} (Junction to Ambient)	180°C/W (0.4" leads) 160°C/W (0.125" leads)	440°C/W	165°C/W
θ_{jc} (Junction to Case)	N/A	32°C/W	80°C/W

Note 6: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

iM
112

Appendix-C

0.1 Hz to 110 G...

Features:

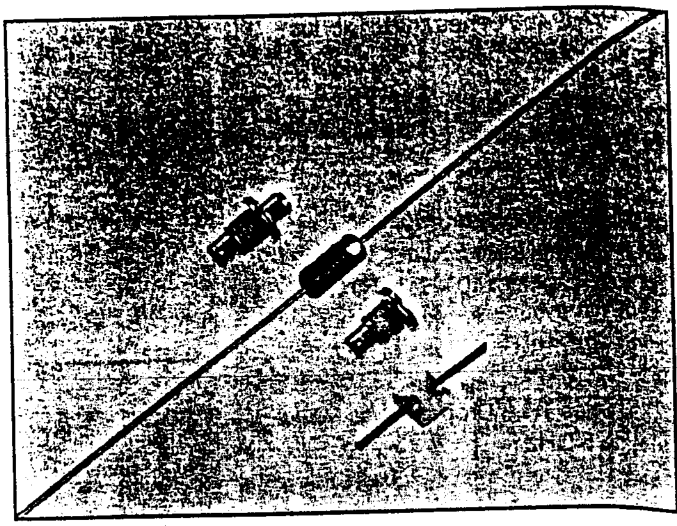
- Five package options
- Flat output
- Operating temperature 0 to +55°C for NC 100 Series, -55 to +1..°C for all others
- Storage temperature ... to +1...
- Meet MIL-STD-7...

Noise Com's noise diodes are the fundamental building blocks of ... systems. They are hand-picked for ... characteristics that make ... ideally suited to broadband noise generation with flat response.

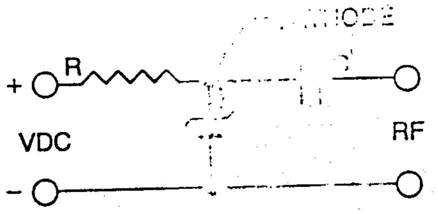
All Noise Com noise diodes deliver symmetrical white Gaussian noise and flat output power versus frequency. The diodes are burned-in for 168 hours, meet MIL-STD-202, and are hermetically sealed. Noise Com noise diodes are ava... in a wide variety of package styles, ... in special configurations on request.

The NC 100 and ... are designed for a... tions. The NC 300 ... diodes are design... cations in which a ... quired.

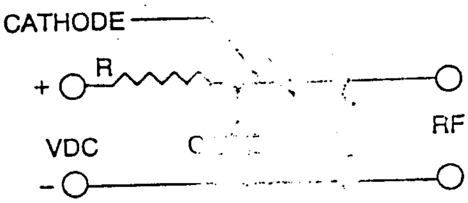
See page 16 for ... and dimensions.



Express



LOW-FREQUE... CIRCUIT



HIGH-FREQU... CIRCUIT

$R=\frac{V_{DC}-V...}{I_{op}}$ ... ency

AUDIO & VHF TYPES

MODEL	FREQUENCY RANGE	OPERATING CONDITIONS V_b (V)	I_{op}	RL (Ω)	MINIMUM OUTPUT (µV/√Hz)	PACKAGE
NC 101	0.1 Hz — 100 kHz	7-10	30-60 µA	2200	3.0	DO-35
NC 102	0.1 Hz — 500 kHz	7-10	30-60 µA	2200	3.0	DO-35
NC 103	0.1 Hz — 1 MHz	7-10	30-60 µA	2200	3.0	DO-35
NC 104	0.1 Hz — 3 MHz	7-10	30-60 µA	2200	3.0	DO-35
NC 201	0.1 Hz — 10 MHz	7-10	0.2-0.5 mA	2200	0.1	DO-35
NC 202	0.1 Hz — 25 MHz	7-10	0.2-0.5 mA	2200	0.1	DO-35
NC 203	0.1 Hz — 100 MHz	7-10	0.2-0.5 mA	50	0.05	DO-35
NC 204	0.1 Hz — 500 MHz	13-15	1 mA	50	0.05	DO-35

RF & MICROWAVE TYPES

MODEL	FREQUENCY RANGE	OPERATING CONDITIONS V_b (V)	I_{op} (mA)	RL (Ω)	OUTPUT ENR (dB)	PACKAGE*		
NC 301	10 Hz — 1.1 GHz	13-15	1-4	50	32-37	DO-35		
NC 302	10 Hz — 3 GHz	8-12	6	50	30-35	DO-35	BL	CH1
NC 302L	10 Hz — 3 GHz	6- 8	6	50	30-35	DO-35	BL	CH1
NC 303	10 Hz — 8 GHz	8-12	8	50	30-35	DO-35	BL	CH1
NC 304	10 MHz — 12.4 GHz	16-21	12	50	30-35	DO-35		CH1
NC 305	10 MHz — 11 GHz	8-12	10	50	29-34		BL	CH1
NC 401	100 MHz — 18 GHz	8-12	10	50	30-35	C10	C50H	CH2
NC 403	100 MHz — 27 GHz	8-12	12	50	24-28	C50		CH3
NC 404	18 GHz — 50 GHz	8-12	15	50	20-25	C50		CH3
NC 405	18 GHz — 75 GHz	8-12	20	50	15-25	C50		CH3
NC 406	18 GHz —110 GHz	8-12	30	50	15-25			CH3

* For chip configuration — Add suffix "C".
For beam lead configuration — Add suffix "BL".
For C50H configuration — Add suffix "H".

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Appendix- D

COMPONENTS LIST

Symbol	Component	Part No.	Package/Type	Quantity	Value	Tolerance	Regulation	Rating	Description	Manufacturer
Q1	Transistor	LM334Z	TO-92 Plastic Package	1	-	3%	0.02%/V	400mW	3-Terminal Adjustable Current Source	National Semiconductor Corporation USA
Q2	Transistor	LM317H	TO-39 Metal Can	1	-	1.00% Output Voltage	0.01%(line) 0.3%(load)	2W	3-Terminal Adjustable Voltage Regulator	National Semiconductor Corporation USA
C1, C2	Capacitor	-	Radial Case	2	120pF	1%	-	25V	Multilayer Ceramic	Philips Holand
C3, C4	Capacitor	-	Chip	2	4700pF	1%	-	25V	Multilayer Ceramic	AVX USA
R1	Resistor	-	MFR Axial Lead	1	220	1%	-	1/4W	Precision Metal Film Resistor	Thermax India
R2	Resistor	-	MFR Axial Lead	1	1.8K	1%	-	1/4W	Precision Metal Film Resistor	Thermax India
R3	Resistor	-	MFR Axial Lead	1	12	1%	-	1/4W	Precision Metal Film	Thermax India

Symbol	Component	Part No.	Package/Type	Quantity	Value	Tolerance	Regulation	Rating	Description	Manufacturer
R4	Resistor	-	Chip	1	153	5%	-	1/4W @70 °C 200 Vrms	Thick Film Chip Resistor	RS Components UK
R5	Resistor	-	Chip	1	68	5%	-	1/4W@ 70 °C 200 Vrms	Thick Film Chip Resistor	RS Components UK
R6	Resistor	-	Chip	2	68	5%	-	1/4W@ 70 °C 200 Vrms	Thick Film Chip Resistor	RS Components UK
L	Inductor	-	Axial Lead	2	100nH	10%	-	1/4W	Moulded RF Choke	RS Components UK
D	Noise Diode	NC 302	DO-35 Axial Lead	1	-	-	-	78mW	Avalanche Diode	Noise/Com USA

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