A Precision Calibration Solid State Noise Source with smooth Spectrum

Hamdi Mani, Judd Bowman

***Abstract*—A Solid state calibration noise source for precision radio astronomy receivers has been designed built and tested. The Noise source has flat output noise spectrum, stability in time and frequency (smooth response), very low power dissipation, excellent power match…all on a very compact package that can easily be integrated with a radio astronomy receiver. The noise source has an integrated precision temperature sensor to measure the physical temperature during the "cold" state.**

***Index Terms*— radio astronomy, radiometry,**

I. INTRODUCTION: RADIO ASTRONOMY RECEIVER CALIBRATION USING BROADBAND NOISE GENERATORS

The receivers in radio astronomy need to be calibrated using known signal. Those signals are usually broadband noise signals generated using either thermal noise source or solid state noise generators.

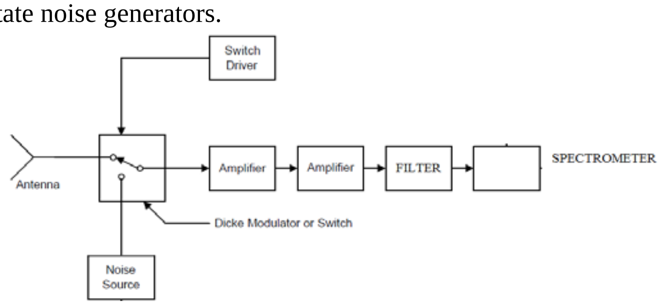

Fig. A block diagram of a 3-position radio receiver. A front end switch is used to select: the antenna whose power needs to be measured, an ambient temperature load and a load at a different temperature or eqauivalently a noise generator with > 300K output noise.

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$$p_0(\nu) = g(\nu)[p_{\rm atten}(\nu) + p_{\rm amp}(\nu)],$$
$$p_1(\nu) = g(\nu)[p_{\rm load}(\nu) + p_{\rm amp}(\nu)],$$
$$p_2(\nu) = g(\nu)[p_{\rm ant}(\nu) + p_{\rm amp}(\mu)],$$

$$T_{\rm ant}(\nu) = T_{\rm atten}(\nu) + [T_{\rm load}(\nu) - T_{\rm atten}(\nu)][p_2(\nu) - p_0(\nu)]/[p_1(\nu) - p_0(\nu)],$$

II. SOLID STATE NOISE GENERATORS: AVALANCHE BREAKDOWN IN SEMICONDUCTOR JUNCTIONS

The avalanche process occurs when the carriers in the transition region(depletion layer) are accelerated by the electric field to energies sufficient to free electron-hole pairs via collisions with bound electrons.Avalanche breakdown usually destroys regular diodes, but avalanche diodes are designed to break down this way at low voltages and can survive the reverse current.(http://www.radio-electronics.com/info/rf-technology-design/noise/avalanche-noise-basics.php) http://en.wikipedia.org/wiki/Avalanche_breakdown)

An electron avalanche is a process in which a number of free electrons in a medium (usually a gas) are subjected to strong acceleration by an electric field, and subsequently collide with other atoms of the medium and thereby ionize them in a process called impact ionization. This releases additional electrons which are themselves accelerated and collide with further atoms, releasing more electrons, in a chain reaction. The result is the affected region of gas becomes a plasma, making it electrically conductive. The avalanche effect was discovered by John Sealy Townsend in his work between 1897 and 1901, and is also known as the Townsend discharge. (http://en.wikipedia.org/wiki/Electron_avalanche)

There is a generation process called impact ionization, the generation mechanism that is the counterpart of Auger recombination. Impact ioniz ation is caused by an electron/hole with an energy, which is much larger/smaller than the conduction/valence band edge. The excess energy is given off to generate an electron-hole pair through a band-to-band transition. This generation process causes avalanche multiplication in semiconductor diodes under high reverse bias: As one carrier accelerates in the electric field it gains energy. The kinetic energy is given off to an electron in the valence band, thereby creating an electron-hole pair. The resulting two electrons can create two more electrons which generate four more causing an avalanche multiplication effect. Electrons as well as holes contribute to avalanche multiplication. [2]

In order to look at avalanche noise, it is necessary first to look at the phenomenon that gives rise to it.

Avalanche breakdown occurs in semiconductors where a very high potential gradient exists. When this occurs electrons rapidly gain momentum and may hit the crystal lattice through which they travel with such energy that they can dislodge other charge carriers creating hole electron pairs. In turn these carriers are accelerated and may similarly hit the lattice and dislodge further carriers.

This process can lead to an avalanche of new carriers, and the breakdown of the pn- junction.

The way that breakdown occurs results in a very uneven or ragged current flow. This means that high levels of noise - avalanche noise are generated.

The stable burning avalanche discharge in a reverse biased p-n junction, especially designed for uniform breakdown, generates noise which has a flat spectrum on the RF/microwave frequency range, high output stable level, high efficiency, low power dissipation, low temperature and bias dependence and high reliability.[1]
The solid state noise generators have also the advantage of being able to be switched fast.

A p-n silicon junction under reverse bias, can be modeled as a depletion layer capacitance, a space charge resistance, a spreading resistance and lead inductance.

The output match of a noise diode is poor and varies between the "ON" and "OFF" states, an attenuator is used at the output to improve the power match and reduce its variability.

The noise diode can not be used as primary noise standards, they need to be calibrated against thermal noise sources.

III. SOLID STATE NOISE SOURCE DESIGN

The noise generation device is the NoiseCom NC302L diode, reverse biased using a constant current source. The constant current is supplied from the LM134 current source integrated circuit which is powered using a voltage regulator from usmicrowaves (LM78xx-adj). The current source and the voltage regulator are mounted on the package for better heat sinking and temperature stability. The voltage regulator is on die form and was connected to the rest of the circuit using gold bond wires. The LM134 current source is packaged on a TO-46 metal can package. The unregulated voltage is applied to a capacitive feedthrough connectors acting like low pass filters rejecting noise picked up by power cables. The current flowing through the diode can be adjusted using an external potentiometer to allow measurement of the output spectrum at different bias conditions.
The diode is mounted on an alumina board in very good thermal contact with the package. An inductor was used as a wideband Rf choke. Chip attenuators (from Skyworks) were used at the output to improve the power match and set the noise level. To improve the output impedance even better, a matching circuit was designed and implemented according to Fig.11.The inductance was just a bondwire and the resistance was implemented using 0402 SMT resistors.

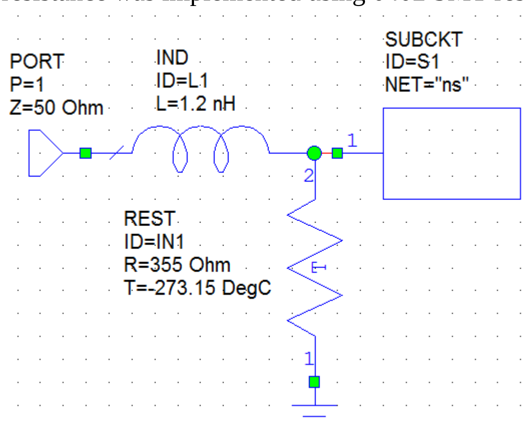

Fig. Sinple Matching network used to improve the power match of the noise source on the 40-200MHz band.

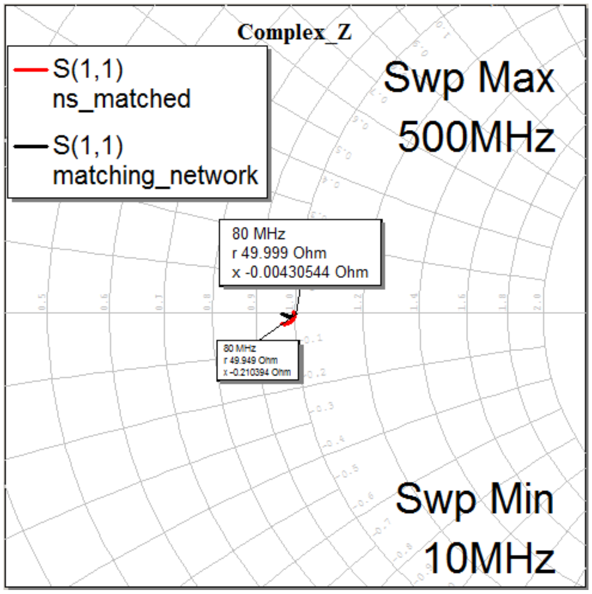

Fig. A smith Chart plot showing the improvement of output impedance with the addition of the above matching network.

The whole system was packaged on a 1 X 1 in custom designed enclosure that is RFI tight. Microassembly techniques and soldering were used to put together the noise source.

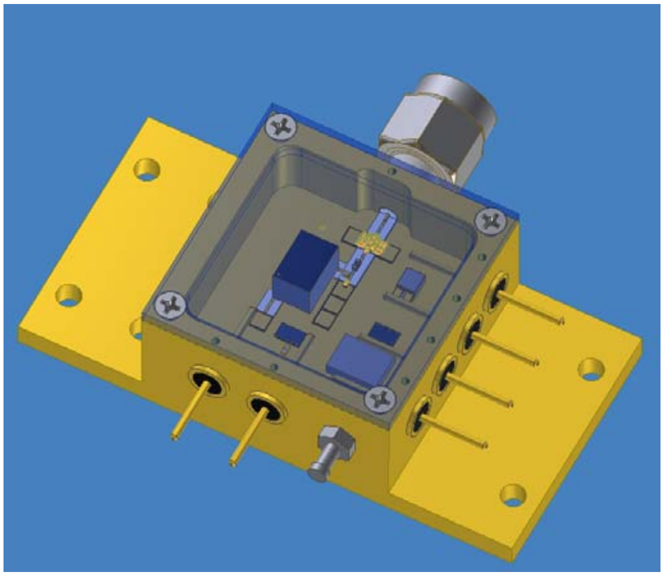

Fig1. 3D drawing of the Packaged Noise source before fabrication

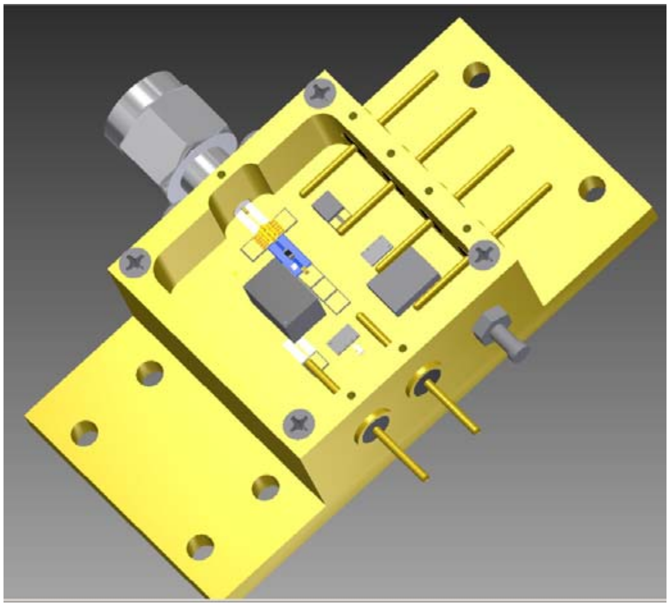

Fig. The package of the noise source has been designed using Autodesk Inventor 3D design software. The assembly was performed with inventor before building the actual hardware.

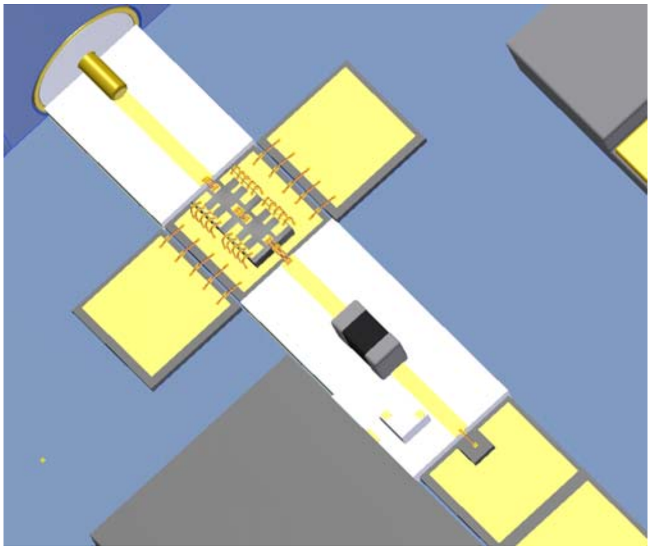

Fig2. Close up view of the noise generator diode

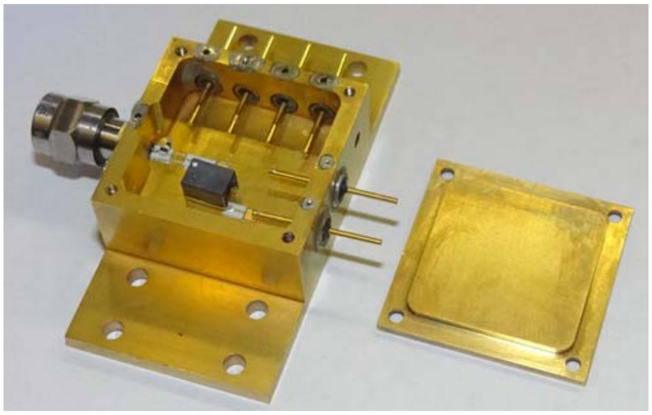

Fig2. Coaxial package with Cover

Fig. DC / RF Automated Measurement Setup

IV. DC MEASUREMENTS OF THE NOISE GENERATOR DIODE

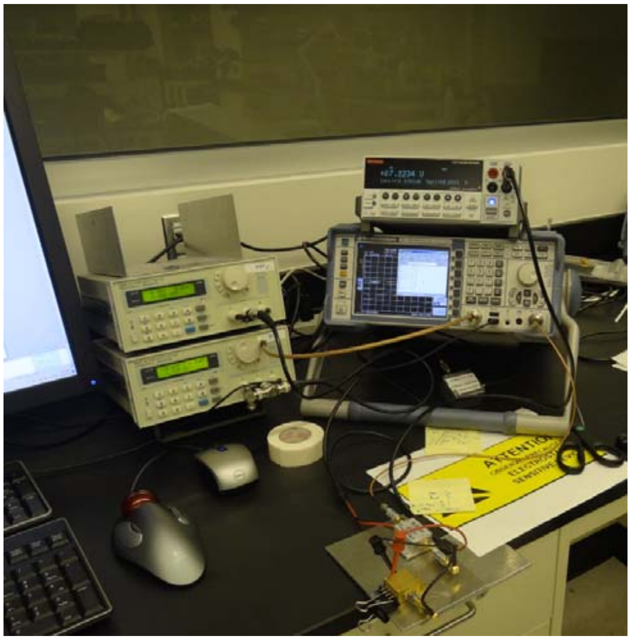

Fig. State of the art DC and RF precision tested equipment were used to make initial measuremets of the DC and RF parameters. All the test equipment were automated using MATLAB.

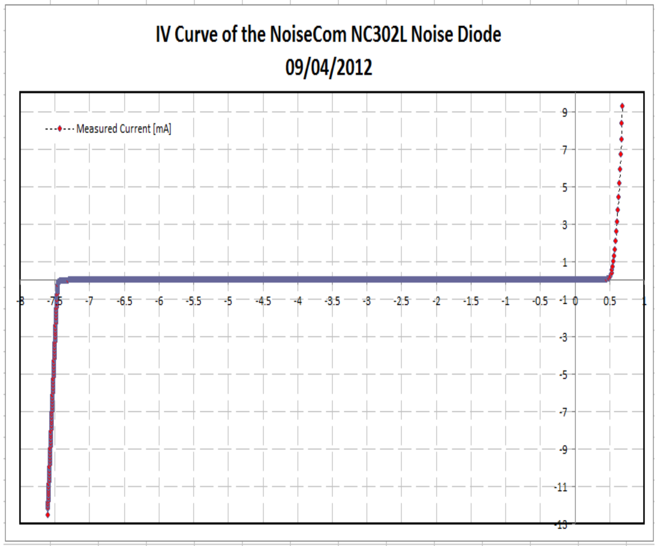

Fig. IV curve of the diode was measured with a Keithley 2400 precision programmable power supply. This is a good health check of the diode after all the assembly steps and handling. The curve clearly shows about 0.65 forward voltage drop and about -7.5V reverse voltage. It tells that the diode will drop 7.5V across it to generate the RF noise. The power dissipation of the diode itself is very low: less than 7.5V x 1ma = 7.5mW.

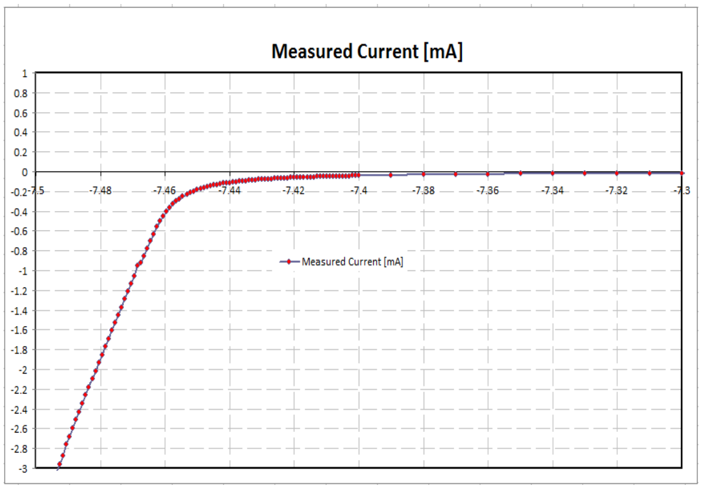

Fig. A close up view of the avalanche region where the diode junction was biased with a reverse current.

V. RF MEASUREMENTS OF THE NOISE SOURCE

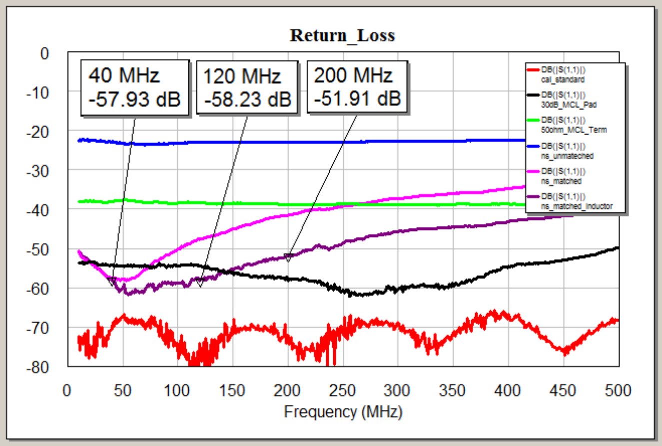

Fig. Blue Curve: Measured Return loss of the noise source module before adding an impedance matching network. Pink curve: simulated RL with the matching network. Violet curve: Measured RL after the addition of a matching network. Green Curve: RL of a minicircuits 50Ohm Load. Black Curve: RL of a minicircuits 30 dB Pad. Red curve: RL of the calibration load considered by the VNA as perfect load. The trace noise increases with decreasing return loss: VNA noise dominates due to the fact that the measured reflected signal is very small.

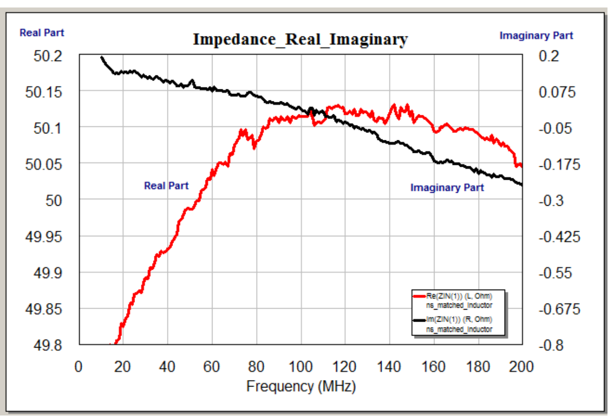

Fig. Real and imaginary part of the impedance calculated from the complex reflection coefficient measured using a ZVL3 VNA.

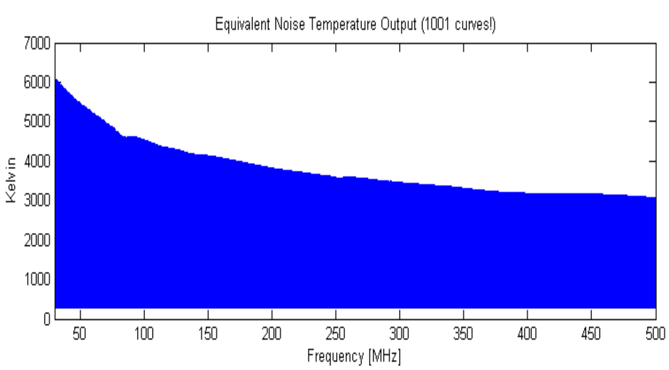

Fig. 1001 Curves shown on one plot, calibrated output Spectra measured with a spectrum analyzer. The calibration relies on the absolute power measurement accuracy of the spectrum analyzer. The is an initial functional test of the module. Each of the 1001 curve was measured at different current: from 0uA to1000uA in 1uA step. Each curve is the average of 100 measurement(Averaged). This plot also shows that it is possible to generate any noise output level between 300K and about 4000K.

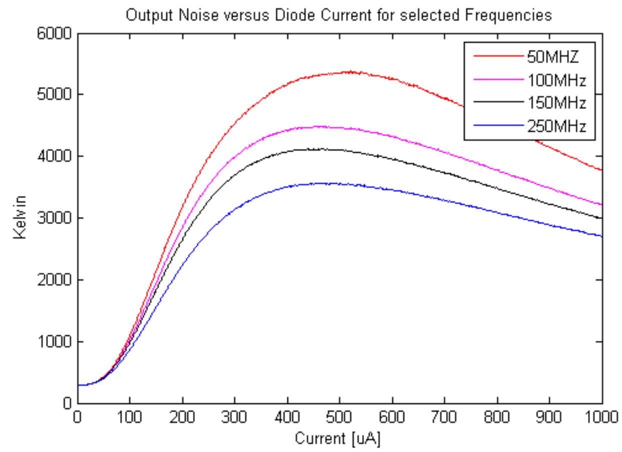

Fig. Output noise for 4 fixed frequencies at different currents. These curves are useful in deciding what current level should be used to drive the noise source. The bias current is chosen where the dT/dI minimizes to generate a more stable output. It is interesting to see that it is possible to generator > 4000K of noise with just 3.725 mWof power consumption making the biasing of the noise module possible with a battery.

VI. **PRECISION MEASUREMENT OF THE NOISE SOURCE**

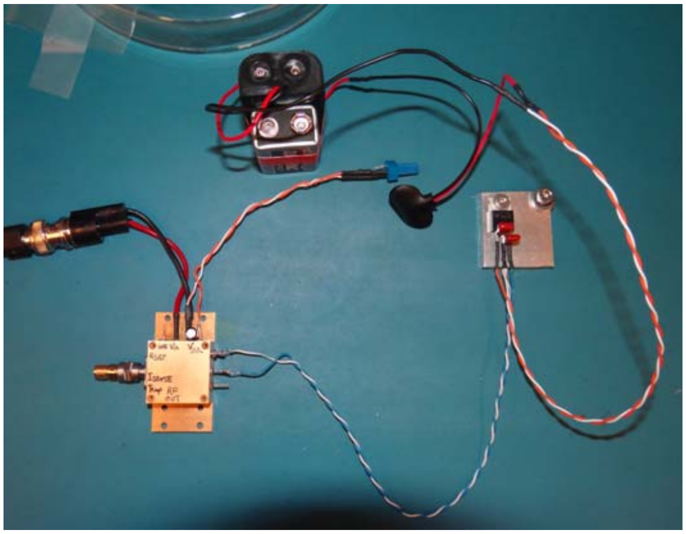

Fig. Noise source modified to operate from an external voltage regulator and a battery to avoid power supply noise. The current source also has an external current sense port (BNC cable) to check the stability of the current.

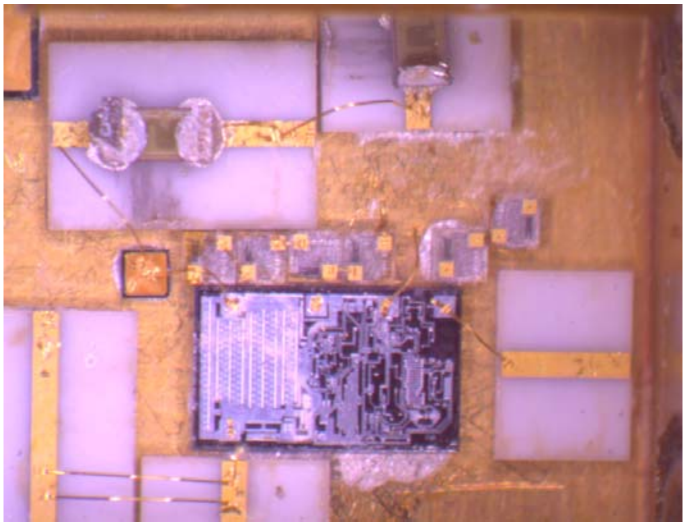

Fig. an internal voltage regulator circuit in bare die format connected to the set resistors and to the rest of the circuit using bond wires.

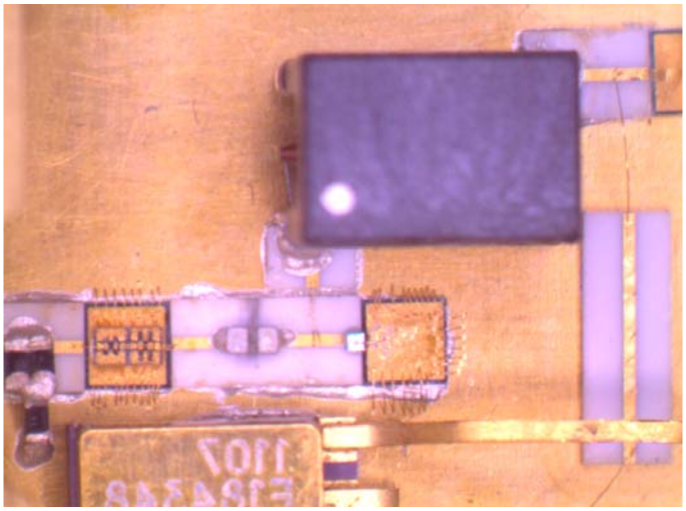

Fig. Some internal details of the noise source: the matching network resistors (black 0402 resistors), pads, diode, Rf choke (conical inductor) and temperature sensor (AD590).

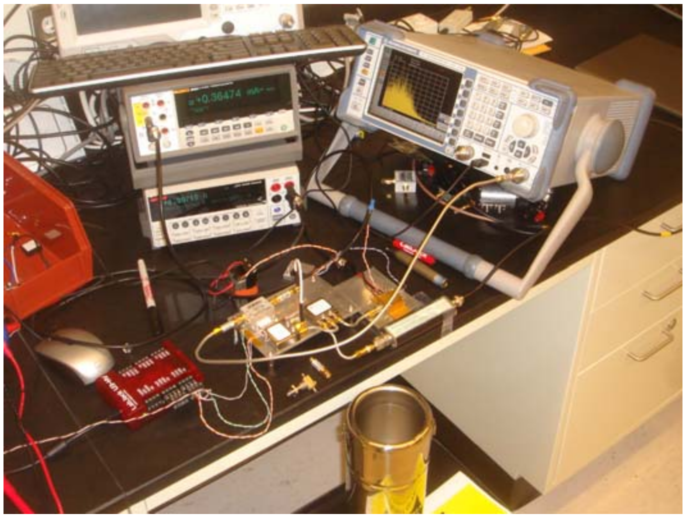

Fig. Measurement setup used to compare the modified solid state noise source to thermal noise generators. A Switching radio receiver was built controlled by a labjack. The noise source will be compared to Liquid Nitrogen cooled load(77k).

Fig. The cryostat used to cool a termination to 9K. This setup was used to compare the solid state noise source and the thermal noise source. The setup was used also to compare the smoothness of the output spectrum of the noise source compared to 300K and 9K thermal noise sources.

VII. Conclusion & discussion

VIII. Accompanying files

AKNOLWEDGEMENT

References

[1] A Solid state broadband microwave noise source, R.H Haitz, F.L Opp, Texas instruments,Inc.
[2] *Principles of Semiconductor Devices*, Second Edition
[3] http://ena.tm.agilent.com/e5071c/manuals/webhelp/eng/measurement/fixture_simulator/evaluating_balanced_devices_balance_unbalance_conversion.htm
[4] http://www.home.agilent.com/agilent/product.jspx?nid=-536902643.426031.00&cc=US&lc=eng
[5] www.**awrcorp**.com
[6] *Book1*

[7] *Book2*
[8] *Article*
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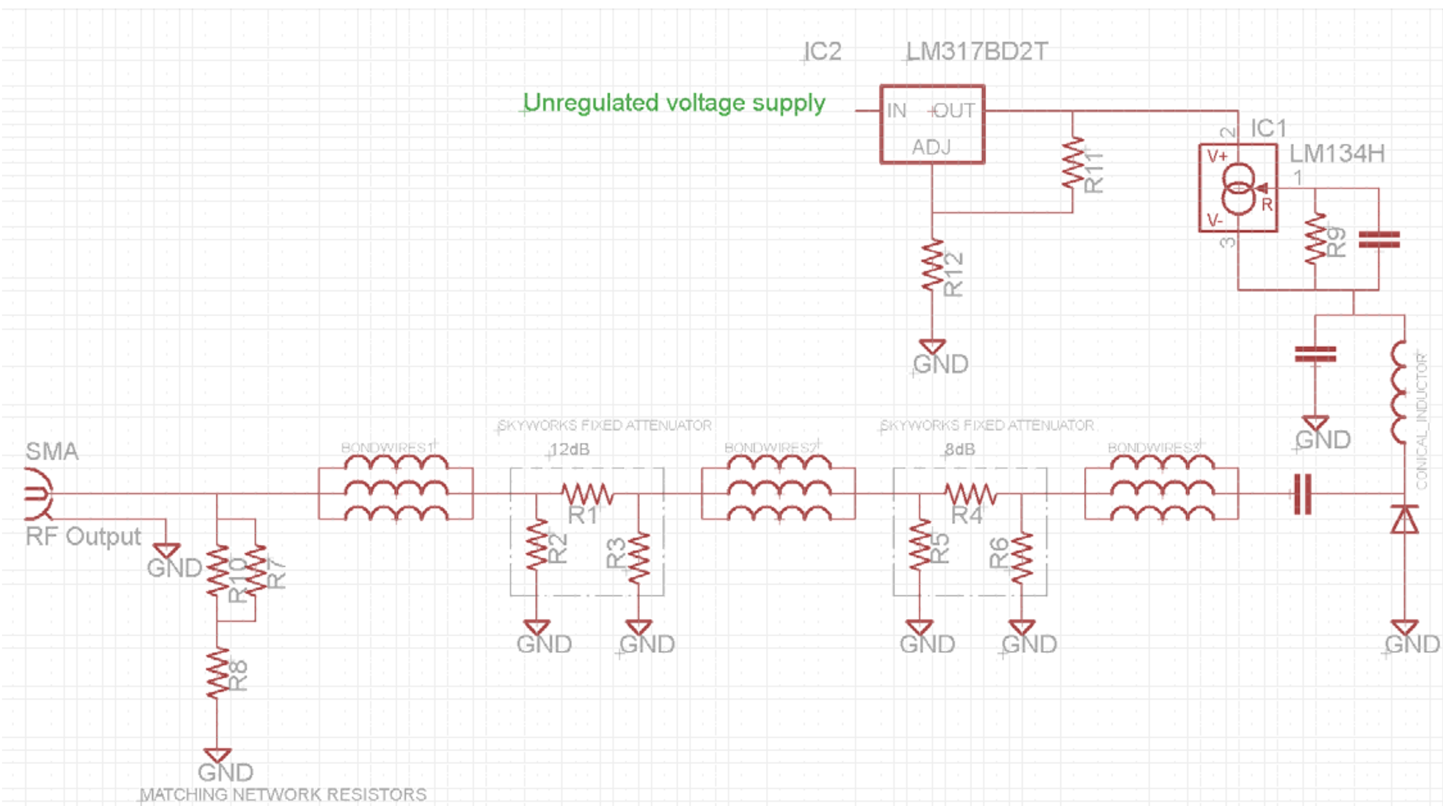
APPENDIX A: SCHEMATICS OF THE FINAL VERSION OF THE NOIS SOURCE



APPENDIX B: PARTS USED TO BUILD THE CALIBRATION NOISE SOURCE

PRECISION CALIBRATION NOISE SOURCE COMPONENTS

(Quantities are for 1 Noise source assembly)

Item #	Part Description	Vendor	Part Number	Quantity	Price	Comment
1	SMI 2.92mm(M) 2-Hole .190"x.500" Connector /2 Holes	http://mpd.southwestmicrowave.com/products.php?prd=1013-21SF	1013-21SF	1	$38.35 each	
2	Southwest microwave 50 ohm Hermetic Seal (.012 Dia.)	http://mpd.southwestmicrowave.com/launchaccess.php?model=490-00G	290-07G	1	$4.68 each	
3	18-8 SS Button Head Socket Cap Screw 2-56 Thread, 1/8" Length	http://www.mcmaster.com/#92949a074/=d5y2bb	92949A074	1 Pack	$4.71 per Pack	PACK OF 100
4	18-8 SS Flat Head Phillips Machine Screw 0-80 Thread, 1/4" Length	http://www.mcmaster.com/#phillips-machine-screws/=d8j5db	91771A055	1 Pack	$9.01 per pack	PACK OF 100
5	Keystone 1595-1 Terminals TERM TURRET .093	http://www.mouser.com/ProductDetail/Keystone-Electronics/1595-1/?qs=sGAEpiMZZMvlX3nhDDO4AJPw4VedANGFwZVeSnfwJog%3D	534-1595-1	1	$0.64 each	grounding the noise source case
6	50 Ohm Microstrip Line: 10 mil thick, 70mil wide KIT	http://www.ionbeammilling.com/MICROSTRIP_TRANSMISSION_LINES	KIT Z50–010–070-LLL	1	$350	his enough to make a lot of assemblie
7	DC Bias Connector: FILTER EMI 50000 PF C TYPE	http://www.mouser.com/ProductDetail/Tusonix/4300-014LF/?qs=MAKYsf4oimnKUkalCuR6%252bQ%3d%3d	800-4300-014LF	6	$12.12 each	Bias connector and temp sensor
8	1000pF Skyworks Capacitor SC99906068	www.rfmw.com	SC99906068	7		
9	30 dB attenuator chip	www.rfmw	ATN3580-30	1		
10	20dB attenuator chip	www.rfmw	ATN3580-20	1		
11	1dB Attenuator chip	www.rfmw	ATN3580-1	1		