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Abstract:

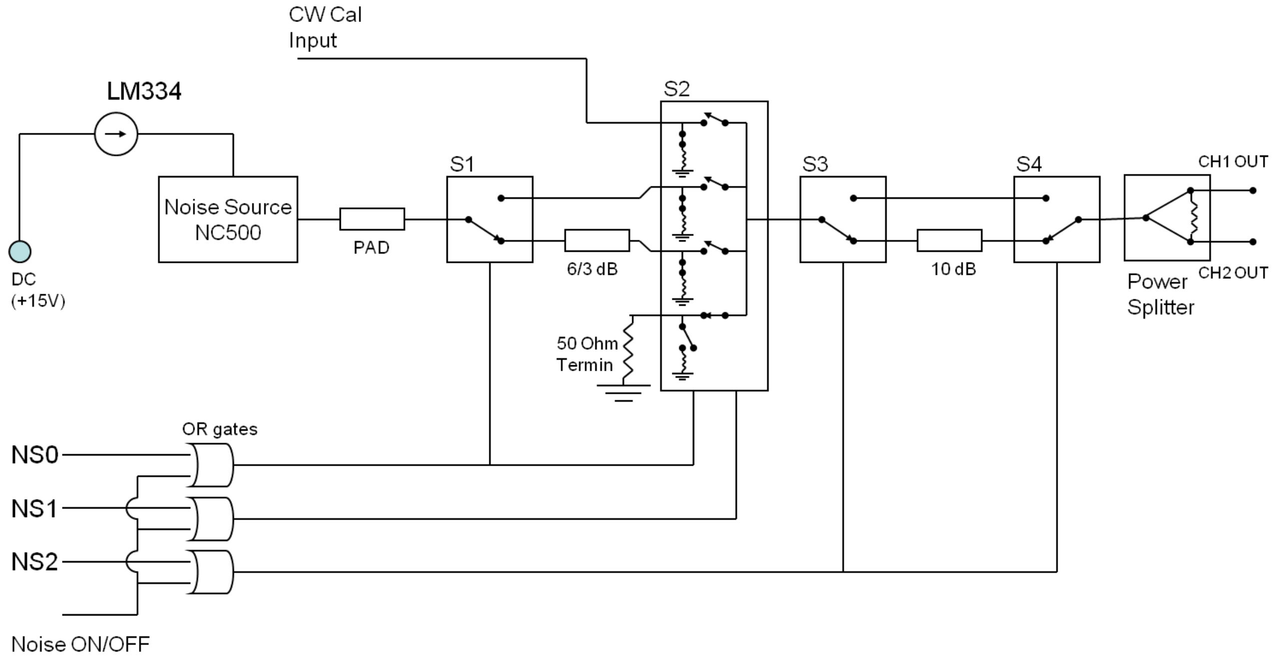
This short report deals with how ‘Noise and continuous wave cal injection Unit’ works. Effect of **temperature** and **supply voltage** variation on **output ENR** is found out theoretically as well as practically. It also compares various noise modules available in market and shows why Noise modules NC500 series, NoiseCom make, are suitable for our application.

Along with this, Calibrated Temperature (Tcal) injected in RF path using **existing** Noise Injection Unit is calculated. Expected **deflection** for **existing** Noise Injection Unit between Noise ON and Noise OFF is calculated **theoretically**.

Description:

'Noise and continuous wave cal injection Unit' is used for injecting calibrated RF signal in both channels of RF Front-End of GMRT receiver. Calibrated signal can be selectively attenuated to create different cal levels viz. Extra High cal, High cal, medium cal, Low cal.

Block diagram of Noise/Continuous Wave Calibration Unit



Noise module NC500 series, NoiseCom make, is used for generating Noise Signal. Constant current source LM334 provides constant current of 5mA. RF switches S1, S2, S3 and S4 are switched using control signal to provide different levels of attenuation. PAD is used to adjust Noise Signal to get given temperature (Tcal) for given Front-End box. E.g. 8dB pad for 150MHz FE Box to get Tcal of 800K and 4 dB pad for 233MHz FE-Box to get Tcal of 400K. Calibrated signal is equally divided by 3dB power divider and injected in both channels using 20dB directional coupler.

Specification of NC500/12:

NC500/12 Noise Modules contains complete bias circuits and requires no external components. Output ENR of these noise modules is insensitive to variations in temperature and supply voltage.

1. Frequency Range:
    - NC501/12 200KHz-500MHz
    - NC502/12 200KHz -1GHz
    - NC503/12 200KHz -2GHz
2. Output: White Gaussian Noise
3. Minimum Power Output: 31dB ENR (-143dBm/Hz)
4. Supply current: 0.2 to 5mA
5. Temperature Coefficient: 0.01dB/°C
6. Supply Sensitivity: 0.1dB/%ΔV
7. Operating Temperature: -55°C to 85°C
8. Packaging: Drop In TO8 Metal Can package
9. Output Flatness:
    - NC501/12 +/-0.5 dB
    - NC502/12 +/-1.0 dB
    - NC503/12 +/-1.5 dB

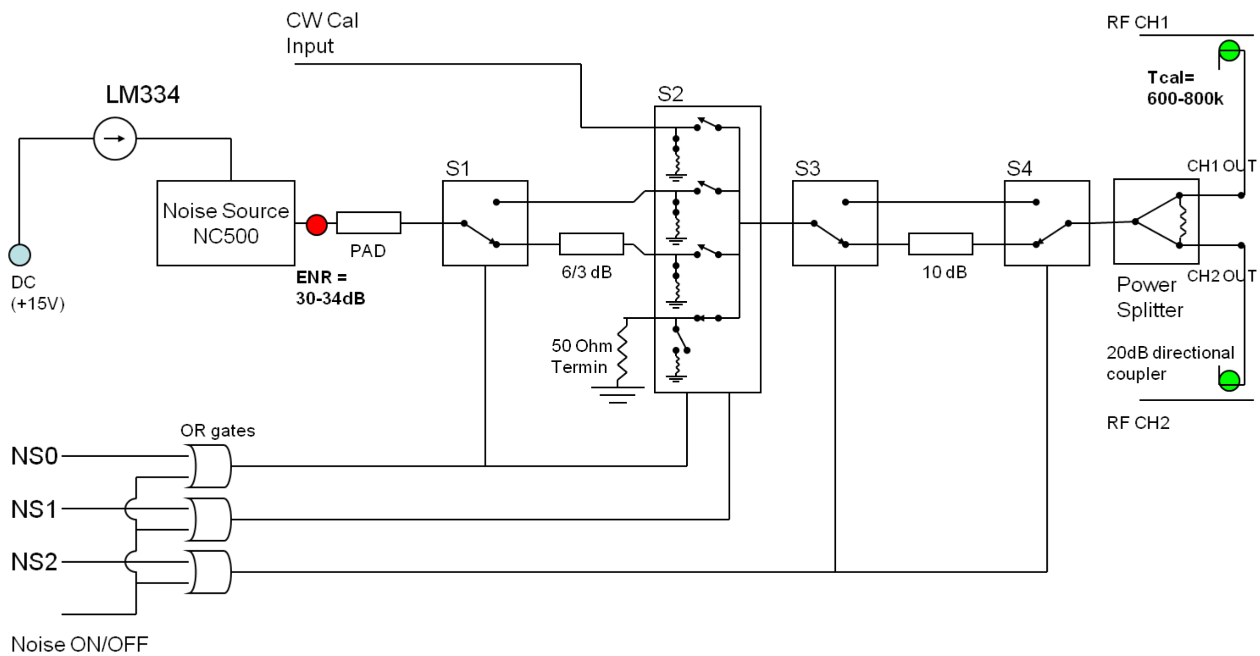
Specification of LM334:

LM334 is 3 terminal adjustable current source with current range from 1uA to 10mA. It has good current regulation and wide dynamic voltage range i.e. 1V to 40V. LM334 is true floating current source with no separate Power Supply or Ground connections.

1. Programmable current range: 1uA to 10mA
2. Supply voltage Range: 1V to 40V
3. Current Regulation: 0.02% /V
4. Sense voltage to establish current 64mV @ 25°C
5. Operating Temperature: 0°C to 70°C
6. Packaging: Drop In TO46 Metal Can package (3pin)
7. Change in SET current with i/p voltage 0.02 % /V (typical)

Why NC500 Noise Module is chosen:

1. To get Tcal (Temperature inserted in RF-channels) around 600-800 K, ENR of noise source has to be between 30dB and 34dB. **NC500 Noise modules** give ENR of **31dB.**



In above diagram, to get Tcal of 600-800K (at green dots shown), Output ENR of Noise module (at red dot shown) has to be between 30 and 34dB.

2. NC500 has very less temperature coefficient of 0.01dB/°C

3. Output ENR of NC500 is insensitive to variation in supply voltage.

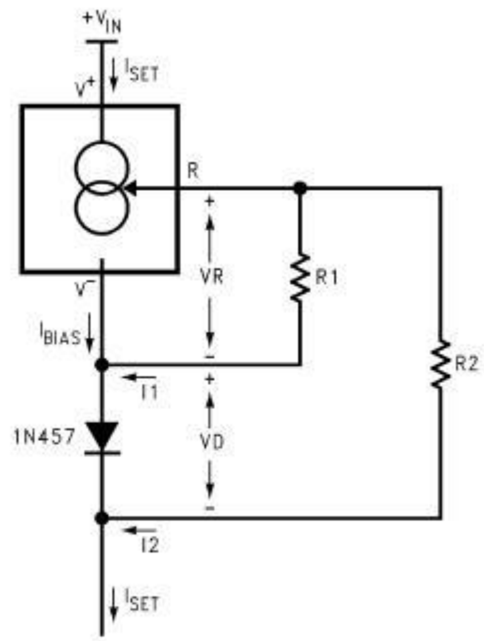
Supply sensitivity of NC500 is 0.1dB/%ΔV

4. It contains complete bias circuits and requires no external components.

5. Output power versus frequency characteristic is extremely flat

Design of Constant current Source LM334:

A forward biased diode is added to cancel temperature dependent characteristic of LM334 as shown in figure below. This balances +ve temperature coefficient of LM334 with -ve temperature coefficient of diode. Diode used is 1N457 which has negative temperature coefficient of value -2.5mV/°C.



Step1: Finding out ratio of R1 to R2 for compensating +ve temperature coefficient of LM334 with -ve temperature coefficient of diode.

$$Iset = I1 + I2 + Ibias$$

$$Iset = \frac{VR}{R1} + \frac{VR + VD}{R2}$$

here Ibias is very small & adjusted in +ve tempco of LM334

To calculate temperature coefficient, differentiate with temperature,

$$\frac{d(Iset)}{dT} = \frac{1}{R1} * \frac{d(VR)}{dT} + \frac{1}{R2} * \frac{d(VR + VD)}{dT}$$

Now as given in datasheets, $\frac{d(VR)}{dT} = +227\mu V/°\text{C}$ and $\frac{d(VD)}{dT} = -2.5mV/°\text{C}$

$$\frac{d(Iset)}{dT} = \frac{+227\mu V/°\text{C}}{R1} + \frac{+227\mu V/°\text{C} - 2.5mV/°\text{C}}{R2}$$

To get output current, Iset, of LM334 independent of temperature, $\frac{d(Iset)}{dT} = 0$

Thus,

$$0 = \frac{+227\mu V/°\mathrm{C}}{R1} + \frac{+227\mu V/°\mathrm{C}\ - 2.5mV/°\mathrm{C}}{R2}$$

It gives

$$\frac{R2}{R1} = 10.0132$$

Step2: Calculating values R1 and R2 for getting current Iset = 5mA. This 5mA is typical current requirement of NC500 Noise module.

From above equation,

$$Iset = \frac{VR}{R1} + \frac{VR + VD}{R2}$$

VD = Forward voltage across diode = 0.6V
VR = Voltage across R1 @ T0 (298K) = 0.677V

$$5mA = \frac{0.677\mathrm{V}}{R1} + \frac{0.677\mathrm{V} + 0.6}{10R1}$$

$$R1 = \mathbf{26.8\Omega}$$
$$R2 = 10\mathrm{R1} = \mathbf{268\ \Omega}$$

Thus practical values of R1 and R2 are selected as **27Ω and 270Ω** respectively.

Need of constant and stable ENR:

Noise Injection Unit will be used for calibrating Front-End system of GMRT. Such calibration should be repeatable irrespective of change in any parameter. Such repeatable calibration will be achieved only when injected Noise has constant ENR independent of anything.

Parameters affecting ENR:

Any noise module has NOISE DIODE which generate noise signal of given ENR. In case of NC500, Noise diode which is operated in Bulk Avalanche Mechanism under reverse biased condition is used. Output ENR of this Noise Diode depends upon

1. Ambient Temperature
2. Current flowing through Noise diode
3. Voltage Applied

Thus effect of these parameters on output ENR can be minimized by taking following steps into consideration:

1. Selecting Noise Module which is insensitive to these parameters
2. Keeping these parameters constant

In case of our Noise injection unit,

1. We have selected Noise module NC500, which is insensitive to temperature and supply voltage variation.
2. Current flowing through Noise diode is kept constant using constant current source LM334.

Effect on output ENR can be measured (theoretically and practically) studying:

1. Effect of **supply voltage** variation on **output current** of constant current source LM334
2. Effect of **Temperature** variation on **output current** of constant current source LM334
3. Effect of **supply voltage** variation on **output ENR** of Noise Source NC500
4. Effect of **Temperature** variation on **output ENR** of Noise Source NC500

Effect of supply voltage variation on output current of constant current source LM334:

LM334 has good current regulation over operating input voltage.
As given in datasheet, for conditions 5V < Vin < 40V and 1mA < Io < 10mA,
Average change in SET current (o/p current) with input voltage = 0.02 % /V (typical)
= 0.05 % /V (Max)

Actual measurements:
(Measurements taken with existing Noise Generator Unit in L-band)

Voltage (V)	Current (mA)
12	0.837
12.5	0.949
13	1.055
13.5	1.161
14	1.263
14.2	1.307
14.4	1.348
14.6	1.384
14.8	1.420
15	1.436
15.2	1.440
15.4	1.441
15.6	1.442
15.8	1.442
16	1.442
16.5	1.443
17	1.444
17.5	1.444
18	1.445

Effect of Temperature variation on output current of constant current source LM334

Temperature coefficient of output current = **0.33% / Celsius**
Output current (I_set) of LM334 is directly proportional to temperature.
I_set at any temperature can be calculated as,

I_set = Io*K*(T/To)

Where, Io = I_set at absolute temperature To.

A forward biased diode is added to cancel temperature dependent characteristic of LM334.This balances +ve temperature coefficient of LM334 with -ve temperature coefficient of diode

Actual Measurements:
(Measurements taken with existing Noise Generator Unit in L-band)

Temperature (C)	Current (mA)
0 to 5	1.434
6-19	1.433
20-22	1.434
23-28.5	1.435
29-36.5	1.436
37-43	1.437
44-52	1.438
53-56	1.439
57-59	1.440
60-65	1.441

Effect of supply voltage variation on output ENR of Noise Source NC500:

Supply sensitivity of NC500 = **0.1 dB / %ΔV**
As per datasheet, NC500 requires typically 5mA input current, but can work on from 0.2mA to 5mA.

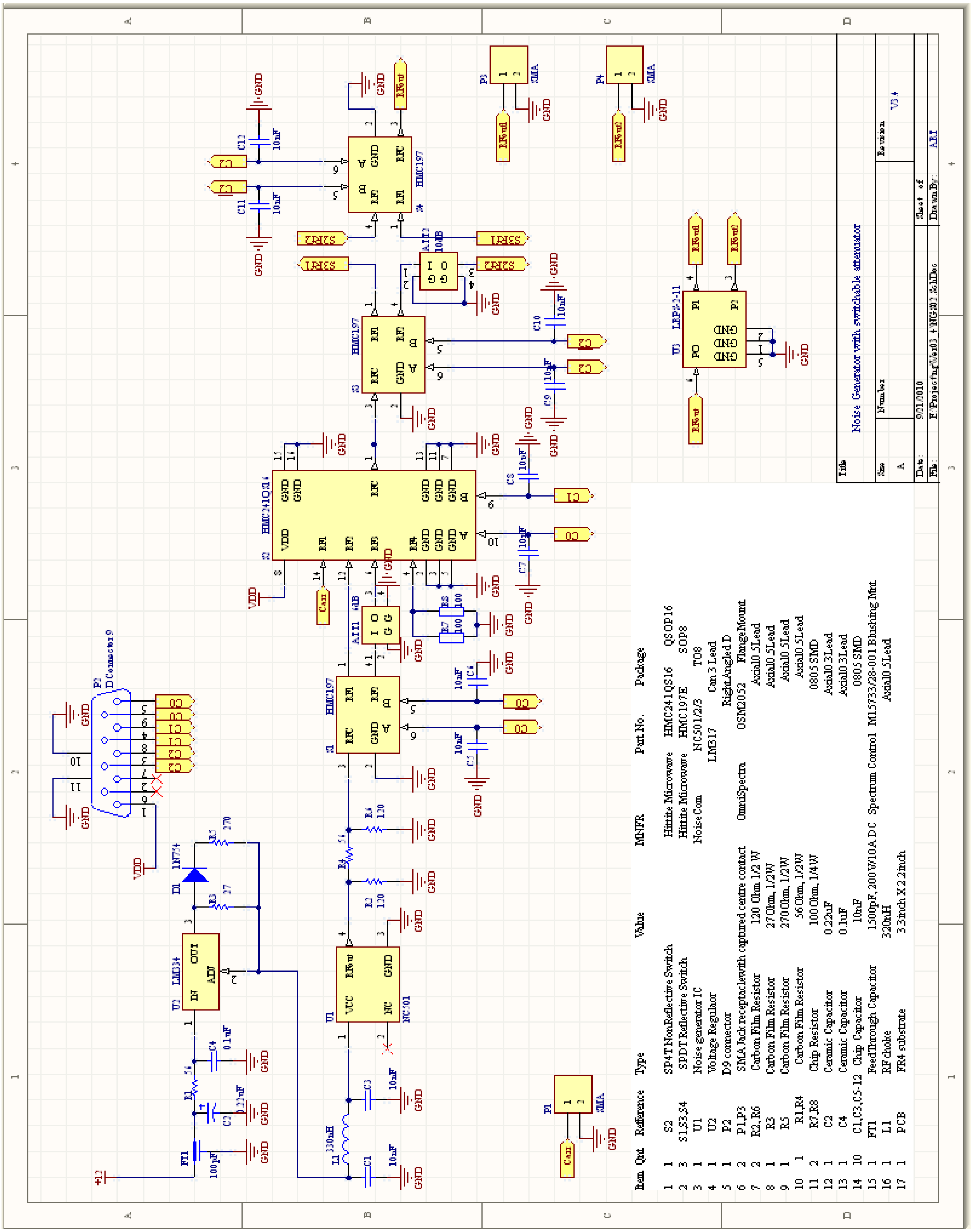
Effect of Temperature Variation on output ENR of Noise module NC500:

As given in datasheet, Temperature coefficient is **0.01dB/°C**.
Assuming temperature inside the FE-Box varies from 15°C (minimum) to 45°C (Maximum), change in Tcal inserted is calculated theoretically as below

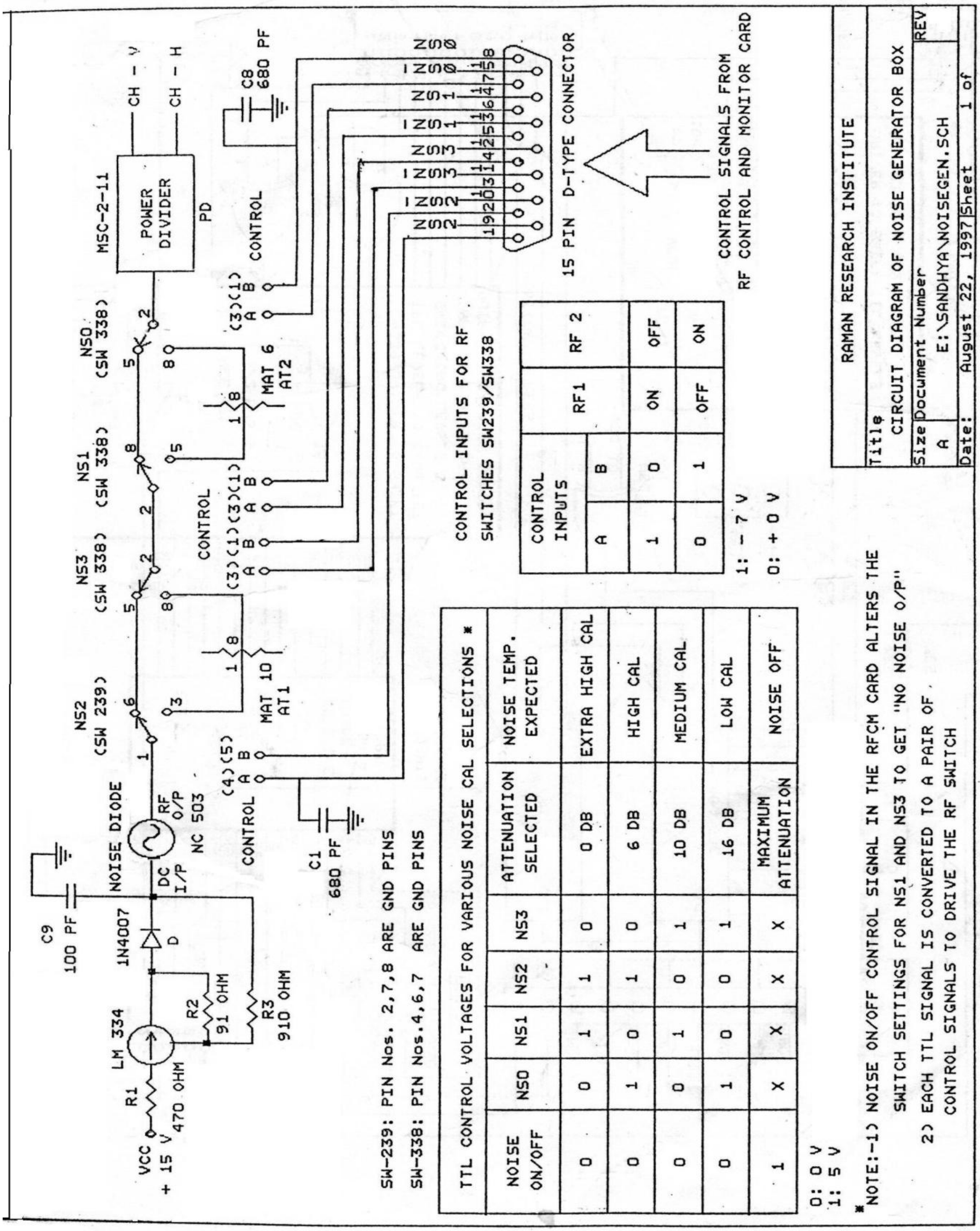
Temperature (°C)	ENR (dB)	Tcal injected in FE RF path (K)
25	31	599
15 (minimum)	30.9	585
45 (maximum)	31.2	627

Maximum variation in Tcal = 627K – 585K
= 42K (Theoretically)

Schematic of *Upgraded* 'Noise and continuous wave cal injection Unit':



Schematic of *Existing* 'Noise and continuous wave cal injection Unit'



TTL CONTROL VOLTAGES FOR VARIOUS NOISE CAL SELECTIONS *

NOISE ON/OFF	NS0	NS1	NS2	NS3	ATTENUATION SELECTED	NOISE TEMP. EXPECTED
0	0	1	1	0	0 DB	EXTRA HIGH CAL
0	1	0	1	0	6 DB	HIGH CAL
0	0	1	0	1	10 DB	MEDIUM CAL
0	1	0	0	1	16 DB	LOW CAL
1	X	X	X	X	MAXIMUM ATTENUATION	NOISE OFF

0: 0 V
1: 5 V

CONTROL INPUTS FOR RF SWITCHES SW239/SW338

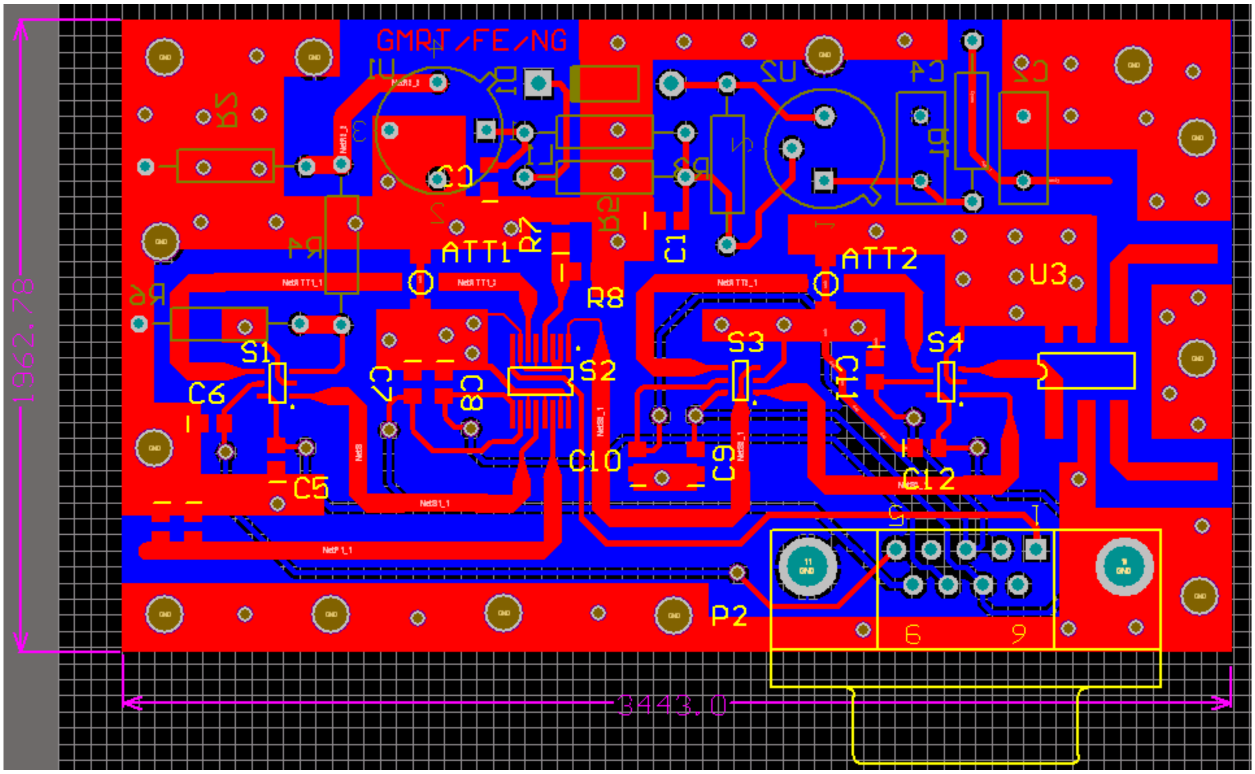
CONTROL INPUTS A	CONTROL INPUTS B	RF1	RF 2
1	0	ON	OFF
0	1	OFF	ON

1: - 7 V
0: + 0 V

* NOTE:-1) NOISE ON/OFF CONTROL SIGNAL IN THE RFCM CARD ALTERS THE SWITCH SETTINGS FOR NS1 AND NS3 TO GET "NO NOISE O/P"

2) EACH TTL SIGNAL IS CONVERTED TO A PAIR OF CONTROL SIGNALS TO DRIVE THE RF SWITCH

PCB layout of Upgraded 'Noise and continuous wave cal injection Unit':



Difference between Existing and Upgraded Noise Injection Unit

SR. No.	Existing	Upgraded
1.	Switches are +/-5 controlled	Switches are TTL controlled
2.	Continuous wave cal injection facility is not available	Continuous wave cal injection facility is available.
3.	6 control signals are required	4 control signals are required
4.	Resistive power divider is used	Minicircuits make wideband Power divider LRPS-2-11+ is used which is having good isolation and less insertion loss compared to resistive power divider. Phase and Amplitude unbalance in two channels is very less.
5.	Diode 1N4001 is used for canceling temperature dependence characteristic of LM334.	Diode 1N457 is used which has negative temperature coefficient of -2.5mV/ °C. It exactly nullifies the effect of positive temperature coefficient of LM334. Thus SET Current of constant current source becomes independent of temperature changes.
6.	Input current of Noise Module is set to 1mA. While datasheet says to keep it typically 5mA.	Input current of Noise Module is set to 5mA.
7.	Pad attenuation is not set such that calibrated temperature inserted (Tcal) is equal to 400%Tsys.	Pad attenuation will be set such that calibrated temperature inserted (Tcal) is exactly equal to 400%Tsys. Also thinking of using PAT attenuator type pad instead of using resistive T or Π attenuator pad.

Theoretical Deflection measurement between Noise ON and Noise OFF:

I searched through different texts in GMRT for such Theoretical Deflection Measurement for Noise ON and Noise OFF, but I couldn't find reference. This simple measurement is based on 'power calculation from temperature'. I would like to welcome some suggestions on this.

A) Deflection measurement using Noise Source NC500 series at Antenna (T0= Room Temperature =300K)

Sr.No.	Fre	Tsys	Tcal*	Tsys+Tcal	P(Tsys+Tcal)	P(Tsys)	Deflection
Unit	(MHz)	(K)	(K)	(K)	(dBm)	(dBm)	(dB)
1	150	580	800	1380	-106.4085598	-110.1730707	3.76451093
2	233	234	800	1034	-107.6621452	-114.1151920	6.45304681
3	327	108	400	508	-110.7487135	-117.4731131	6.72439957
4	610	100	400	500	-110.8176506	-117.8073506	6.98970004
5	1060	83	760	843	-108.5490749	-118.6165697	10.06749480
6	1170	77	720	797	-108.7927674	-118.9424434	10.14967600
7	1280	74	640	714	-109.2703685	-119.1150334	9.84466492
8	1390	72	600	672	-109.5336579	-119.2340257	9.70036777

B) Deflection measurement using Noise Source NC500 series at Lab (T0= Room Temperature =300K)

Sr.No.	Fre	Trx	Tcal*	T0+Tcal	P(T0+Trx+Tcal)	P(T0+Trx)	Deflection
Unit	(MHz)	(K)	(K)	(K)			
1	150	260	800	1100	-116.4719615	-120.3254704	3.85350881
2	233	103	800	1100	-117.0046944	-121.7543002	4.74960581
3	327	55	400	700	-119.0278811	-122.3050671	3.27718599
4	610	59	400	700	-119.0049329	-122.2564061	3.25147327
5	1060	53	760	1060	-117.342399	-122.3296036	4.98720459
6	1170	49	720	1020	-117.5175736	-122.3790964	4.86152278
7	1280	47	640	940	-117.8641791	-122.4040559	4.53987678
8	1390	45	600	900	-118.0530325	-122.4291597	4.37612713

*Note: Tcal (Temperature injected in RF channels) is taken from RF manual.

Study of cal levels in existing 'Noise and continuous wave cal injection Unit'

SR. No.	Frequency (MHz)	Tsys (K)	Tcal * (Assuming Tcal = 400%of Tsys)	Tcal ** (assumed to be inserted in RF Front-End)	Tcal *** (theoretically calculated)
1	150	580	2320	800	193.85
2	233	234	936	800	193.85
3	327	108	432	400	307.23
4	610	101	404	400	486.93

*We assume that, Noise equivalent to 400% of Tsys is injected in both RF channels

**RF manual says that, these values are inserted in both RF channels

***This Tcal value is theoretically calculated assuming various insertion losses in path. This needs more citation.

Comparison of Noise Modules:

Parameters	NC500	NC510	NC2600	SMN7114	NMA-2012
Current Requirement (Typical & Max)	5mA & 10mA	15mA & 30mA	100mA	90mA(max)	75mA
Supply Voltage	+12V or +15V	+12V or +15V	+12V or +15V	+8 to +18V	+15V
Minimum ENR	31dB	51dB		45dB	54dB
Temperature coefficient	0.01 dB/ ° C	0.01 dB/ ° C	0.025dB/° C	0.04dB/° C	0.025dB/° C
Packaging style (Minimum pins)	TO8 Metal can (4)	TO8 Metal can (4)	DIP(14)	SMT (16)	DIP(14)
Cost (approximate)	$60	>$60	$800		

Background of Solid State Noise Sources:

The solid state noise source generates precise amount of electrically conducted noise equivalent of thermal noise generated from resistor with physical temperature, Thot. The Solid state noise source output is maintained constant if current regulator controls the constant current through the noise diode.

Theory of operation:

A solid state noise source basically consists of Noise Diode. The Noise diode operates in bulk avalanche mechanism under reversed biased condition. A typical solid-state noise source is special low capacitance diode that generates noise with a constant current. When the diode is biased, the output noise will be greater than $KT\Delta f$ due to avalanche noise generation in diode. When unbiased, the output will be thermal noise produced in attenuator and equal to $KT\Delta f$. These are sometimes called Th and Tc corresponding to terms hot and cold respectively.

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

Bulk avalanche mechanism:

The dynamic resistance in a forward biased junction does not add excess noise to system. But when diode is reversed, an electric field is formed between the cathode and anode specifically across depletion region. When PN junction is reverse biased, majority carriers i.e. holes in P-material and electrons in N-material, move away from the junction. The barrier or depletion region becomes wider and majority carrier current flow becomes very difficult across high resistance of wide depletion region. The presence of minority carriers causes a small leakage current that remains nearly constant for all reverse voltages up to certain value. Once this value is exceeded, there is sudden increase in the reverse current. The voltage at which the sudden increase in current occurs is called as 'The breakdown voltage'. At breakdown, the reverse current increases very rapidly with slight increase in reverse voltage.

In avalanche breakdown, the field accelerates minority carriers in depletion region associated with small leakage currents to high enough energy so that they can 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). This newly created minority carriers accelerates in opposite directions causing further collisions and resulting very large current.

For reverse voltage slightly greater than breakdown voltage, the avalanche effect releases an almost unlimited number of carriers so that the diode essentially becomes short circuit. Only an external series current-limiting resistor limits the current flow in this region. Removing reverse voltage permits all carriers to return to their normal energy values and velocities.

For avalanche breakdown in PN junction diode, impurities are lightly doped and thus depletion region is wider. This breakdown generally occurs at high reverse voltage.