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10MHz - 10GHz Noise source diodes

1.

Introduction

In VHF Communications 1/2007 [1] I described a simple 10MHz to 3.5GHz noise source, the purpose of that article was to explain how to build a very simple noise generator using the NS-301 noise diode, either for applications like noise figure measurement or for a broadband noise generator for scalar applications with a spectrum analyser.

Now I will describe a 10MHz - 10GHz noise source generator with an improved bias network that uses the NS-303 noise diode.

This project was born some months ago for the 13th E.M.E. (moon bounce) conference in Florence during August 2008, the organisation asked me to cooperate to build some noise source generators to give to participants during the conference.

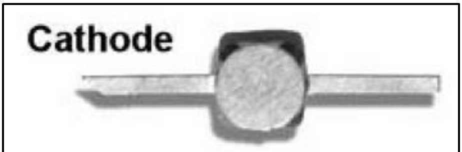


Fig 1: NS-303 noise diode.
Specification:
Case : Metal-ceramic gold plated
Frequency range: 10Hz - 8GHz (max 10GHz)
Output level: about 30dBENR
Bias: 8 - 10mA (8 - 12V)

Tests and measurements are supported by 20 pieces of noise source generators built for this conference, so I think that results are very reliable and repeatable.

2.

Schematic diagram and components

The noise generator uses the NS-303 diode (Fig 1) that is guaranteed up to 8GHz but following the descriptions below it will be very easy to reach 10.5GHz making it possible to use it up to the 3cm band (10.368 GHz), using a diode of moderate price.

The aim of this article is to explain how to build a noise generator using easy to find components.

The circuit diagram, Fig 2, is very simple, the power supply is 28V pulsed AC applied to connector J1 which is normalised in all the noise figure meter instruments. U1 is a low dropout precision regulator to stabilise the voltage for the noise diode to 8 - 12V, the current through the diode can be around 8 to 10mA set by trimmer RV1.

2.1 R3, R4 and R5 resistors

These resistors can be a total of 100 - 220Ω, the total value is not critical, the 0603 case is very important in order to keep the stray capacity as low as possible, it would be better to solder the

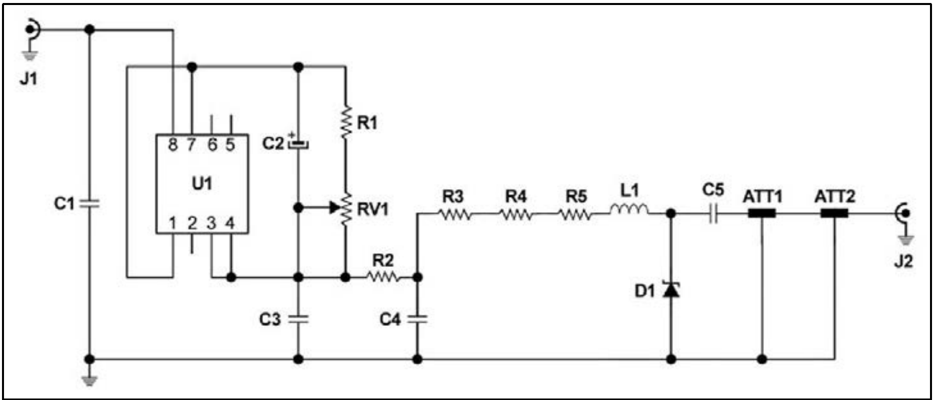


Fig 2: Circuit diagram for a noise source 10MHz - 10GHz using a NS-303 noise diode.

resistors without using copper track on the PCB see Fig 5.

2.2 ATT1, ATT2 Attenuators

These attenuators are very important to obtain an output level of about 15dBENR but more important to obtain an output return loss as low as possible.

In my previous article in issue 1/2007 I described this concept very well, the mismatch uncertainty is the main cause of errors in noise figure measurement [2].

The total value of attenuators ATT1 + ATT2 can be around 14dB, the pictures in Fig 5 – 6 show a 6dB chip attenuator mounted on the PCB and a 7 or 8dB external good quality attenuator, in fact the output return loss depends mainly on the last attenuator (ATT2). The first attenuator (ATT1) can be less expensive and built directly on the PCB because it is less important for the output return loss.

I used a 7 or 8dB external attenuator in order to obtain the best output ENR value because every diode has it's own output noise.

Everyone can change the output attenuator depending on the ENR that is needed; in this project I chose an output level of 15dBENR so the attenuators have a value of 14dB.

2.3 C5 dc block output capacitor

The selection of this capacitor is very important to flatten the output level; in the previous article I only quickly mentioned this fact because we were only talking about 3.5GHz, now in order to reach 10.5GHz I will do a better description.

The DC blocking capacitors are used to

Table 1: Parts list.

D1	NS-303 noise diode	NS-303	J1	BNC female connector	
U1	LP2951CMX SMD SO8 case	LP2951CMX	J2	SMA male panel mount connector Suhner 13SMA50-0-172	SMA-24A
C1	10nF 0805				
C2	1µF 25V tantalum		R1	100Ω 1206	
C3	100nF 0805		R2	18Ω 0805	
C4	1nF 0805 COG		R3, R4, R5	33Ω to 68 0603	
C5	2 x 1nF 0805 COG in parallel	see text	L1	6.8 or 8.2nH 0603	BCG-6n8-A
ATT1	6dB chip attenuator DC-12GHz		RV1	100Ω trimmer multi turn SMD	POT-SM-101-M
ATT2	7 or 8dB external attenuator CD - 12GHz or better DC - 18GHz		PCB	25N or RO4003 or RO4350 30 mils, εr 3.40, 11 x 51mm	see text

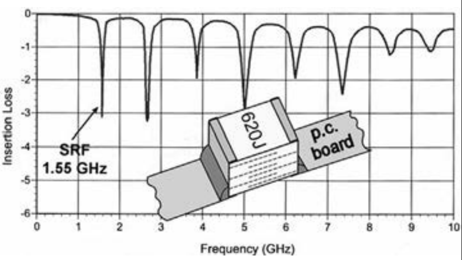
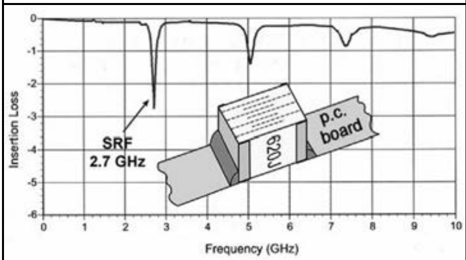
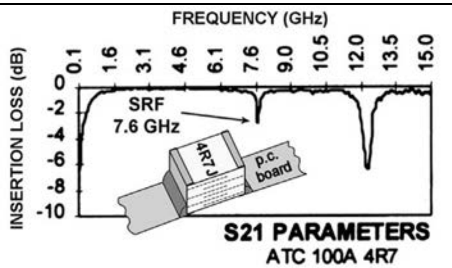
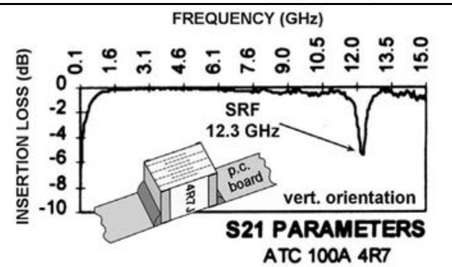
	**ATC100B 62pF 110mils = 3mm** **The manufacturer guarantees an SRF > 900MHz, in fact the network analyser shows an SRF of 1.55GHz with parallel orientation.**
	**ATC100B 62pF 110mils = 3mm** **With the same capacitor the network analyser shows an SRF 2.7GHz with vertical orientation**
	**ATC100A 4.7pF 55mils = 1.5mm** **The manufacturer guarantees an SRF > 4GHz, in fact the network analyser shows an SRF of 7.6GHz with parallel orientation.**
	**ATC100A 4.7pF 55mils = 1.5mm** **With the same capacitor the network analyser shows an SRF 12.3GHz with vertical orientation**

Fig 3: Examples of SRF frequency and its improvement.

block the DC voltage and to pass the RF signal with the minimum possible attenuation. If you use the ATC100A or 100B capacitors they have a very low insertion loss but have the problem of self resonance in ultra wide band applications, the graphs in Fig 3 show 2 examples how you can improve the SRF with vertical orientation.

Fig 3 shows 4 graphs of the SRF frequencies for ceramic capacitors and how to improve the SRF of ATC100A or 100B capacitors for ultra wide band applications.

My decision was to avoid ATC capacitors and to find some capacitors without any SRF and lower Q, after many at-

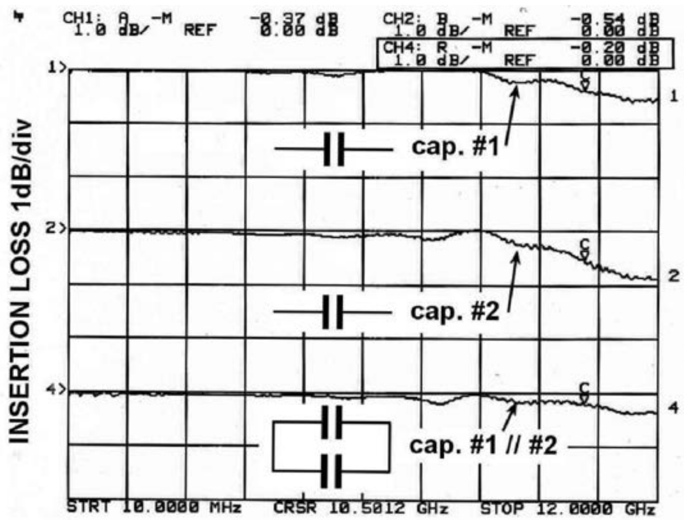


Fig 4: C5 capacitor CCB 1nF. Insertion loss of 1nF NP0 class 1 capacitor with a span from 10MHz - 12GHz, 1dB/div.

It is demonstrated that there are no SRFs in the entire band.

C = 10,5GHz marker

tempts and researches I found that NP0 class 1 multi-layer capacitors with an 0805 case have the best performance referred to low level applications (not to be used in RF power applications or in low noise amplifiers).

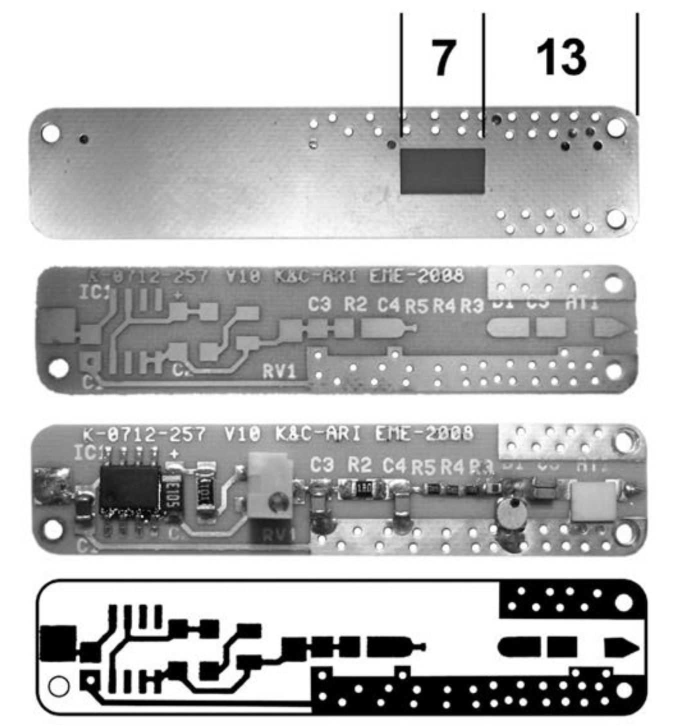


Fig 5: PCB and component layout.

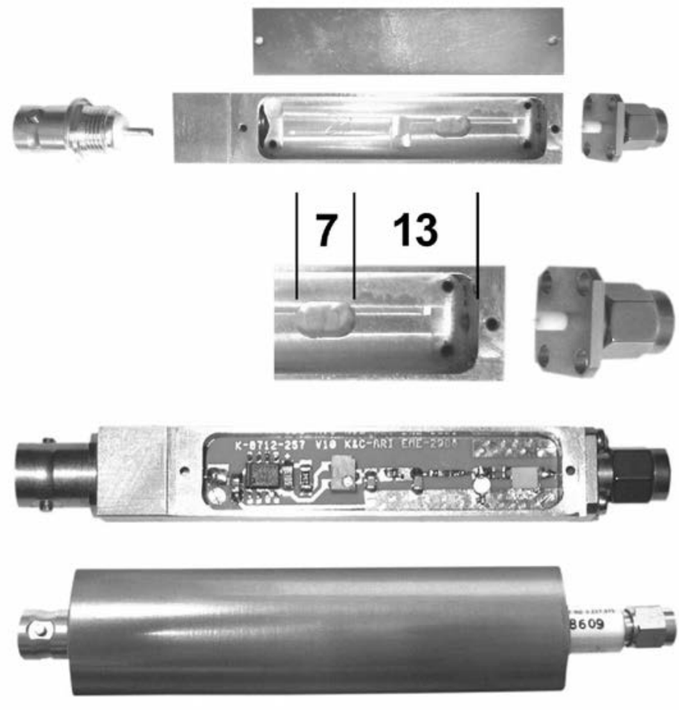


Fig 6: Box and final release.

I choose to put 2 1000pF capacitors in parallel in order to reach a minimum frequency of 10MHz.

For ultra broadband applications the ATC manufacturer has a capacitor of 100nF with 16kHz to 40GHz frequency operation in a 0402 case [3] but I prefer to avoid this special component and use more easy to find one.

In Fig 4 the 1nF capacitors show a low insertion loss, with 2 capacitors in parallel, the marker C shows an insertion loss of about 0.2dB at 10.5GHz that is appropriate for this project at low price.

2.4 PCB

The noise generator is considered a passive circuit so it is not necessary to use very expensive Teflon laminates, moreover the track length is so short that the attenuation introduced makes it unnecessary to use Teflon laminates. I selected ceramic laminate, that is very popular in RF applications, with εr 3.40. It is available in several brands and they all have the same performance, Rogers RO4003 or RO4350, Arlon 25N etc…, with a thickness of 30mils (0.76mm).

In order to easily reach the 10GHz band it is necessary to remove the ground plane around R3, R4, R5 and L1, the size is 7 x 4mm (Fig 5)

2.5 Metallic box

As shown in Fig 6 the components of the noise source generator are enclosed in a very small milled box. Every box behaves like a cavity excited by several secondary propagation modes. For higher frequencies or in medium size boxes the RF circuit will also have many secondary propagation modes at various frequencies. Since every box is different in size, shape and operating frequency the calculation of secondary propagation modes is very difficult. To avoid this problem

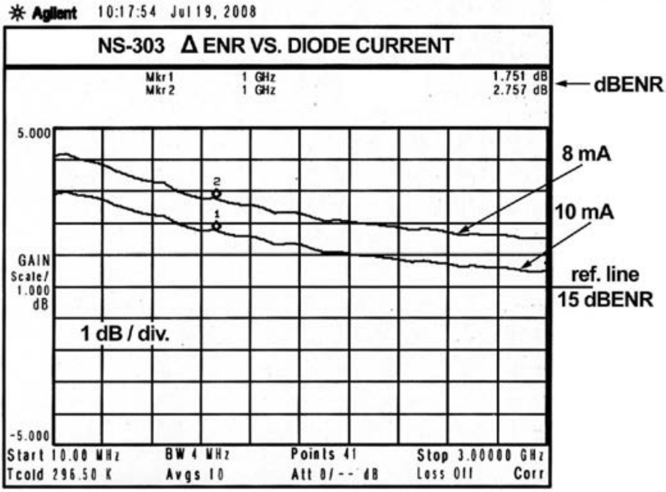


Fig 7: Shows the variation of output noise level vs. current. Span 10MHz - 3GHz, 1dB/div.

microwave absorbers are very often used placed into the cover of the box to dampen the resonance [4].

I selected a very small box in order to avoid both the secondary propagation modes and the microwave absorber; the size that I used gives no trouble up to 10GHz.

If someone wants to increase the size of the box (internal size) it will be necessary to use a microwave absorber.

It is also necessary to remove part of the ground plane in the metallic box by milling a 7 x 4 x 3mm deep slot corresponding to R3, R4, R5 and L1.

3. Bias current

The nominal current should be 8mA, during my tests I found that the output

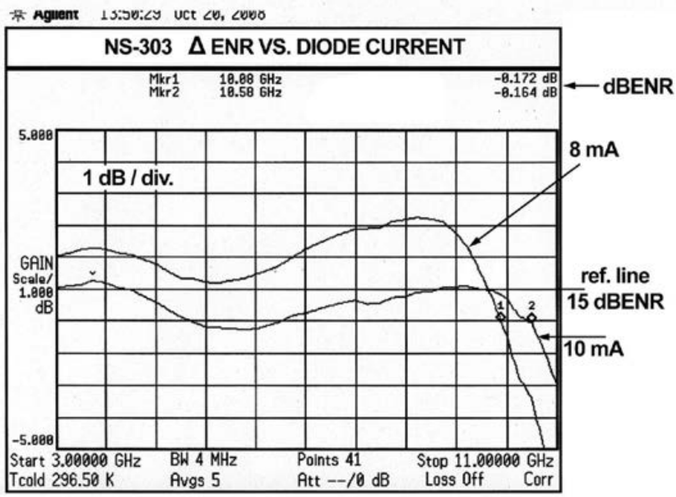


Fig 8: Shows the variation of output noise level vs. current. Span 3GHz - 11GHz, 1dB/div.

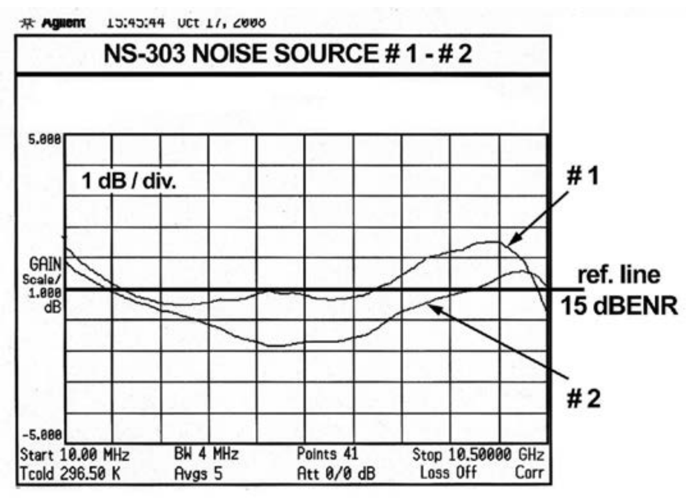


Fig 9: Typical output noise from 2 different noise sources. Span 10MHz - 10.5GHz. Reference line 15dBENR, 1dB/div.

noise level has a quite strange but interesting variation: increasing the diode current the output noise level decreases by about 0.5dB/mA up to about 9GHz, beyond this frequency the effect is exactly the opposite.

Fig 7 shows the difference in output ENR of about 1dB with 8 and 10mA bias current and Fig 8 shows a little improvement of frequency range by about 500MHz with 8 and 10mA bias current.

Fig 8 shows the decrease of about 1dB of ENR level with 10mA instead of 8mA maintaining the same shape in the diagram.

During the calibration it is possible to play with the current to "tune" the ENR level, if you can loose 1dB of ENR level, you will have a more extended frequency range which is exactly what is needed to reach the 3cm amateur radio frequency band (10.4GHz).

The bias current can be measured easily directly on the BNC input connector with +28V DC from a normal power supply; the input current is more or less the same current through the noise diode.

4.

Test results

I tested 20 pieces of the noise source generator and they all gave nearly the same results, the measurement in Fig 9 refer to the use of a 6dB internal attenuator plus a 8dB external attenuator (MaCom or Narda DC - 18 GHz).

A typical output noise level can be 15dBENR +/-1.5dB or 15dBENR +/-2dB or 15dBENR +1/-2dB, a ripple of +/-1.5dB or +/-2dB is a normal values.

The output return loss depends mainly on the external attenuator; I measured a 30dB return loss up to 5GHz, 28dB up to 8GHz and 25 to 28dB at 10GHz.

We have to consider that each 1dB more of external attenuation will improve the output return loss by 2dB, so if you can use, for instance, an attenuator of 17/18dB you will reach a very good return loss (>30/35dB) with an output noise around 5dBENR.

5.

Calibration

Unfortunately the calibration of a noise source is not an easy thing to do.

We know very well that RF signal generators have an output level precision of typically +/-1/1.5dB and this doesn't worry us, we also know that our power meter can reach +/-0.5dB precision or even better. We need a very high precision for a noise generator used with a noise figure meter. For the classic noise source 346A, B and C, Agilent gives ENR uncertainty of +/-0.2dB max. (< 0.01dB/°C). The new N4000 series are used for the new noise figure analyser N8975A with ENR uncertainty of +/-0.15dB max.

In my lab I used the new noise figure analyser N8975A with the precision noise source N4001A so I can guarantee a typical precision of +/-0.1dB up to 3GHz and 0.15dB up to 10GHz.

It means that the calibration must be done with a good reference noise source, it can be a calibrated noise source compared with the one you have built with a low noise preamplifier and a typical noise figure meter.

Example: you have a low noise amplifier with 0.6dBNF and your calibrated noise source indicates a 15.35dB of ENR, now you can change the noise source to the one you have built and for instance you measure 0.75dBNF, it means that your noise source has 15.35 + (0.75dB - 0.6dB) = 15.50dBENR.

6.

Other application

As I described in the previous article [1] that the noise source can be used as a broadband noise generator combined with a spectrum analyser like a "tracking generator" for scalar applications.

This is not a true tracking generator because it works in a different way (read my previous article [1]). The problem here is to reach 3 decades of frequency range, 10MHz to 10GHz, with a flat amplifier of at least 50dB.

Today some MMICs are available that can do this work like ERA1, ERA2, MGA86576 etc…, the problems can be to reach a flat amplification and to avoid self oscillations with such high amplification.

This device can be very interesting because it can be a useful tool to use with any kind of obsolete spectrum analyser to tune filters, to measure the return loss etc… up to 10GHz.

For more information regarding noise source diodes see: www.rfmicrowave.it/pdf/diodi.pdf (from page A 14)

7.

References

[1] VHF Communications 1/2007 "Noise source diodes"

[2] For those who need more information about the mismatch uncertainty in noise figure measurement I suggest 3 application notes:
- Ham Radio, August 1978
- Noise figure measurement accuracy AN57-2 Agilent
- Calculating mismatch uncertainty, Microwave Journal May 2008

[3] R.F. Elettronica web site catalogue www.rfmicrowave.it (capacitors section)

[4] VHF Communications 4/2004 "Franco's finest microwave absorber"