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NEW MILLIMETER WAVE NOISE SOURCES WITH HIGH RELIABILITY

Peter P. Tong, Noel G. Fernandez, Jerry M. Gladstone, Edward G. Cristal

Hewlett-Packard Company, 1501 Page Mill Road, Palo Alto, CA 94304

ABSTRACT:

Two new highly reliable broadband millimeter wave noise sources have been developed. One operates from 26.5 to 40 GHz, R-band, and the other from 33 to 50 GHz, Q-band. The R-band source has an excess noise ratio of 12.1 ±0.4 dB with a reflection coefficient of less than .11 when turned on. The Q-band source has an excess noise ratio of 10 ±1.8 dB with a reflection coefficient of less than .16 when turned on. A new GaAs avalanche diode specifically designed for high noise output and long term reliability was developed for the noise source. The diode with its embedding structure will be described. Reliability data as well as noise measurement techniques and examples will also be presented.

CONTENT:

Reliable noise sources in the R-band (26.5-40 GHz) and Q-band (33-50 GHz) have been developed. Both of them use similar technologies. The circuit block diagram is shown in Figure 1.

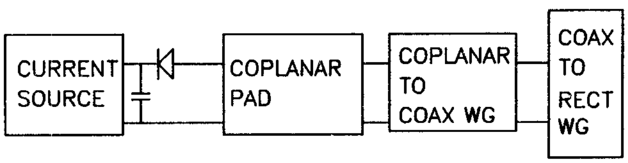

Figure 1. Noise Source Block Diagram

The GaAs noise diode, biased by a current source, is an HP proprietary diode specifically designed for high noise output and reliability. It is a beam lead Schottky diode with a breakdown voltage of about 10 volts and operated at a reverse bias current of 4.6 ma. Under this condition, there will be an avalanche region and a drift region in the diode. The current and impedance in these zones in the diode have been derived by other researchers (1, 2). One unknown factor in the derivation is the dc multiplication factor M. Its definition is shown in Eq. 1. It is the number of holes or electrons created in the avalanche zone due to one hole or electron initially generated there. GaAs has similar hole and electron ionization rates so the multiplication factor is in a very simple form. We quantified it by measuring the low frequency resistance of the diode in avalanche and equating it with the theoretical impedance of the drift and avalanche zone in the diode. The result is shown in Eq. 2.

$$M = \left[1 - \int_0^{La} \alpha \, dx\right]^{-1} \quad (1)$$

where
M = multiplication factor
α = ionization coefficient
La = avalanche zone width.

$$M = \left[\frac{La+Ld}{La}\right] x \left[\frac{1}{\alpha' Jo}\right] x \left[RA - \frac{Ld^2}{2\,\epsilon v}\right] \quad (2)$$

where α' = rate of change of α with respect to the electric field.
Ld = drift zone width.
Jo = dc current density.
R = diode dynamic resistance.
A = diode area.
ϵ = GaAs dielectric constant.
v = saturation drift velocity.

Figure 2 shows the experimental and theoretical results of the noise generated by the diode at 26.5 GHz based on the multiplication factor found above. The solid line is the theory while the dots are the experimental points. These are room temperature results of the diode itself. For temperatures from 25 to 60°C and 0 to 25°C we experimentally found that the excess noise varies by less than 0.5 dB.

In order to minimize the amount of uncertainty in using the noise source in measuring device noise figure, the noise source must be well matched in both its on and off states. However when the diode is turned on and off, its impedance changes. The way we achieved a good broad band match is to put a resistive pad in front of the diode. The coplanar attenuator pad is designed using a tantalum nitride thin film resistor on a sapphire substrate. It

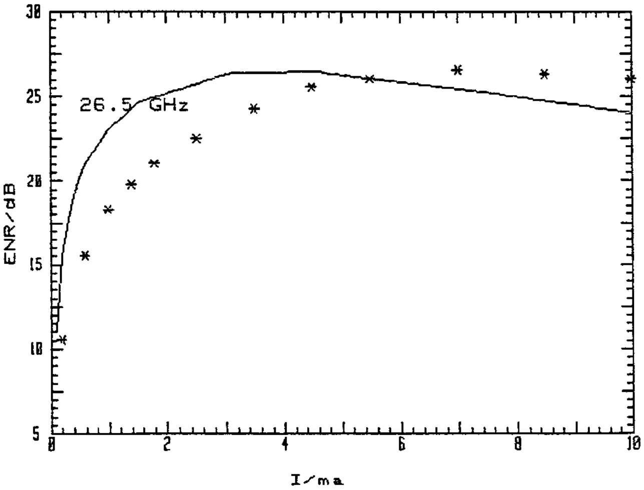

Figure 2. ENR Against Bias Current
——— theory
* experiment

is a π structured resistor designed to have 12 dB attenuation and 50 ohms input. After being attenuated by the pad, the noise signal goes through a coplanar to co-axial and then a co-axial to rectangular waveguide transition. The noise sources need a 27 to 29 volt power supply that can deliver 6 ma to run it. They are temperature-compensated so that the change in noise output against temperature is less than .0065 dB per degree Celsius. The on-off response time of the noise source is less than 10 microseconds. The maximum reverse input power rating is 100 mW.

Figure 3 shows the typical excess noise ratio of both the R and Q band noise source. The R-band source has an excess noise ratio of 12.1 ±0.4 dB, while the Q-band source has an excess noise ratio of 10 ±1.8 dB. They are calibrated based on two standards: one is a room temperature load and the other is a liquid nitrogen load. Figure 4 shows the worst case reflection coefficient of the R and Q band noise sources for both biased on and off. The R-band source has a reflection coefficient of less than 0.11 when it is turned on and 0.15 when it is turned off, while the Q-band source has a reflection coefficient of less than 0.16 when it is turned on and 0.2 when it is turned off.

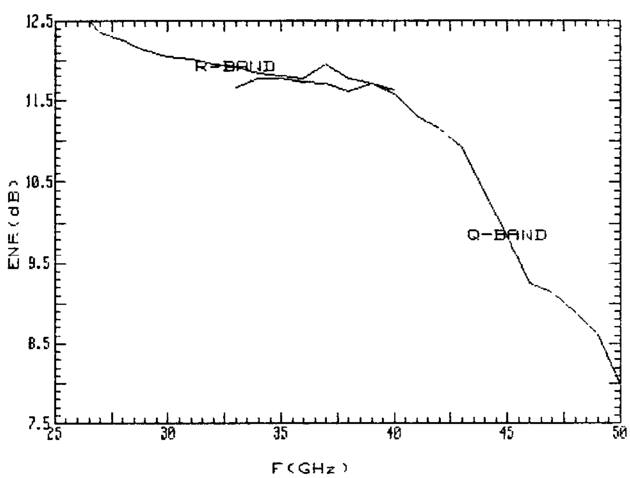

Figure 3. ENR of the Noise Sources

Both the noise diode and the noise source have undergone thousands of hours of reliability testing. Batches of 20 diodes were operated at different elevated temperature in an accelerated life test. At 130°C, there was no failure after 1500 hours and similarly at 150°C after 1000 hours. At 175°C, only one out of twenty failed after 1500 hours of operation and similarly at 200°C after 1000 hours. No

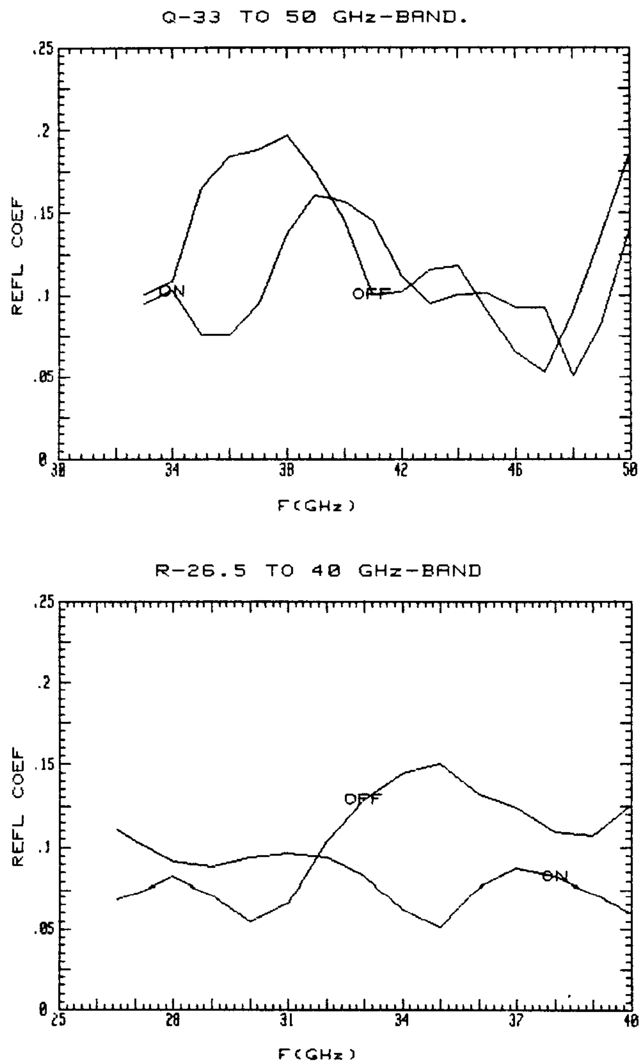

Figure 4. Reflection Coefficient of the Noise Sources

change can be observed in the dc characteristics of the rest of the diodes. Different batches of diodes were also stored at 200°C for 1500 hours and 95% humidity for 1000 hours with no observable change.

Eight R-band and four Q-band sources were life tested at 80°C. The worst case change in the excess noise ratio for R-band after 1500 hr. is less than .15 dB while for Q-band after 900 hr. is less than .25 dB. Units were cycled on and off in 95% to 50% humidity for 5 days and 65°C to -20°C temperature for 6 days. They were zapped by 15000V to simulate electrostatic discharge hazards. They have also been through random vibrations of 2 G rms at 5 to 500 Hz, 10 minutes each axis. The change in noise coming out is always less than 0.3 dB for every test. Table 1 summarizes some of the tests and results. These tests are to the level of Mil-Standard-T28800C.

Table 1. Reliability Data Summary. (Bracket Values = Hours)

DIODE:

1. HIGH TEMP OPERATION AGAINST TIME:
   130C(1.5K), 150C(1K) – 0/20 FAILED.
   175C(1.5K), 200C(1K) – 1/20 FAILED.
2. STORAGE – 200C(1.5K) – 0 FAILED.
3. HUMIDITY – 95%(1K) – 0 FAILED.

NOISE SOURCE:

ENR CHANGE < 0.3 dB

1. HIGH TEMP OPERATION AGAINST TIME:
   80C–R BAND(1500),Q BAND(900)
2. CYCLED ON AND OFF OVER HUMIDITY
   95% TO 50%, 40C, 5 DAYS.
3. CYCLED ON AND OFF OVER TEMP.
   65C TO –20C, 6 DAYS.
4. ESD – 15000 V
5. RANDOM VIBRATION 2Grms 5–500 Hz:
   10 MINUTES EACH AXIS.

The noise sources were then used to measure some devices. Figure 5 shows the noise measurement setup. The local oscillator for the mixer is generated by first amplifying and then multiplying a synthesized signal. Part of the output is fed back to the synthesizer for levelling. The IF signal is amplified by a low noise amplifier and then detected by a HP noise figure meter. A R-band amplifier and a 10 dB directional coupler were then measured and the noise figures of the devices are shown in Figures 6 and 7. Additional measurement techniques and examples will be presented.

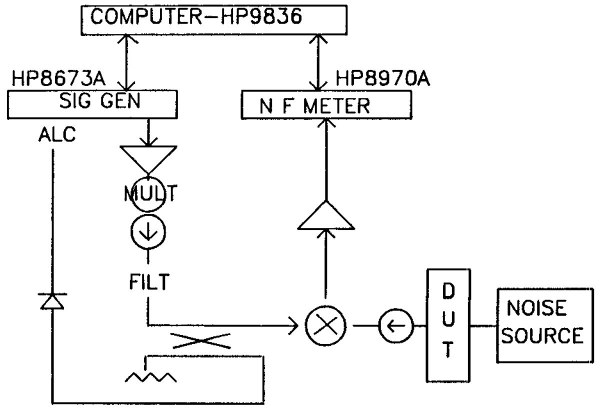

Figure 5. Noise Measurement Setup

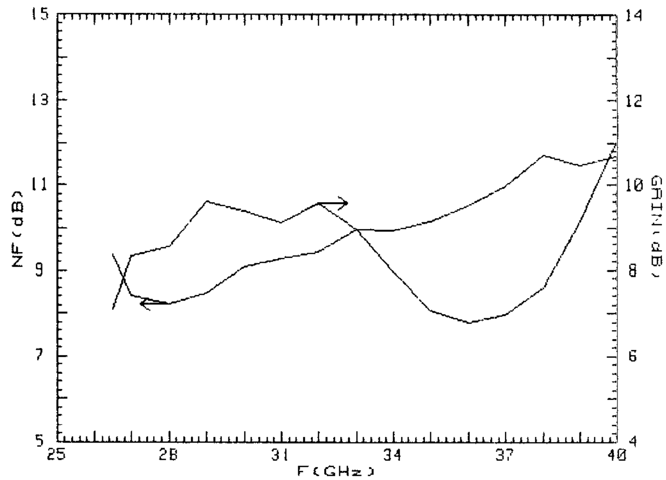

Figure 6. R-Band Amplifier Noise Figure

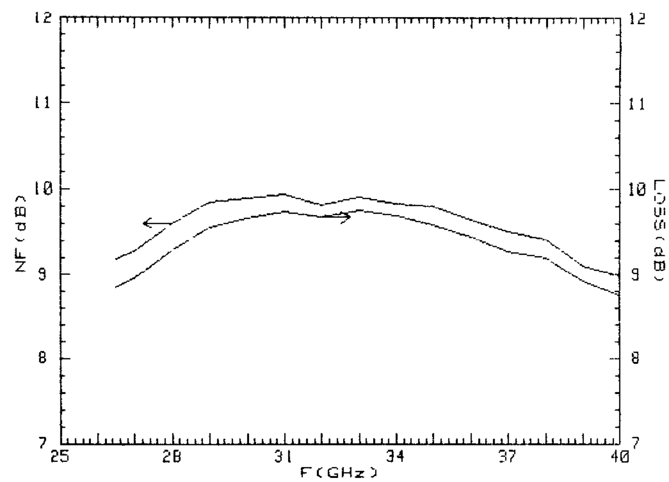

Figure 7. Noise Figure of a 10 dB Directional Coupler

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