Millimeter-Wave Noise Sources at V-Band (50 to 75 GHz)

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Introduction

Since the publication of a paper[1] on the use of avalanche diodes as solid-state noise sources at mm-wavelengths, there have been numerous theoretical and experimental investigations of the noise performance of avalanche diodes.[2-5] Recently, a paper was published on solid-state noise sources that presents the theoretical aspects of these noise sources. Several experimental investigations and their results, which confirmed the feasibility and the design considerations that should be taken into account when dealing with avalanche diodes for the creation of noise at mm-waves, have also been presented.

This paper, based on a previously presented noise theory,[6] presents the production of noise at V-band using IMPATT noise sources and the results for a series of IMPATTs, and three types of waveguide cavity mounts.

Test Set-up and Design Considerations

The measuring system, shown in Figure 1, includes a noise/gain analyzer and is the heart of the test set-up. In this configuration, a calibrated noise tube is used as a standard noise source to calibrate the system over the entire V-band before the actual noise measurement of the IMPATT source can begin. With the help of a V-band sweeping local oscillator, the mixer downconverts the noise power to a fixed IF of 100 MHz, which, once amplified, is fed into the noise/gain analyzer. Next, the IMPATT noise source is routed through to the analyzer, replacing the noise tube assembly, where its value is then compared to the calibrated source, and its excess noise ratio (ENR) is displayed on an oscilloscope or drawn on a plotter. Figure 2 shows the RF assembly's internal parts and noise source that were used in this investigation.

The utilized noise analyzer is capable of taking into consideration the second-stage noise contri-

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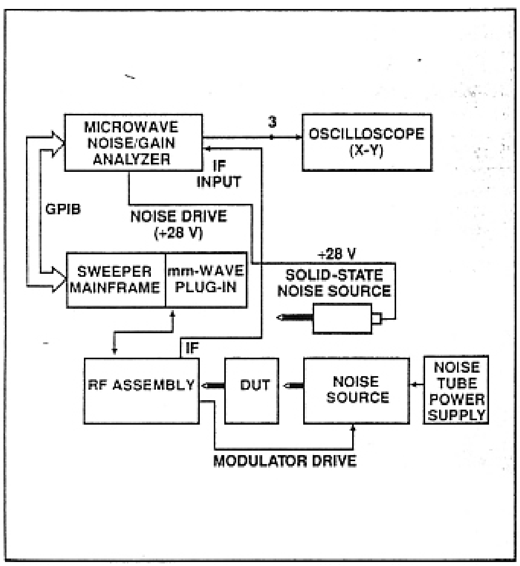

Fig. 1 A schematic diagram of the noise/gain test set.

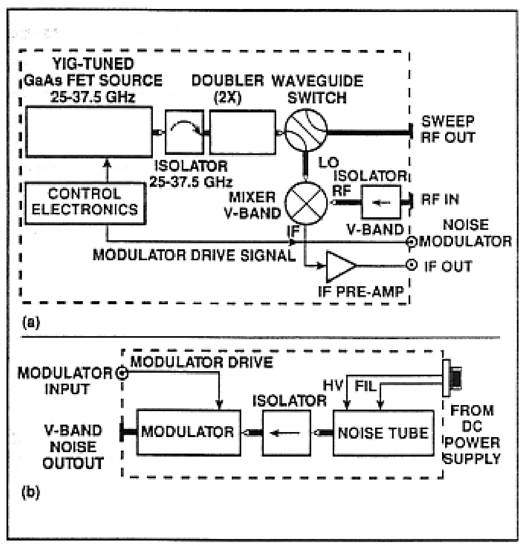

Fig. 2 The (a) noise/gain test set RF assembly and (b) noise source.

butions, and thus automatically eliminates them from the actual measured value of noise figure or power. Noise power is expressed in terms of ENR in dB, which can be displayed across the whole band of frequencies of interest.

Three types of configurations were used in the experiments. Each type has a different height for the cavity section and tuning portion. Figure 3 shows the full-height full-height (FH-FH), the full-height reduced-height (FH-RH), and the reduced-height reduced-height (RH-RH) cavity configurations.

The position of the load was critical to the output noise power (level and flatness) because the cavity tended to act as an oscillator in a nonoptimum position of the load. With this and all other configurations, use of a short circuit instead of a load led to unstable operation, where the noise source generated noise only in a portion of the bandwidth and oscillated at some frequencies within V-band.

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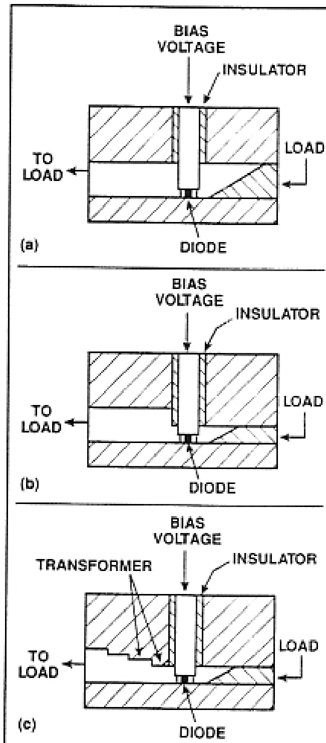


Fig. 3 IMPATT noise-source configurations; (a) FH-FH (b) FH-RH and (c) RH-RH with load.

Selection of an appropriate diode for flat noise generation is extremely important. In addition, the breakdown voltage of the diode, the current I and the diode's cross-sectional area A all play an important role in determining the noise power spectrum of the IMPATT diode.[6] The two significant factors that should be considered in the design of these IMPATT sources are noise power and noise power spectrum flatness over the whole frequency band.

The noise power of the diode, in terms of ENR, is, among other factors, directly proportional to the DC current I. Thus, to obtain a higher ENR value, one may want to increase the DC current. However, while this might be a sound idea, there are important considerations, such as power dissipation and temperature increase, that limit this operation. Therefore, it is best to operate the IMPATT source at a relatively low DC current (around 40 mA or below), and select a relatively high frequency diode that will not promote oscillation.[1]

The flatness of the noise power spectrum is inversely proportional to the breakdown voltage V_b and cross-sectional area A of the diode. Since there is an inverse relationship between the operating frequency of the diode and the breakdown voltage, and the diode capacitance is proportional to the cross-sectional area of the diode, theoretically a high frequency diode (>100 GHz) with the lowest possible capacitance (0.7 to 0.9 pF) should be chosen to satisfy both requirements.

A prototype of this noise source with a built-in DC current regulator was built and is shown in Figure 4. The controlling electronics that function essentially as a constant DC current source are mounted on

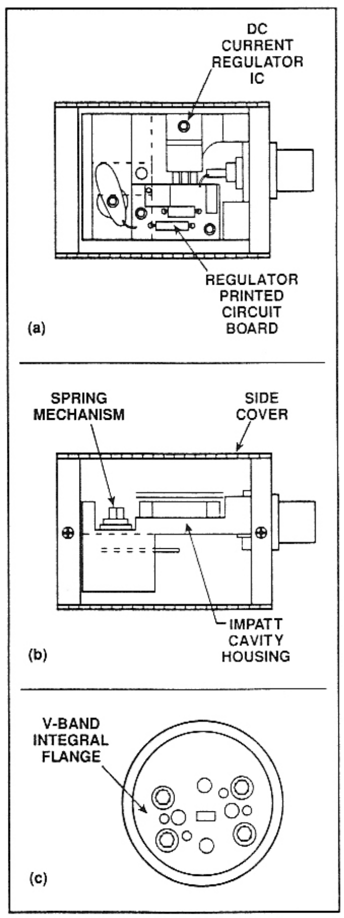
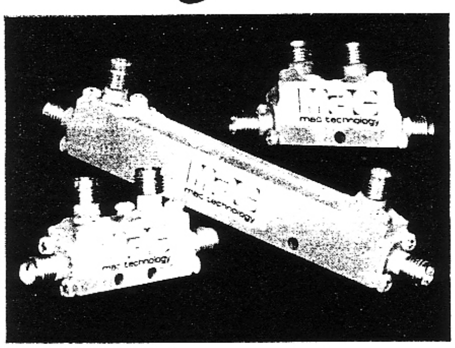


Fig. 4 Prototype of the V-band noise source; (a) top view, (b) side view and (c) WR-15 flange.



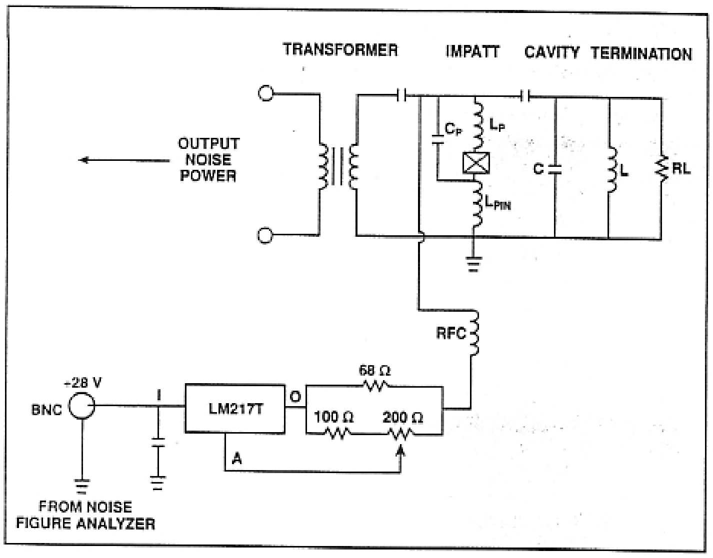


Fig. 5 Noise source equivalent circuit.

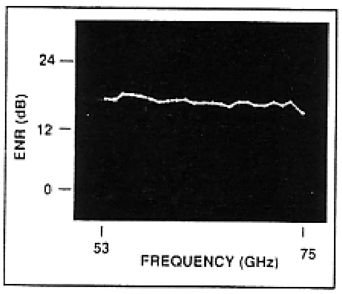


Fig. 6 An ENR plot over the V-band in an FH-FH cavity mount (I_{DC} = 40 mA).

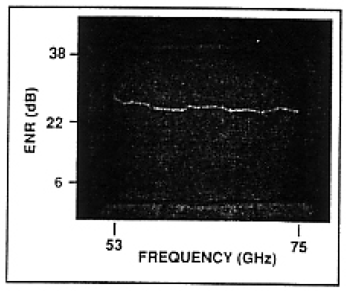


Fig. 8 An ENR plot over the V-band in an RH-RH cavity mount (I_{DC} = 40 mA).

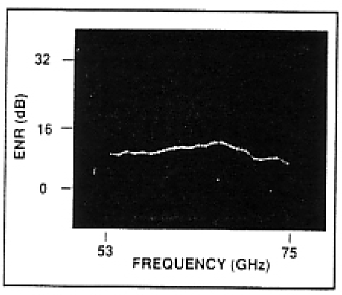


Fig. 7 ENR vs. frequency in a V-band FH-RH waveguide cavity mount (I_{DC} = 40 mA).

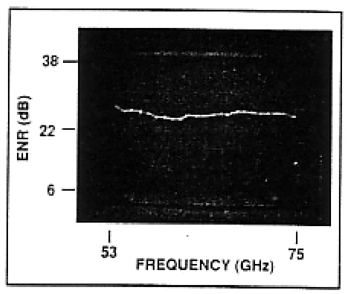


Fig. 9 An ENR plot over the V-band in an RH-RH cavity mount (I_{DC} = 40 mA).

a printed circuit board on top of the cavity configuration. This circuit is energized by the +28 V noise drive pulse signal originating from the noise gain analyzer and feeds the IMPATT diode via the spring and bias pin mechanism. This prototype is self contained and does not need an external power supply to generate noise at V-band, in contrast to a noise tube that requires a bulky and relatively expensive power supply to provide the high voltages necessary to start the gas discharge process.

Figure 5 shows the equivalent circuit of V-band noise source. The noise figure analyzer feeds in a +28 V pulse signal that is converted by a simple circuit into a regulated DC current. This DC current is adjustable by a variable resistor, thus providing any desirable output noise power usually below 30 dB ENR. However, the practical aspects of the noise source are complicated by the existence of the waveguide cavity in which the diode is placed.

Experimental Results

The described experimental results were obtained through intensive investigation of several types of cavity configurations loaded with a proper IMPATT diode. The purpose of these investigations was to propose workable and stable IMPATT-loaded waveguide cavities at V-band to replace the existing high cost, relatively cumbersome gas discharge noise tubes.

In the V-band IMPATT noise sources investigation, several diodes were studied for noise production. The capacitance of these diodes was as small as possible (0.7 to 0.9 pF). Among the many diodes tested, only a few proved to be of reasonable value when the performance characteristics of power spectrum flatness and output noise power value expressed in terms of ENR were considered.

Figure 6 shows a photo of the ENR plot of an IMPATT diode in an FH-FH cavity. Several diodes were used in this configuration and were tested for noise power spectrum flatness and the ENR value for an arbitrary DC current of 40 mA. One of the tested diodes produced 15 ± 1 dB of ENR at 40 mA.

Similar experiments were conducted for an FH-RH cavity and the same IMPATT diode emerged as the best noise producer, 13 ± 2 dB of ENR at 40 mA, as shown in Figure 7. Even though the noise performance of this cavity configuration is far from optimum, its performance characteristic is described here for the record.

Next, an RH-RH configuration was investigated. In this particular case, several diodes proved to be of good performance. Figure 8 shows the noise power spectrum plot of the IMPATT diode with an ENR of 26 dB and ± 1 dB of flatness. Using an RH-RH cavity configuration loaded with an IMPATT produced a relatively high ENR (26 dB) with a good degree of flatness (± 0.5 dB), as shown in Figure 9.

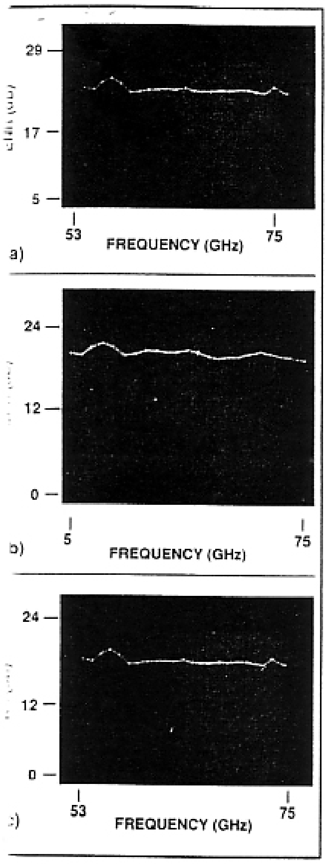


Fig. 10 ENR plot in the V-band n an RH-RH waveguide cavity mount I_{DC} = (a) 20, (b) 10 and (c) 5 mA.

Another category of diodes (0.8 0.9 pF) was explored. Figure 10 ɔws the performance character- c of this type of IMPATT diode ɔer several bias conditions. For = 20 mA, an ENR of 23 ± 1 dB s obtained, while for a bias cur- ıt of 10 and 5 mA, ENRs of 19.5 1 dB and 16 ± 1 dB were ob- ıed, respectively.

ı Resistance Problem

There is considerable uncertain- regarding the performance sta- ty of the IMPATT-loaded wave- de cavities because of a struc- al bias problem, commonly erred to as a pin resistance ıblem, that is found in IMPATT cillator cavities. This bias prob- ı may be caused by the diode ng mounted at an angle and not sh with the surface of the atsink slab, creating a nonuni- m current distribution in the cross-sectional area of the pin and the diode; or by oxidation of the pin and the bellows surfaces due to a high current of 250 to 300 mA (electrolysis). This leads to an increase in resistance of the bias circuit oxidation build-up at the pin-bellows interface and the diode-pin interface, which reduces the DC current to the diode and causes deterioration of the diode's performance. This problem of pin bias resistance manifests itself as frequency jitter and frequency shift in IMPATT-loaded oscillator cavities. Generally, this is believed to be caused by the high temperature operation of the diode. Some stability testing was carried out continuously on an IMPATT-loaded cavity (I_{DC} = 20 mA) for a period of 15 days, with a pulse generator turning the diode on and off at a rate of 20 Hz. The test results indicate that no such effects were observed, and it is highly doubtful that they will occur at all because the noise diodes operate at a very low current of 5 to 40 mA. As a result, there is small thermal generation in the cavity. Also, the diode is not oscillating; therefore, the jitter and frequency shift manifestations are of no major consequence in this type of operation. A 48-hour stability test on these cavity structures produced a change of only 0.1 dB or less in the ENR value.[6]

Conclusion

This paper presented the noise characteristics of numerous diodes using the three types of waveguide cavities that were investigated experimentally. Amongst these three possible waveguide mounts, the RH-RH configuration was found to provide the optimum noise power spectrum in terms of both power level and its flatness over the V-band. As a result of these investigations, noise tubes to a large degree may be replaced by IMPATT-loaded RH-RH waveguide cavity mounts, with good stability of operation in time and temperature.

Acknowledgment

The diodes used in the described experiments include the Hughes DDW75, SPD63, SPD110, 30MMW, SPG20, SPG21, SPW41, SPD49, SPW38, DDV198, and DDW248. The SPW41 was used for the FH-FH, FH-RH and RH-RH configurations. The SPG was used in the investigations of 0.8 to 0.9pF diodes. ■

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