AN IMPATT PUMP FOR A LOW NOISE PARAMETRIC AMPLIFIER

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Abstract

Noise measurements have been made on an IMPATT pumped S-band parametric amplifier. For the properly adjusted pump, no significant increase in noise temperature was observed for interfering signal levels up to -40 dBm, 20 MHz from the noise measurement frequency.

Introduction

Parametric amplifiers are sensitive to pump noise if a high level signal is present. In this event, the noise temperature for other signals is increased by an amount proportional to the power of the high level signal, the gain of the amplifier, and the modulation index of the AM pump noise. It has been estimated that for Gunn and IMPATT oscillators the interfering signal effect due to FM noise is at least 10 dB below the effect for AM noise.[1]

It has been widely believed that the AM noise modulation index of IMPATT oscillators is inherently too large for use in low noise parametric amplifier pumps. We have measured the increase in noise temperature as a function of input signal level for IMPATT as compared to Gunn oscillator pumps. We find that, with proper adjustment, IMPATT pumps can be made to perform almost as well as Gunn pumps. This is an important result because fundamental Gunn pumps cannot deliver sufficient pump power at frequencies above 50 GHz. The ever increasing demand for higher signal frequencies, wider bandwidths, and lower noise is making the use of mm-wave pumps more common.

Noise Measurement

We have used the hot and cold load Y-factor method of measuring noise temperatures. The setup we used is shown in Figure 1. What we measure is the noise temperature of the entire signal path. The largest contribution, however, is for the first stage which is the parametric amplifier in our case. We have made provision to inject the interfering signal at the input port via a directional coupler, and to remove it at the output by means of a narrow band-pass filter and isolator. This is to avoid overloading the succeeding stages of our setup. The provisions for injection and removal of the interfering signal increased the measured noise temperature from about 110 to about 140 K.

The parametric amplifier was adjusted to have the gain versus frequency curve shown in Figure 2. The input levels required to produce an observable noise temperature increment caused gain compression as shown. The noise measurement frequency was 2542 MHz. The input signal could be set to any desired frequency. Its power could be varied up to -20 dBm. The passband of the filter at the parametric amplifier output was 36-MHz wide. We were thus limited to input signals no closer than 18 MHz from the noise measuring frequency.

The 18.2-GHz Gunn pump normally used with the parametric amplifier and the experimental 18.2-GHz IMPATT oscillator could be easily interchanged and adjusted to give identical performance at low levels of input signal.

The IMPATT Source

The IMPATT cavity is similar to the design attributed by Kenyon[2] to Kurokawa.[3] We designed the WR-42 waveguide cavity to be a full wavelength long rather than a half wavelength in order to make more room for the fine tuning screw. This choice of cavity mode (TE102) necessitated the placing of a narrow band-pass filter and isolator at the output of the cavity in order to remove a peak in the noise spectrum at the TE101 resonant frequency. This noise peak caused elevation of the parametric amplifier noise temperature with no signal present probably because the peak happened to be near the idler frequency.

The coupling to the load is via a variable twist joint.[4, 5] An iris could be placed in the plane of the twist. This type of coupling can be treated as if it were a length of line with a iris in it. The equivalent iris diameter and line length vary with twist angle. In the special case of a real iris of diameter equal to the waveguide height centered in the twist plane, the electrical length of the cavity is independent of the twist angle. With this configuration, lower loss is obtained but maximum coupling is limited to that of the iris with zero twist.

The coaxial line which passes through the cavity has an impedance of 76.8 ohms. This choice minimizes skin effect losses in the line. The outer diameter was 0.281-inch, about two-thirds the width of the WR-42 waveguide. Dc bias is applied to the center conductor beyond a polyiron termination which presents a matched load at microwave frequencies. Embedded in the polyiron is a bias circuit choke of the type recommended by Brackett.[6] We found that there must be sufficient polyiron between the diode and the choke to absorb any reflections from the choke. Otherwise, the interfering signal effect increases.

Various lab type power supplies were used to provide the dc bias. It did not seem to make any difference what power supply was used. No difference in particular was noticed between constant current and constant voltage power supplies.

The diodes used were Raytheon Micro State MS856B and MS858B GaAs IMPATT diodes. Hewlett-Packard HP 5082-0657 silicon double drift IMPATT diodes were tried but we were unable to obtain oscillation. The HP diodes had an optimum operating frequency of about 14.3 GHz and had been operated by Hewlett-Packard at 18.0 GHz in a different type of cavity.

Results and Discussion

Figure 3 is a log-log plot of the increase in noise temperature as a function of interfering signal level for several pump and measurement conditions. The three IMPATT curves are for the same diode. The top two relate to a set of measurements with a fixed IMPATT pump and interfering signals at the indicated frequencies. By making adjustments on the IMPATT oscillator, the noise temperature increment could be greatly reduced as indicated in the third curve which approaches the noise performance obtained with the Gunn source. All the curves approximate to straight lines with a slope of unity in agreement with a first order theory.[1] The performance difference between the various curves is a result of differences in pump noise content at modulation frequency equal to the separation between the signal and the noise measurement frequency.

Data showing the variation of noise temperature increment with the frequency of the interfering signal is presented in Figure 4 in which each curve is labeled by the signal level in dBm. Measurements in the central portion between 2520 and 2560 MHz were not made because in this band, the amplified interfering signal would not be blocked by the output filter. The rapid rise as the signal frequency approaches the noise measurement frequency indicates a similar rise in the noise spectrum of the IMPATT oscillator as the modulation frequency approaches zero. The rise is faster than 1/f and is probably characteristic of the diode used. Further investigation of this effect is now in progress. It is of interest to note that the noise data given by Hewlett-Packard for their silicon double drift IMPATT diodes does not show any rise at low modulation frequencies.

As mentioned previously, adjustments on the cavity had dramatic effects on the interfering signal's effect on noise temperature. The effects of various adjustments are described later in the paper. After each adjustment the frequency of the oscillator was brought to the correct value by means of the fine tuning screw. The correct pump power was maintained by adjustment of a variable attenuator in the pump line. (See Figure 1.)

Effect of Diode Position in the Coaxial Line

Our data does not show much difference in noise performance for diode positions a half wave length apart in the coaxial line. But, there are considerable changes for small shifts of the diode near positions for maximum output. If the diode is closer to the wave-guide axis than this, the effect of the interfering signal is increased. If the diode is moved the other way, a small decrease in the interfering signal effect is observed.

The Effect of Transformer Impedance

Between the diode and the 76.8-ohm coaxial line, we used various quarter-wave transformers. The impedance of the quarter-wave sections ranged from 20.6 to 48.6 ohms. We found little difference in either the minimum interfering signal effect or maximum output power obtainable with any of these.

The Effect of Output Coupling

We have found in most instances that the smaller the output coupling (the nearer to 90 degrees twist), the higher the interfering signal effect. If the coupling is increased too much, the diode stops oscillating. The least interfering signal effect is obtained by starting the oscillator, then increasing the coupling to a value higher than would allow the diode to start oscillation. This is an easy adjustment with the rotatable step-twist output coupling.

It may seem strange that increasing coupling to the load improves noise performance since the increased coupling also lowers the Q of the cavity. Apparently the reason is that the AM noise is little effected by variation of the external Q, but is increased by excessive RF current amplitude. This would be increased by reducing the coupling to the load. It is of interest that the negative resistance for bias circuit oscillations behaves in the same way.[6]

The Effect of Bias Current

Each diode seems to have an optimum bias current for least AM noise. In many cases, this current apparently was above the maximum operating current recommended by the manufacturer.

Conclusions

A common type of specification for parametric amplifiers is that all performance parameters should be met below some level of input signal. This level is often -40 dBm. Our parametric amplifier shows gain compression at input levels of -40 dBm and above. At -40 dBm, 20 MHz from the noise measurement band, there is about a 3 percent increase in noise for the Gunn pump and less than a 10 percent increase for the properly adjusted IMPATT pump. The theory[1], with which our data agrees well, shows that the interfering signal effect is proportional to gain. Our data is for gain of about 17 dB. Operation of the parametric amplifier at 7-dB gain would shift the curves of Figure 3 downward by 10 K. Therefore, we are confident that the properly adjusted IMPATT pump would allow the parametric amplifier to meet the specifications of most users.

IMPATT diode noise usually has a flat spectrum with only a slight rise near the output frequency. The rise for low modulating frequencies is dependent on the quality of the semiconductor junction. We observed a strong increase as the signal frequency approached the noise measurement frequency. This suggests that we can expect considerable improvement in IMPATT noise performance as the manufacturers improve the quality of their product.

Although we used GaAs IMPATT diodes in this experiment, we believe that silicon IMPATT diodes would probably work as well. Quality control in the manufacture of silicon devices is much better than for GaAs devices. This should make up for any intrinsic advantage that GaAs may have over silicon.

The Gunn oscillator normally supplied with the parametric amplifier performed slightly better than our best adjusted IMPATT. We anticipate that the use of IMPATT pumps for parametric amplifiers will usually be restricted to the range of pump frequencies above 50 GHz where inadequate power is obtainable from Gunn oscillators and more than enough power can be obtained from IMPATT oscillators. We are confident that in this range of pump frequencies, the added cost and complexity of pumps using Gunn oscillators and frequency multipliers can be saved by substitution of IMPATT pumps. There will be little or no penalty in noise performance in the presence of strong input signals.

References

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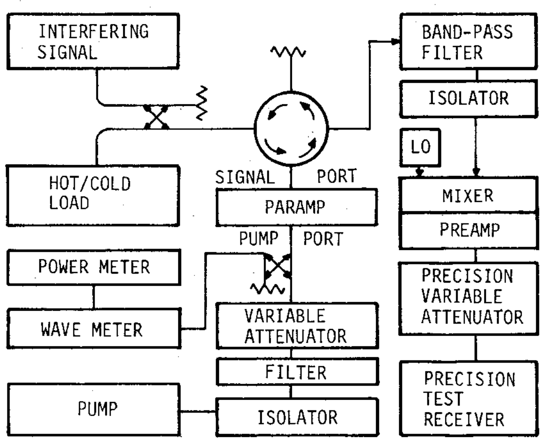

Fig. 1. The noise measurement setup

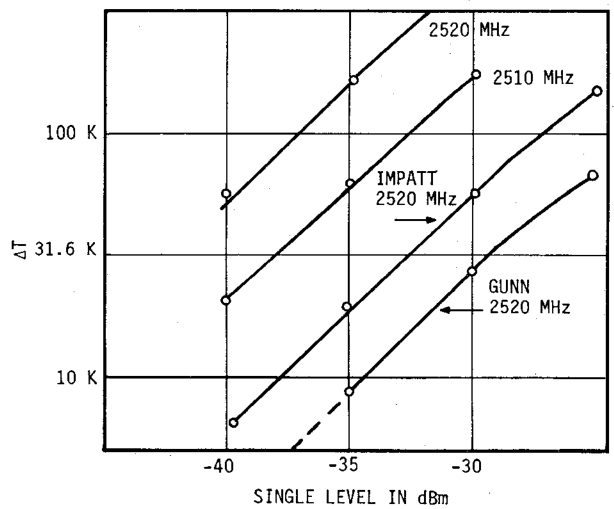

Fig. 3. Noise temperature increment versus signal level for various conditions

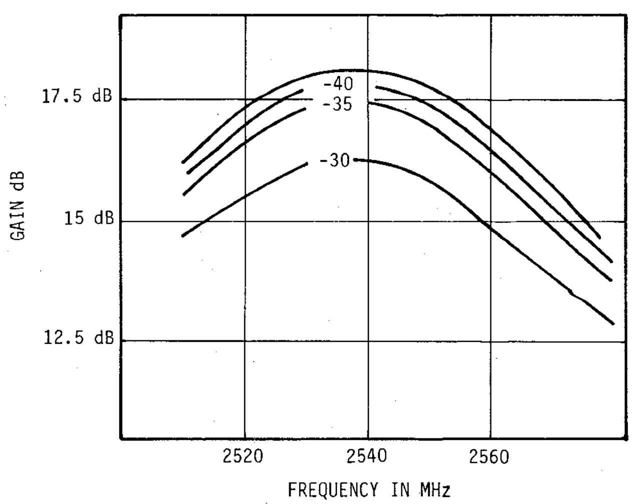

Fig. 2. Gain versus frequency for various signal levels

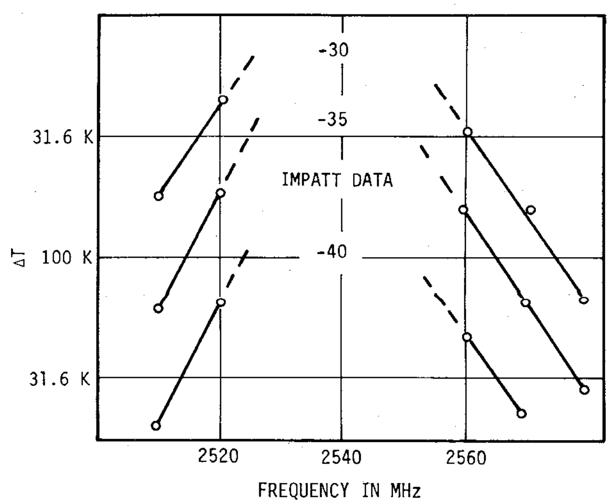

Fig. 4. Noise temperature increment versus frequency for various signal levels