IMPATT PUMP SIDEBAND NOISE AND ITS EFFECT ON PARAMETRIC AMPLIFIER NOISE TEMPERATURE

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Abstract

This paper describes an investigation of the amplitude modulation noise sidebands of 38 GHz silicon IMPATT oscillators and the effect these noise sidebands have on the excess noise temperature of parametric amplifiers.

It is shown that the noise temperature may be affected under both large- and small-signal conditions to an extent which depends on the level of pump sideband noise. Simple relationships between easily measureable amplifier properties and pump noise power are given which enable the performance of any combination of pump and amplifier under the two signal conditions to be predicted.

A method which simultaneously eliminates the small-signal effect and reduces the large-signal effect to an acceptable level is proposed and demonstrated to be a practical solution.

Introduction

In 1972, Clunie et al[1] obtained satisfactory IMPATT pumping of a low-noise room-temperature wideband parametric amplifier then under development in this laboratory. The only consequence of replacing the klystron pump with an IMPATT was an acceptable level of noise degradation in the presence of a large input signal. Subsequent experience with these pumps, however, brought to light a more serious type of degradation which affected the small-signal performance of the amplifier. Not all combinations of pumps and amplifiers exhibited this effect, but the worst combinations resulted in degradations of some 1000 K or more. It was with the objects of understanding the causes of these two types of degradation and overcoming their effects that the following work was undertaken.

Parametric Amplifiers and IMPATT Pumps

The amplifiers examined throughout these experiments were of the type using the modified Pearson-Lunt double-diode circuit[1-4]. The idler-loop resonance frequency was 31 GHz, the gain 13 dB, the ½ dB instantaneous bandwidth 500 MHz at a centre frequency of 7.5 GHz. Most of the measurements were made on such single-stage amplifiers while some were made on a 26 dB-gain amplifier comprising two of these single stages in cascade and pumped by a single IMPATT oscillator.

The IMPATT pumps were AEI Type DA 1166G oscillators each with its own isolator. These oscillators use single-drift silicon diodes, mounted in a cap-type circuit ($Q_L \simeq 100$), tunable from 38.0 to 38.5 GHz and capable of producing about 150 mW.

Small-Signal Effect

Experiments proved that far-from-carrier pump AM noise was entering the parametric amplifier at idler frequencies; therefore, a three-pole pump-line bandpass filter was constructed to have a 0.1 dB-ripple bandwidth just greater than the pump tuning range. This filter completely eliminated any small-signal degradation and furthermore placed no constraints on parametric amplifier alignment.

This then afforded, at least, a temporary but very effective solution to the small-signal degradation problem. In order to understand why the filter was so effective it was felt necessary to measure the IMPATT oscillator AM noise far from carrier. Because by far the greater effect was due to noise power at low-idler frequencies, the measurements were confined to the region from 1 to 10 GHz below the pump carrier frequency.

Measurement of far-from-carrier pump noise

Amplitude modulation sideband noise measurements were carried out using the equipment shown in the block diagram of Figure 1. The RF circuit is similar to that used by Scherer[5] except that the carrier power is suppressed by a three-port circulator and bandpass filter arrangement instead of a high-Q cavity. The carrier and close-to-carrier noise sidebands are absorbed in the matched load on port 2 while the far-from-carrier noise sidebands are reflected to appear at the output port. The noise power can then be compared with the power from the noise tube, over a range of pump bias currents and a range of pump frequencies without having to re-tune the noise gear. To measure closer to carrier it was necessary to replace the bandpass filter arrangement with a high-Q cavity and matching element. This extended the range of measurements to within 50 MHz of the carrier frequency.

Typical measurements obtained with this apparatus are shown in Figure 2, where the pump noise power is now expressed as a noise-to-carrier ratio N/C (dB/Hz). It will be seen that large differences occur between pumps, especially over the amplifier low-idler region, referred in Figure 3 to the amplifier passband. This clearly shows the effect of change of carrier frequency. The carrier frequencies and bias currents chosen were therefore appropriate for pumping available amplifiers.

The amplifier excess noise temperature T_e was measured with both klystron and IMPATT pumps. The increase of excess noise ΔT_e obtained with the IMPATT pump showed some correlation with the N/C ratio of the pump but it was clear that differences existed between amplifiers in their ability to reject pump noise power at idler frequencies.

Measurement of parametric amplifier idler conversion

Each amplifier was klystron pumped under the same conditions as before except that idler power was injected into the pump line via a high directivity coupler. The resulting power in the amplifier signal passband was recorded for a known injected idler power and frequency. Saturation effects were avoided.

The results are shown in Figure 4 as the ratio of injected idler power to output signal power versus frequency. This ratio we call the conversion loss A of the amplifier. The curves labelled Amplifier I and Amplifier III are from different 13 dB-gain stages, while Amplifier II is from a two-stage 26 dB-gain amplifier which had idler power injected into the first-stage pump line only. It is therefore necessary to add 13 dB to the conversion loss in the latter case in order to compare this result with the other two.

Clearly there are differences in conversion loss between amplifiers and the loss varies across the passband of any amplifier.

Small-signal theory

It is now possible to consider a simple down conversion mechanism which relates pump noise and amplifier conversion loss to degradation produced in T_e.

The following equation is derived:

$$10 \log \Delta T_e = N/C + P_o - A - 10 \log k - G$$

where P_o is pump power in dBm,
G is the amplifier gain in dB,
A is expressed in dB
and k in mJ/K.

Figure 5 shows the good agreement obtained between measured and calculated results for two typical cases. Amplifier I was pumped by IMPATT 2 at 38.28 GHz, while Amplifier II was pumped by IMPATT 2 at 38.50 GHz. These and other results indicate that the down conversion mechanism is sufficiently well understood to predict the behaviour of any pump on any amplifier.

Large-Signal Effect

It has been noted[1,6] that the presence of a large input signal can significantly degrade parametric amplifiers using IMPATT pumps, therefore noise measurements were made on an amplifier with pumps of known but different AM sideband N/C ratios, when a simulated transmitter signal was injected 150 MHz above the 1 dB passband of the amplifier. This represents a worst case frequency difference for one of our applications.

Figure 6 shows the marked difference in pumps. The worst IMPATT labelled -140 dB/Hz raises the amplifier T_e to 180 K when the simulated transmitter power is increased to -40 dBm, while IMPATT labelled -156 dB/Hz only degrades the amplifier T_e by 2 K at this same power level.

An extension of the small-signal theory to cover this case results in the equation:

$$10 \log \Delta T_e = N/C + P_{so} + 10 \log\beta - 10 \log k - 10 \log G$$

where $\beta = \dfrac{\delta G}{G} \Big/ \dfrac{\delta P_o}{P_o}$

G is the in-band gain of the amplifier,
and P_o is the pump carrier power in mW.

P_{so} is the power of the injected signal out of the amplifier in dBm. The value of pump N/C used is determined by the separation between the large-signal frequency and the frequency at which ΔT_e is to be measured.

With a measured value of 10 logβ of 4.07, a receiver frequency of 7.75 GHz, and the associated value of pump noise for a transmitter at 7.9 GHz, ΔT_e may now be calculated for various transmitter powers. Figure 6 shows the good agreement obtained between calculated (small squares) and measured values. It should be pointed out that the large variations in N/C of the worst oscillator are unusual. A more typical variation is exhibited by the broken line in the close-to-carrier region of Figure 2.

As in the small-signal case this and other easily verified examples indicated that this simple treatment is of considerable practical use.

Discussion

The small-signal degradation of parametric amplifiers can be reduced by:

(1) improving pump N/C at amplifier idler frequencies,
(2) increasing the amplifier conversion loss A.

The first has been achieved by the use of a suitable pump-line filter. The second can be realised by optimising the inherent filtering of the double-diode amplifier by careful balancing of the varactors. Figure 4 shows the improvement obtained when Amplifier I was optimised. While this technique looks very attractive and will be investigated further, the immediate and practical solution of the pump-line filter is preferred as the noise profile of the pump can be tailored to suit any signal frequency. Figure 2 illustrates the effect of two types of filter.

The large-signal effect can also be reduced significantly if narrow-band pump filters are used. If the pump frequency is situated at the low frequency end of the filter bandpass sufficient attenuation of pump noise can exist, certainly at frequencies greater than 100 MHz from carrier to allow satisfactory amplifier performance under large-signal conditions.

Conclusion

Simple expressions relating the IMPATT pump AM sideband noise to the performance of a parametric amplifier give sufficiently good agreement between calculated and measured results to enable the behaviour of any amplifier with any pump to be predicted.

A pump-line bandpass filter reduces sideband noise to a level which allows an IMPATT pump to be used even in stringent satellite communication applications.

Although the work described here has been carried out using 38 GHz pumps, the principles have since been successfully applied to a lower noise parametric amplifier IMPATT pumped at 50 GHz.

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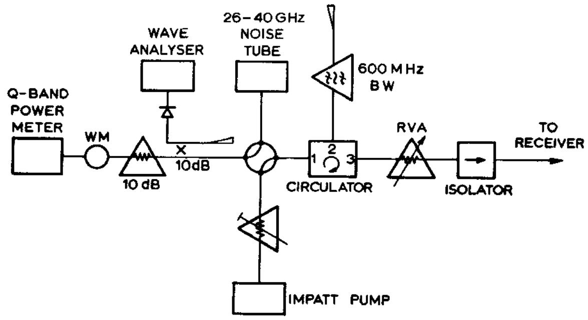

FIGURE 1. Impatt sideband noise measurement: R.F. circuit.

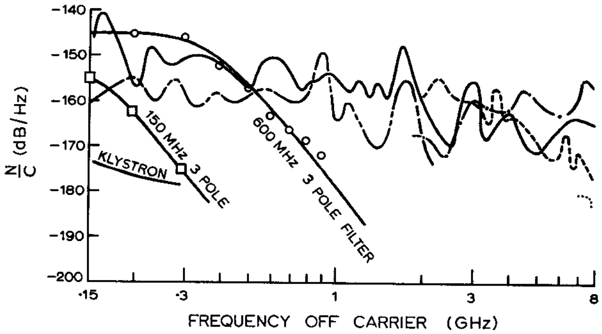

FIGURE 2. Impatt sideband noise.

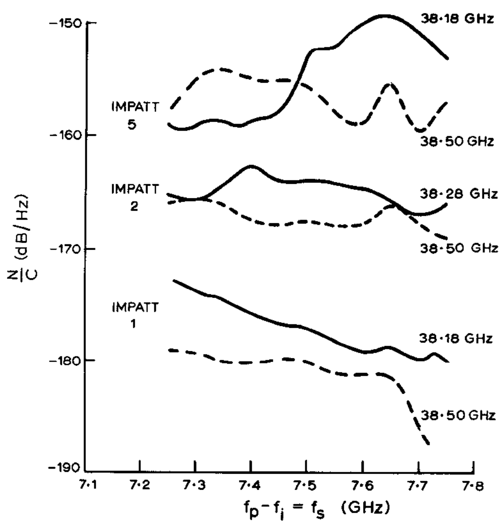

FIGURE 3. Impatt sideband noise expanded idler region.

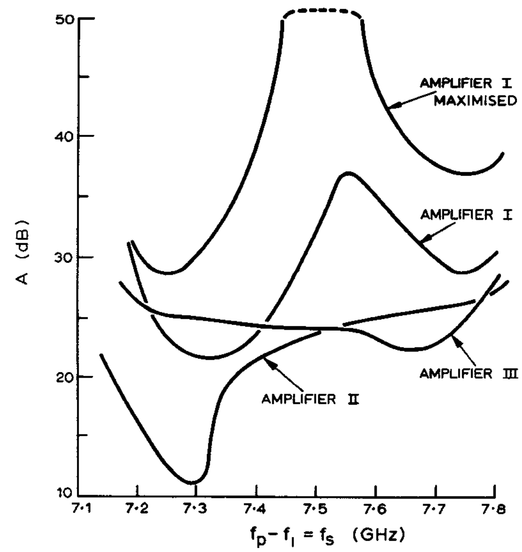

FIGURE 4. Paramp conversion loss.

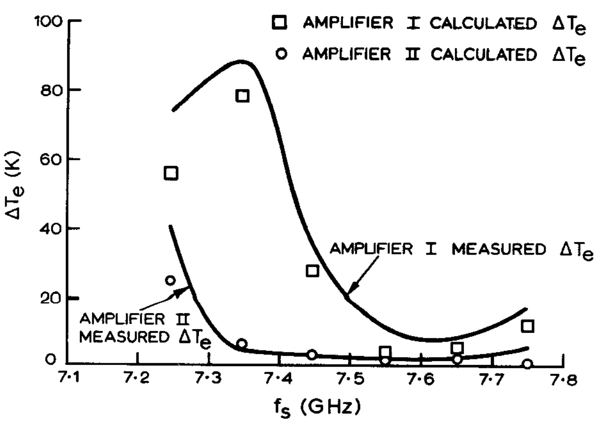

FIGURE 5. Paramp noise degradation.

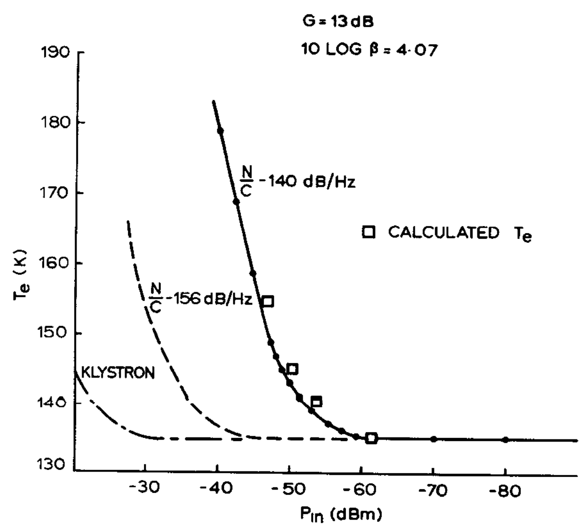

FIGURE 6. Effect of transmitter leakage on paramp noise.