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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.**

I. 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 pump noise. From the theory [1], [8] of parametric amplifier pump noise transfer

$$\Delta T_{\mathrm{AM}}(f_1,f_2) = k_{\mathrm{AM}}(f_2) I_{\mathrm{AM}}(|f_1 - f_2|) G(f_2) P_s \qquad (1)$$

and

$$\Delta T_{\mathrm{FM}}(f_1,f_2) = k_{\mathrm{FM}}(f_2) \overline{\Delta f^2}(|f_1 - f_2|) G(f_2) P_s \qquad (2)$$

where

- $\Delta T_{\mathrm{AM}}(f_1,f_2)$ noise temperature increment at noise measurement frequency f_1 due to AM pump noise and an input signal at frequency f_2;
- $\Delta T_{\mathrm{FM}}(f_1,f_2)$ noise temperature increment at noise measurement frequency f_1 due to FM pump noise and an input signal at frequency f_2;
- $k_{\mathrm{AM}}(f_2)$ AM noise sensitivity coefficient of the parametric amplifier at frequency f_2;
- $k_{\mathrm{FM}}(f_2)$ FM noise sensitivity coefficient of the parametric amplifier at frequency f_2;
- $I_{\mathrm{AM}}(|f_1 - f_2|)$ normalized power spectral density of AM modulation of the pump at modulating frequency $|f_1 - f_2|$; the AM power in a sideband of bandwidth B at modulating frequency f_m is $BP_pI_{\mathrm{AM}}(f_m)$ where P_p is the total pump power;
- $\overline{\Delta f^2}(|f_1 - f_2|)$ mean square frequency deviation per unit bandwidth of the pump for modulation frequency $|f_1 - f_2|$;
- $G(f_2)$ gain;
- P_s power level of the input signal.

The value of k_{FM} is small enough [1] that for typical oscillator noise spectra, the ratio $\Delta T_{\mathrm{AM}}/\Delta T_{\mathrm{FM}}$ is at least 10 dB. The effect of pump noise is to modulate the gain of the parametric amplifier. Gain modulation at f_2, the high-level signal frequency, causes noise sidebands in the noise measurement band at f_1. Thus the effect is strongly dependent on f_2.

In spite of some evidence to the contrary [9], it has been widely believed that the I_{AM} of IMPATT oscillators is inherently too large for use in low-noise parametric amplifier pumps. ΔT was measured as a function of P_s for both IMPATT and Gunn oscillator pumps. With proper adjustment a GaAs IMPATT pump was made to perform almost as well as a Gunn pump, and within tolerable limits on noise. 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 millimeter-wave pumps more common. GaAs IMPATT oscillators will be able to fill the need for solid-state millimeter-wave pumps without resort to frequency multiplication.

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II. NOISE MEASUREMENT

The hot and cold load *Y*-factor method was used to measure noise temperatures. The setup is shown in Fig. 1. What is measured is the noise temperature of the entire signal path. The largest contribution, however, is for the first stage which is the parametric amplifier. The interfering signal was injected at the input port via a directional coupler and removed at the output by means of a narrow bandpass filter and isolator. This is to avoid overloading the succeeding stages of the setup. The provisions for injection and removal of the interfering signal increased the measured noise temperature from 110 to about 140 K. The parametric amplifier was adjusted to have the gain versus frequency curves shown in Fig. 2. The input levels required to produce an observable noise temperature increment caused reduced gain as shown. This gain reduction is a measure of the third-order intermodulation due to the high-level input signal. 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. Measurements were thus limited to input signals no closer than 18 MHz from the midband noise measuring frequency.

The 18.2-GHz Gunn pump normally used with the parametric amplifier, and the experimental 18.2 IMPATT oscillator could be easily interchanged and adjusted to give identical performance at low levels of input signal. The parametric amplifier required about 100

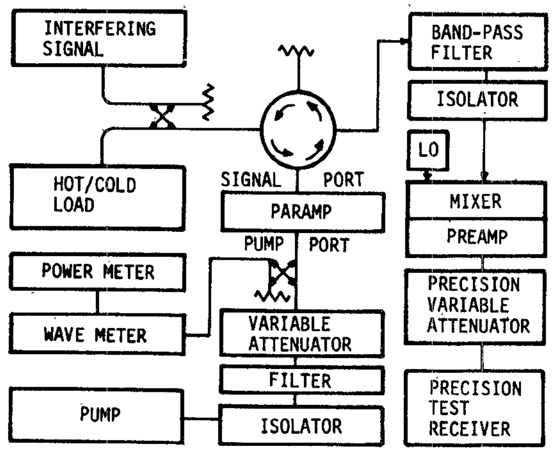

Fig. 1. The noise measurement setup.

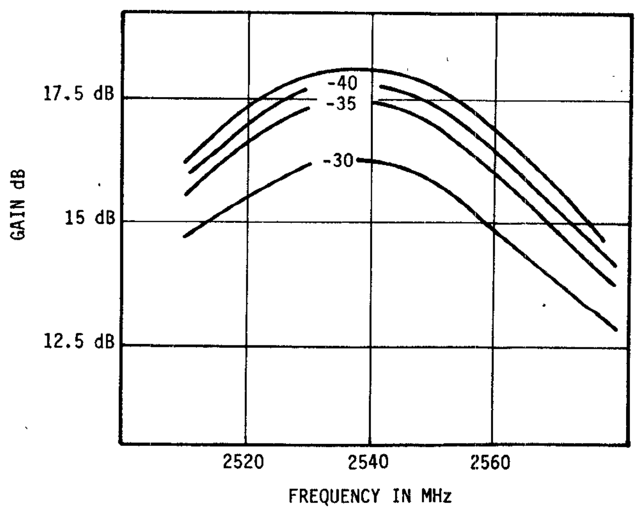

Fig. 2. Gain versus frequency for various levels of interfering signals.

mW of pump power. This was adjusted by means of a variable attenuator.

III. THE IMPATT SOURCE

The IMPATT cavity shown in Fig. 3 is similar to the design attributed by Kenyon [2] to Kurokawa [3]. The WR-42 waveguide cavity was designed 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 bandpass 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.

A coax/waveguide coupling adjustment was provided as shown in Fig. 3. It was found, however, that there were sufficient other adjustments that this was not needed. Since a higher output power was always obtained with the coupling screw all the way out the cavity was always operated in this condition. The coupling to the load is via a variable-twist joint [4], [5]. An iris could be placed in the plane of the twist.

The coaxial line which passes through the cavity has an impedance of 76.8 Ω. This choice minimizes skin-effect losses in the line. The outer diameter was 0.281 in, 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]. It was 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. In particular, no difference was noticed between constant-current and constant-voltage power supplies. This may be due to the bias circuit filter [6] which is a parallel-*RL* circuit designed to prevent rapid changes in bias current.

The diodes used were Raytheon Micro State MS856B and MS858B GaAs IMPATT diodes. Hewlett-Packard HP 5082-0657 Si double-drift IMPATT diodes were tried but they did not oscillate. The HP diodes had an optimum oprating frequency of about 14.3 GHz and had been operated by Hewlett-Packard at 18.0 GHz in a different type of cavity.

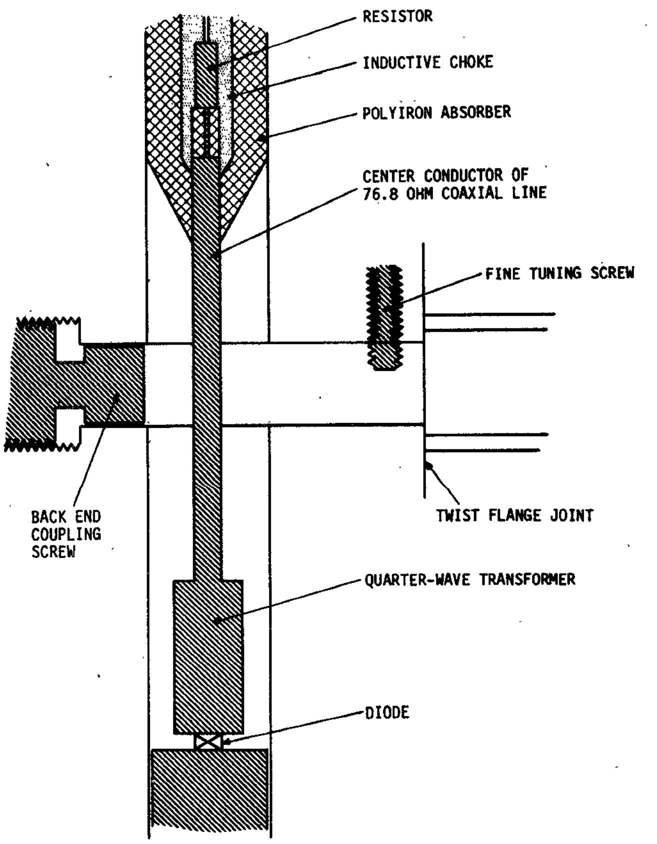

Fig. 3. The IMPATT oscillator cavity.

IV. RESULTS AND DISCUSSION

A. General Results

Fig. 4 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 straight lines with a slope of unity in agreement with a first-order theory [1], [8]. The performance differences between the various curves are a result of differences in pump noise content, I_{AM} in (1), at a modulation frequency equal to the separation between the signal and the noise measurement frequencies.

Data showing the variation of noise temperature increment with the frequency of the interfering signal are presented in Fig. 5 in which each curve is labeled by the signal level in decibels referred to

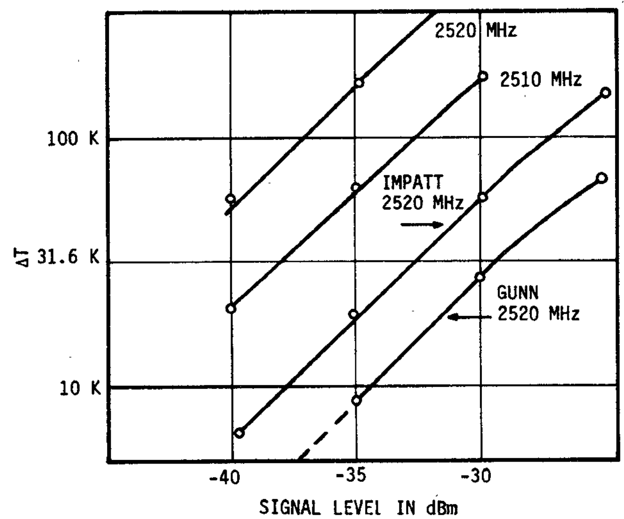

Fig. 4. Noise temperature increment versus signal level for various conditions.

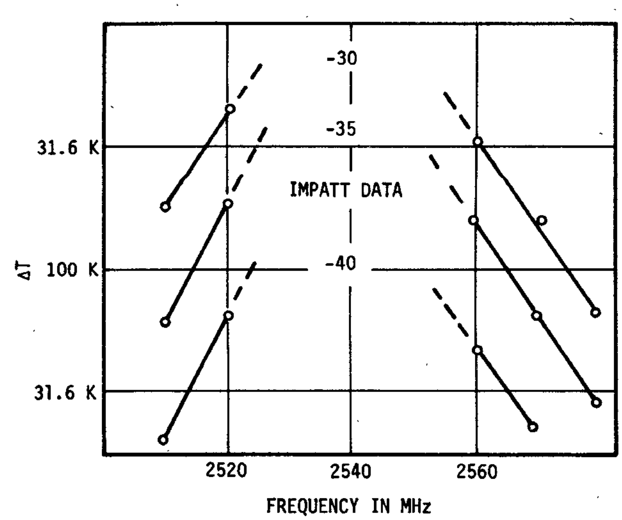

Fig. 5. Noise temperature increment versus frequency for various signal levels.

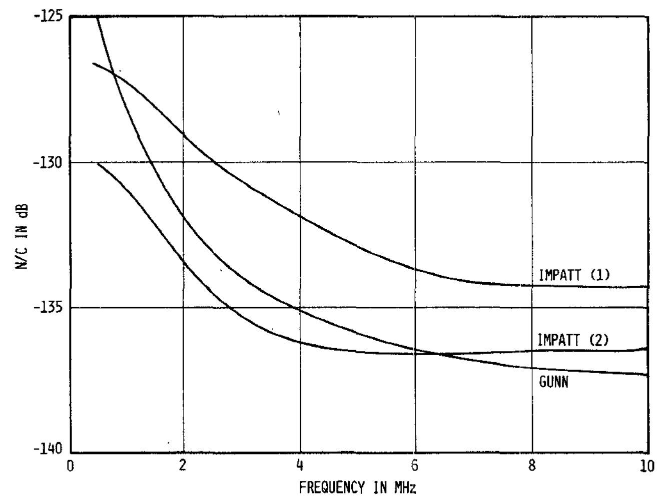

Fig. 6. AM noise-to-carrier ration in 100-Hz bandwidth versus modulation frequency.

1 mW. 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. This restricted measurements to interfering signals on the band edges (see Fig. 2). The observed rise in the effect of the interfering signal as it approaches the center frequency is due to the combined increases in k and G [see (1)]. There may also be some frequency dependence of I_{AM}.

The AM noise-to-carrier ratio of the pump source was measured directly by using a square-law detector [7]. The dc voltage from the detector is proportional to the oscillator output power and the ac component represents the AM noise spectrum of the oscillator. The noise-to-carrier ratio is given by

$$N/C = V_{ac}^2(\mathrm{rms})/(4V_{dc}^2). \tag{3}$$

V_{ac}^2(rms) was measured using an HP 312A selective voltmeter. The results of these noise measurements in a 100-Hz bandwidth are shown in Fig. 6. They are consistent with the noise temperature measurements for the parametric amplifier. That is, by adjusting the IMPATT, different noise levels result as shown by curves labeled IMPATT [1] and IMPATT [2]. The Gunn source has more noise than the IMPATT's close to the carrier. However, the noise from the Gunn source falls below that of the IMPATT's at the high-frequency end which is the portion relevant to the parametric amplifier measurements.

As mentioned before, adjustments on the cavity had dramatic effects on the interfering signal's effect on noise temperature (see Fig. 4). The various adjustments which were used to minimize the noise are described next. After each adjustment, the frequency of the oscillator was brought to the correct value by the fine tuning screw. The correct pump power was maintained by adjustment of a variable attenuator in the pump line (see Fig. 1).

B. The Effect of Diode Position in the Coaxial Line

The data do not show much difference in noise performance for diode positions a half-wavelength apart in the coaxial line. But there are considerable changes for small shifts of the diode near positions for maximum output. The exact form of this dependence varies from diode to diode. For a given diode a position for minimum noise can be located. This is usually close to but not exactly at the position for maximum output power.

C. The Effect of Transformer Impedance

Between the diode and the 76.8-Ω coaxial line various quarter-wave transformers were used. The impedance of the quarter-wave sections ranged from 20.6 to 48.6 Ω. Little difference was found in either the minimum interfering signal effect or maximum output power obtainable with any of these. Outside of this range it was difficult to obtain sufficient pump power.

D. The Effect of Output Coupling

For some diodes the smaller the output coupling (the nearer to a 90° twist), the higher is the interfering signal effect. For those diodes 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 but not so high that the diode stops oscillation. This is an easy adjustment with the rotable step-twist output coupling. For other diodes, the minimum coupling giving sufficient output power yielded the least noise.

The three adjustments discussed above affect the impedance presented to the diode. Position in the coaxial line affects mostly the imaginary part. The other two affect mostly the real part [2], [3]. For a given diode the combination giving the least noise must be found by experiment.

E. 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. The bias current affects the signal-to-noise ratio of the oscillator output. For low values of bias current the signal increases faster with increasing current than the noise.

V. 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 seldom higher than −40 dBm because of the difficulty of avoiding intermodulation products at such high input levels. The parametric amplifier shows gain reduction at input levels of −40 dBm and above. This is a third-order intermodulation effect. 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], [8] with which the data agree well, shows that the interfering signal effect is proportional to gain. [See (1) and (2).] The data are for gain of about 17 dB. Operation of the parametric amplifier at 7-dB gain would shift the curves of Fig. 3 downward by 10 dB. Therefore, 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 has been largely eliminated in Hewlett-Packard silicon IMPATT diodes [10]. Fig. 6 shows a strong increase in noise for low modulating frequencies. This suggests that considerable improvement can be expected in GaAs IMPATT noise performance as the manufacturers improve the quality of their product.

Although GaAs IMPATT diodes were used in this experiment, the authors believe that silicon IMPATT diodes may work as well. Low-noise performance has also been achieved for stabilized silicon IMPATT pumps [9].

The Gunn oscillator normally supplied with the parametric amplifier performed slightly better than the best adjusted IMPATT. It is anticipated 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. 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 GaAs IMPATT pumps with little or no penalty in noise performance in the presence of strong input signals.

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