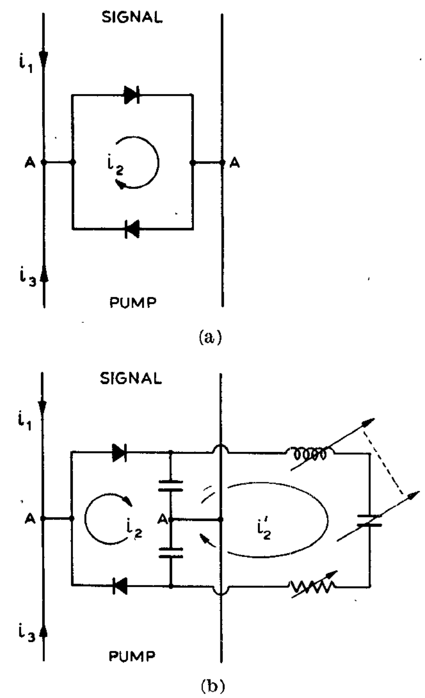

Fig. 1. Schematic diagrams of DD circuit. (a) Pearson's original version. (b) Equivalent circuit of broad-band version.

CURRENTS AT FREQUENCIES ↓	CIRCUITS SIGNAL f_1	IDLER f_2	PUMP f_3
f_1		D.D.	CUT-OFF WAVEGUIDE
f_2	D.D.		D.D.
f_3	RADIAL CHOKE	D.D	
ALL OTHER $mf_3 \pm nf_1$	D.D	D.D. NOT RESONANT	D.D.

Fig. 2. The filtering properties of the Pearson DD circuit.

A Low-Noise Room-Temperature 12-GHz Parametric Amplifier

S. D. LACEY, B. T. HUGHES, AND J. C. VOKES

***Abstract*—A low-noise room-temperature wide-band parametric amplifier is described which could be used, for example, in 12-GHz satellite ground station receivers. The amplifier has a gain of 26 dB, a $\frac{1}{2}$-dB bandwidth of 660 MHz, and a noise temperature between 156 and 171 K.**

INTRODUCTION

A low-noise 12-GHz parametric amplifier is described. This amplifier is a development of those previously outlined [1] for use in satellite ground station receivers operating at 3.7–4.2 GHz and 7.25–7.75 GHz. It is wide band through the use of a novel idler broad-banding circuit [2]. By using very high quality varactor diodes [3] and pumping at high frequency, a low noise temperature is achieved even though the amplifier operates with all parts at room temperature (24°C).

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PRINCIPLE OF OPERATION

Each stage of the amplifier uses two varactor diodes in the Pearson double-diode (DD) circuit [4]. Here two diodes are placed in parallel as far as the pump and signal are concerned, although one diode is inverted with respect to the other as shown in Fig. 1(a). The symmetry properties of this circuit confine the idler current to the loop formed by the two matched diodes. These properties also fulfil most of the filtering requirements met in all parametric amplifiers, i.e., the confining of the signal, pump, and idler currents to their appropriate circuits. Fig. 2 clearly shows that of the nine filters required, six are a consequence of the symmetry properties of this DD arrangement and a seventh results from the resonant nature of this circuit.

This idler circuit may be broad banded by coupling in an extra resonant circuit of variable frequency and Q by means of a common coupling capacity as shown in Fig. 1(b). A double peaked response is then obtained which combines with the single peaked response of the signal circuit to give broad-band characteristics. Note that broad banding is achieved using two very simple controls.

VARACTOR DIODES

The effective use of the Pearson circuit in these amplifiers necessitated the development at SERL of special varactor diodes. An idler loop resonance frequency of 42 GHz was chosen for diodes having zero bias junction capacities of 0.20 pF. The diffused mesa-type GaAs dice is mounted on a gold tape, with the contact to the mesa being made by a gold "preform" of low inductance. A single varactor

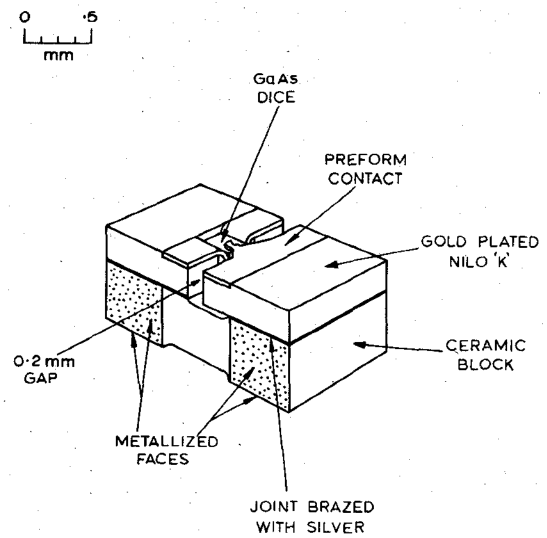

Fig. 3. A single varactor diode.

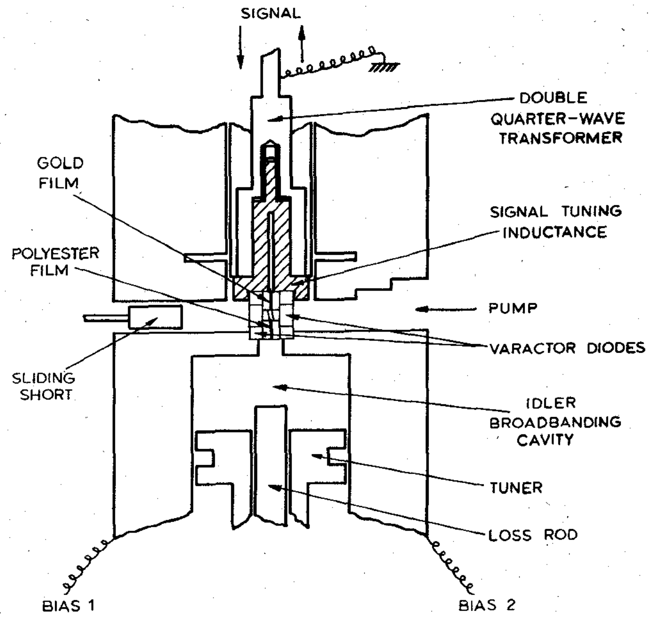

Fig. 4. Schematic layout of the amplifier.

diode is shown in Fig. 3. The effective quality factors (γf_c) of the diodes in the first stage were about 120 GHz, where

$$\gamma = \tfrac{1}{2}(C_{\max} - C_{\min})/(C_{\max} + C_{\min})$$

$$f_c = (2\pi R_s C_j)^{-1}.$$

$C_{\max}$ and $C_{\min}$ are the junction capacities at 1-μA forward conduction current and 1-V reverse bias, respectively, and R_s and C_j are the zero bias values of series resistance and junction capacity. Capacity measurements were made at 1 MHz and the series resistance determined by a variant of the DeLoach transmission method. The γf_c so derived was confirmed by measurement of the amplifier gain with the broad-banding circuit inoperative.

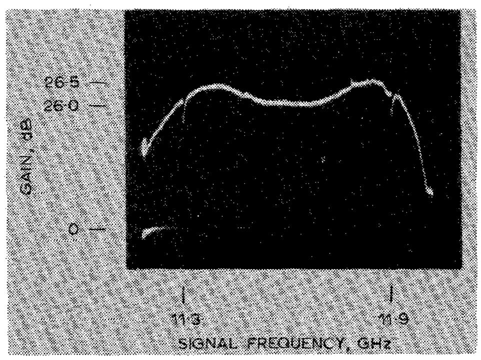

Fig. 5. Gain/frequency response of the two-stage amplifier.

AMPLIFIER CONSTRUCTION AND PERFORMANCE

Before mounting these diodes in the amplifier a thin polyester film is placed between the diodes at one end, thus acting as both the coupling capacity to the idler broad-banding cavity and as a means of biasing and monitoring the diode currents individually. At their other end, the two diodes are held together with a spring claw which also acts as a signal-tuning inductance. This is shown in the schematic amplifier section, Fig. 4. A double quarter-wave transformer, which screws onto the claw, forms the rest of the coaxial signal line. A noncontact tuning plunger and a loss rod constitute the idler broad-banding controls. The pump circuit consists of the diodes mounted across a reduced-height waveguide which is terminated by a variable-waveguide short circuit.

The amplifier body is directly bolted via a nonstandard connector to a stripline circulator having an input loss of 0.15 dB. The input VSWR of the amplifier is less than 1.3. Two such units are placed in series to form a 26-dB gain amplifier, whose gain as a function of signal frequency is given in Fig. 5. The amplifier noise temperature, as shown in Fig. 6, was determined by the standard Y-factor technique using loads at room and liquid nitrogen temperatures. Agreement to within 1 K was found when the Y-factor was measured by attenuating noise powers both at RF and IF. In this instance, klystron pumps were used for the two stages of the amplifier but the powers required were such that IMPATT oscillators could be used [5], [6].

Similar amplifiers have been constructed having bandwidths up to 960 MHz when additional fixed broad banding in the signal circuit is employed.

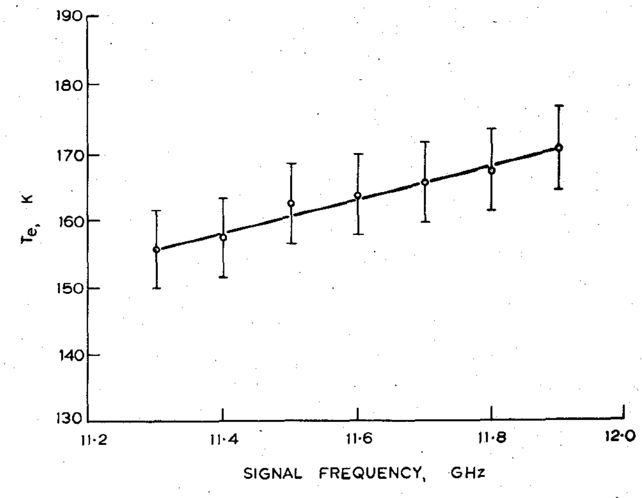

Fig. 6. Noise temperature of the amplifier as a function of signal frequency.

CONCLUSION

A low-noise parametric amplifier has been described which could be used for the future exploitation of the 12-GHz satellite receiving band. This short paper demonstrates both the ability to obtain low noise temperatures in parametric amplifiers operating at room temperature, and the ability to achieve wide bandwidths with simple controls.

ACKNOWLEDGMENT

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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

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

and

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

where

$\Delta T_{AM}(f_1,f_2)$	noise temperature increment at noise measurement frequency f_1 due to AM pump noise and an input signal at frequency f_2;
$\Delta T_{FM}(f_1,f_2)$	noise temperature increment at noise measurement frequency f_1 due to FM pump noise and an input signal at frequency f_2;
$k_{AM}(f_2)$	AM noise sensitivity coefficient of the parametric amplifier at frequency f_2;
$k_{FM}(f_2)$	FM noise sensitivity coefficient of the parametric amplifier at frequency f_2;
$I_{AM}(\|f_1 - f_2\|)$	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 $BP_pI_{AM}(f_m)$ 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 $\Delta T_{AM}/\Delta T_{FM}$ 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

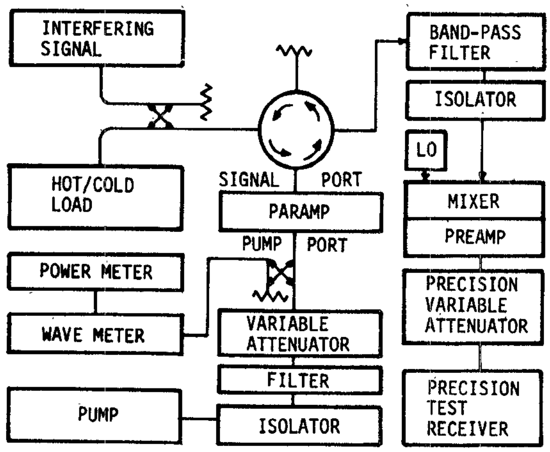

Fig. 1. The noise measurement setup.

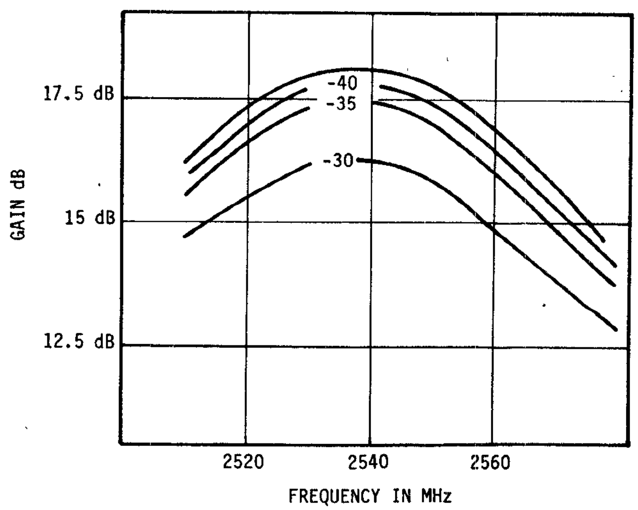

Fig. 2. Gain versus frequency for various levels of interfering signals.