A HIGH POWER 50GHz DDR IMPATT OSCILLATOR WITH LOW SIDE BAND NOISE

Y. Hirachi, Y. Tōyama, Y. Fukukawa, and Y. Tokumitsu
FUJITSU LABORATORIES LTD.
Nakahara, Kawasaki, 211, Japan

Abstract

Low-frequency instabilities in millimeter-wave Double-Drift-Region (DDR) IMPATT diodes are investigated and the oscillator circuit which suppresses low-frequency instabilities is developed. DDR IMPATT mounted in this circuit exhibited output powers 1.6W at 55.5 GHz with 11.5 percent efficiencies.

Introduction

Low-frequency instabilities is IMPATT diodes have a detrimental effect on the micro-wave oscillation. That is, it is known that the low-frequency instability is frequently observed when the RF amplitude of the IMPATT diode increases, to cause the decrease of the output power. That phenomenon is a serious problem in millimeter-wave IMPATT diodes, especially in mm-wave DDR IMPATT diodes which are known to have a high power capability. So that, one can expect that high power mm-wave oscillators having low side band noise could be obtained if this low-frequency instability was suppressed.

This paper presents a study on an oscillation circuit including bias circuit to suppress low-frequency instability as well as, to yield high power output, and proposes a new circuit instead of the conventional coaxial-waveguide circuit.

Low-Frequency Impedance of DDR IMPATT Diodes

Applying the equation $Z_{SDR}(\omega)$ for the low-frequency impedance of Single-Drift-Region (SDR) diodes given by C. A. Brackett[1] to P and N layers in DDR diodes, we obtain the low-frequency impedance $Z_{DDR}(\omega)$ of DDR diodes

$$Z_{DDR}(\omega) = R_{sc} - \frac{R_-}{1 + j\frac{\omega}{\gamma}} \quad \ldots\ldots (1)$$

$$R_- = \frac{m_n + m_p}{4W\ E_c} \cdot \frac{1}{|G_{op}|} \cdot \left(\frac{dPout}{dId}\right)$$

where R_{sc} is the space charge resistance and the meanings of the other notations are found in Ref.(1). At $\omega=0$, $Z_{DDR}=R_{DDR}$ and using each parameter of DDR 39-16S as listed in Table 1, R_{DDR} is calculated about (-)50Ω, which is four times as large as R_{SDR}. This shows that these instabilities will be observed more frequently in DDR than in SDR.

We can derive from eq.(1) the maximum frequency f_{max} for which Z_{DDR} has a negative real part, as shown in Table 1. Smith chart plots of $(-)Z_{DDR}$ and $(-)Z_{SDR}$ with the frequency ω are shown in Fig.1. Equation (1) gives the straight vertical line on the Smith chart.

In order to suppress the low-frequency instability in DDR diodes, we consider the following two methods (conditions):

(1) A method to make the bias-circuit impedance greater than $(-)Z_{DDR}$ at lower frequencies than f_{max} for DDR. (This is the stable condition for low-frequency oscillation.) It is seen from Fig.1 that suppressing the instability in DDR diodes is more difficult than in SDR diodes, since Z_{DDR}, f_{max}(DDR) is greater than Z_{SDR}, f_{max}(SDR), respectively.

(2) A method to make the bias-circuit impedance extremely smaller (~short) than $(-)Z_{DDR}$ at frequencies in excess of the lowest oscillatable frequency for the low-frequency instabilities. (This is the conditionally stable condition.)

As the mm-wave circuit satisfying the condition (1) can not be easily constructed because of the very small dimensions, we have proposed a new circuit to realize method (2) and were successful.

Bias-Circuit Impedance of the Conventional Coaxial-Waveguide Circuit

The bias-circuit impedance $Z_B(\omega)$ seen from the diode was measured with a network analyzer and a small coaxial probe with Z_o=50Ω[6], by which the diode was replaced. Fig.2(b) shows the bias-circuit impedance locus $Z_{B1}(\omega)$ of the conventional coaxial-waveguide circuit as illustrated in Fig.2(a), which has been used in the millimeter-wave communication systems[2]. It is seen from Fig.2 that the $Z_{B1}(\omega)$ locus intersects the $(-)Z_{DDR}$ locus within frequencies from several tens of megahertz to about one gigahertz. In this frequency band the low-frequency instabilities have been observed to be more prominent by experiments.

Fig.3 shows the impedance locus of the same circuit as that of Fig.2(a) except for the insertion of the parallel circuit of the resistor (R~500Ω) and the inductor (L~23μH) in the D.C. bias feed line. The $Z_{B2}(\omega)$ locus has been simpler at frequencies below 0.3GHz than that of Fig.2(a). But as this locus also intersects $(-)Z_{DDR}(\omega)$ locus, no improvement can be expected for the low-frequency instability. In fact, oscillation frequency spectrum observed with the spectrum analyzer showed high side band noise and maximum output power obtained was at most 200mW (see Fig.5(c)). At 0.65GHz, the $Z_{B2}(\omega)$ locus intersects the line of jX=0. The reason for this is that the capacitance C_1(~19.7pF) (see Fig.2(a)) and the inductance L of the inner-conductor in the coaxial are in the series resonance at 0.65GHz. The inductance L obtained from $L=1/\omega^2 \cdot C_1$ is about 2.7nH, which is in reasonable agreement with the calculated value of 1.8nH. It may be concluded that due to the capacitance of the low-pass filter, the $Z_{B2}(\omega)$ locus represents the negative reactance at lower frequencies than 0.65GHz.

In order to realize method (2), it is necessary to remove inductance L and to place a large capacitance in the vicinity of the diode. Therefore, such a millimeter-wave circuit having an inductance near the diode as a coaxial-waveguide type is not suitable for DDR IMPATT diodes. From this point of view, the cap-type circuit might be preferable for DDR diodes as it has no inductance near the diode.

Improvement of Cap-Type Circuit and Performance of DDR Oscillator

The bias-circuit impedance locus of the unimproved cap-type circuit at lower frequencies than 0.65GHz was observed to be similar to that of Fig.3 and so the low-frequency instability would not stop. In fact, maximum output power obtained was at most 550mW (see Fig.5(b)). It is necessary to improve the cap-type circuit so as to satisfy condition (2).

In order to make the bias-circuit impedance extremely small without producing any loss in millimeter-wave power and efficiency, the large capacitance ($C_2 \sim 140$pF) made of aluminum oxide (thickness $\sim 50\mu$) was so placed as to surround the low-pass filter as illustrated in Fig.4(a). The bias-circuit impedance locus $Z_{B3}(\omega)$ of this circuit is shown in Fig.4(b). Compared with Fig.3, the impedance was successfully kept low at frequencies in excess of 80MHz. The low-frequency instability would hardly build up in this circuit configuration.

Fig.5 shows the output power and conversion efficiency versus the input power for typical devices mounted in the three kinds of circuits. In the case of the improved cap-type circuit as illustrated in insert (a), power and efficiency levels as high as 1.6W (point P_1) and 11.5 percent, respectively, were achieved at 55.5GHz, which is the best power frequency product Pf^2 reported so far for any microwave solid-state devices. At this power level, no degradation in frequency spectrum was observed. Output powers larger than 1W were obtained at yield rate of more than 60 percent with diodes having almost the same junction area.

Conclusion

The millimeter-wave oscillation circuit which suppresses the low-frequency instability have been developed to obtain the output power 1.6W at 55.5GHz.

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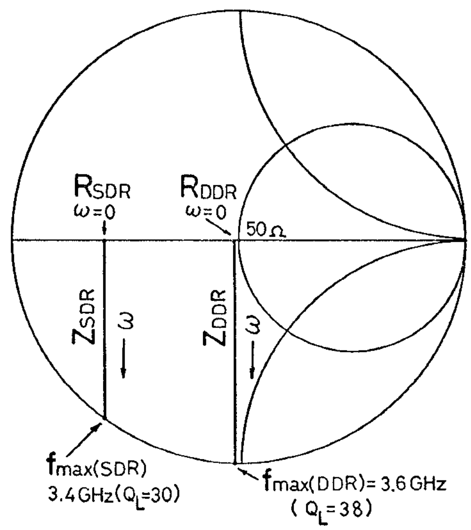

Fig.1 Smith chart plots of the low-frequency impedance $(-)Z_{DDR}(\omega)$ and $(-)\ Z_{SDR}(\omega)$ for DDR and SDR IMPATT diodes, respectively. Equation (1) gives the straight vertical line on the Smith chart.

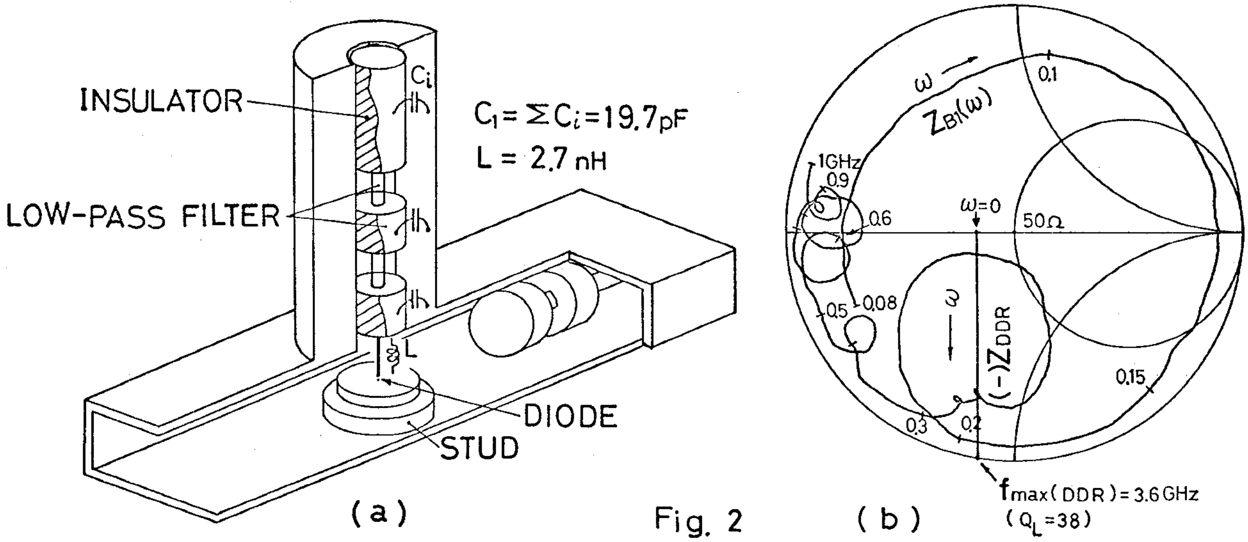

Fig. 2

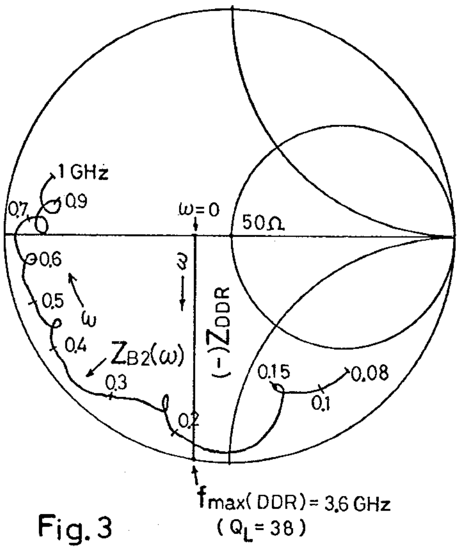

Fig. 3

Fig.2 (a) Coaxial-waveguide circuit which has been used in the millimeter-wave communication systems(2).

(b) The bias-circuit impedance locus of this circuit. The $Z_{B1}(\omega)$ locus intersects the $(-)Z_{DDR}(\omega)$ locus at frequencies between 0.2 and 0.3GHz. The junction area of the DDR diode used in this experiment is 2.2 x 10^{-5} cm^2

Fig.3 The bias-circuit impedance locus $Z_{B2}(\omega)$ of the same circuit as that of Fig.2(a), except for the insertion of the parallel circuit of the resistor (R$\sim$500Ω) and the inductor (L$\sim$23 μH).

Fig.4 (a) Improved cap-type circuit. The large capacitance ($\sim$140pF) made of aluminum oxide (thickness $\sim$50μ) is so placed as to surround the low-pass filter.

(b) The bias-circuit impedance locus $Z_{B3}(\omega)$ of the circuit illustrated in (a). Compared with Fig.3, the impedance is successfully kept low at frequencies in excess of 80MHz.

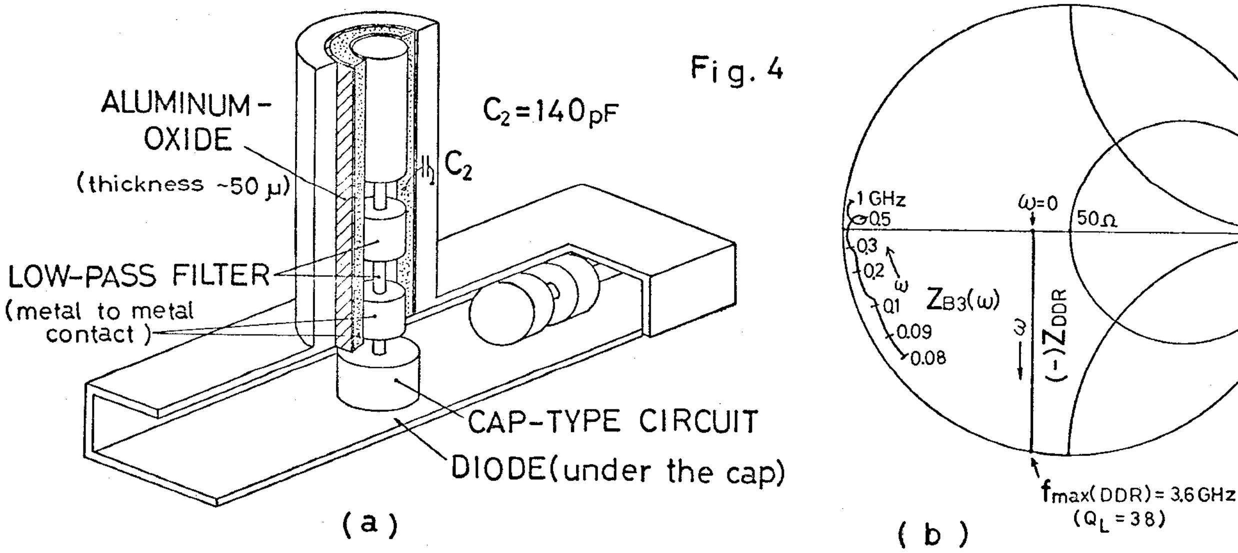

Fig. 4

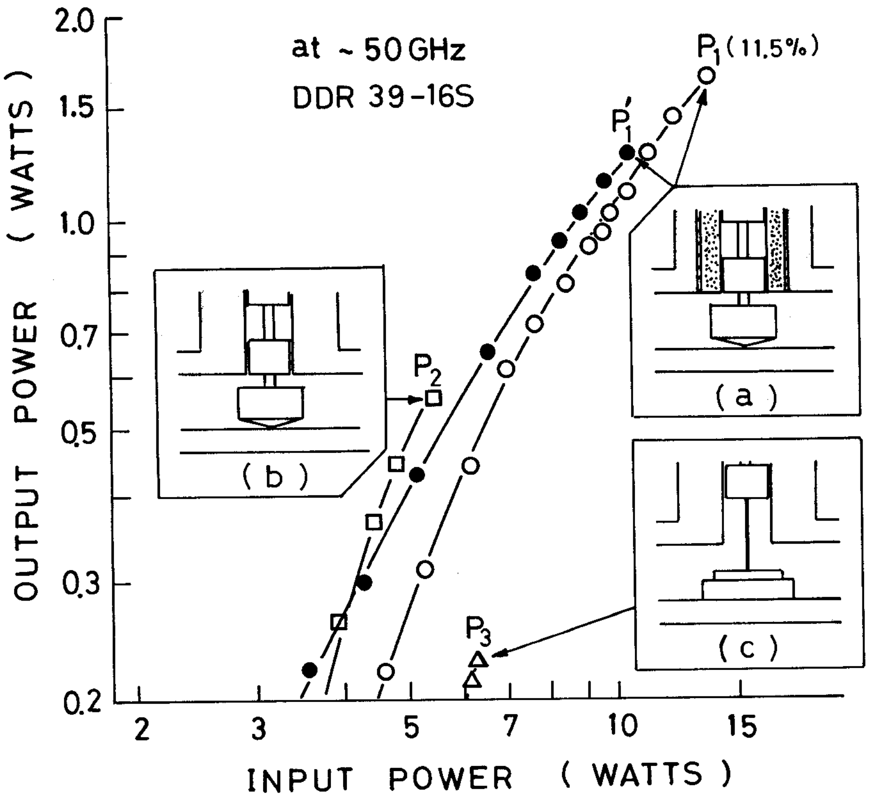

Fig.5 Output power and conversion efficiency versus input power for typical devices mounted in the three kinds of circuits.

(a) ○ ● : improved cap-type circuit. Maximum power and efficiency obtained is 1.6W and 11.5 percent, respectively.

(b) □ : unimproved cap-type circuit. The low-frequency instability (L.F.I.) occurred at P_2.

(c) △ : conventional coaxial-waveguide circuit. L.F.I. also occurred at P_3.

Table 1

	Si SDR	Si DDR	Source
Diode	37 - 1H	39 - 16S	※ foot note
Break Down Voltage V_B (volts)	17.3	21.3	Measured
Junction Area S (cm^2)	1.6×10^{-5}	1.6×10^{-5}	Measured
Deplation Layer Width W (microns)	0.72 at 23 (v)	0.89 at 29 (v)	Estimated
Critical Field E_c (volts/cm)	5.5×10^{5}	4.7×10^{5}	Estimated
$m = E_c/\alpha \cdot (d\alpha/dE)\|_{E_c}$	$m_n = 3.67$	$m_n=4.72$ $m_p=7.40$	Calculated(4)
dP_{out}/dI_d (watts/amp)	4.0	5.9	Measured
Negative Conductance G_{op} (mhos)	10.7×10^{-3}	7.4×10^{-3}	Measured with(5) X-band simulation
R_- (ohms)	17.3	57.5	Calculated
R_{sc} (ohms)	5.0	8.0	Measured
Low Frequency Negative Resistance at $\omega=0$ (ohms)	R_{SDR}(1) -12.3	R_{DDR} - 49.5	Calculated
Loaded Cavity Q Q_L	30	38	Measured
Millimeter-Wave Oscillation Freq. f_o (GHz)	55.5	55.5	
Maximum Frequency f_{max} (GHz)	3.4	3.6	$f_{max}=f_o/Q_L\cdot\sqrt{R_-/R_{sc}-1}$

※ The series resistance of these diodes has been fully reduced by using ion-implanted ohmic contact(3).