DUAL-GATE GaAs FET AS A FREQUENCY MULTIPLIER AT Ku-BAND

Philip T. Chen, Chiung-tung Li, and Patrick H. Wang
Hewlett-Packard Company
Santa Rosa Division
1400 Fountain Grove Parkway
Santa Rosa, California 95404

ABSTRACT

The feasibility of using dual-gate GaAs FET as a frequency multiplier over the Ku-band with a good conversion gain has been demonstrated. Experimentally, it achieved 8dB conversion gain from frequency doubling at 12.6 GHz and 2.5 dB gain from frequency tripling at 12 GHz. Also it possesses a built-in variable gain control over 36 dB dynamic range.

Introduction

The nonlinearities of the transfer characteristics from a dual-gate GaAs FET have been commonly used for mixer applications with a conversion gain [1], and variable-gain microwave amplifiers [2-3]. The objective of this paper is to demonstrate the possibility of using a dual-gate GaAs FET as a frequency multiplier over the Ku-band with a good conversion gain. Also, multipliers utilizing single and dual-gate FET's will be compared.

Device Fabrication & Characteristics

Dual-gate FET's were fabricated on a liquid-phase epitaxial layer doped to 10^{17} with Sn and grown on a Cr-doped semi-insulating substrate. The thickness of epitaxial layer was then adjusted to 0.3μm after growth using the combination of anodic oxidation and chemical etching techniques. A cross-sectional view of the device is shown in Figure 1A. Both aluminum parallel gates, 2μm apart, are 1 μm long and 400 μm wide. The source & drain are alloyed Au-Ge ohmic contacts [3].

All the patterns were defined and aligned photolithographically using AZ positive photoresist. Ohmic contacts or gate area were open in the photo-resist whereas metals were deposited all over the wafer. Subsequently, the desired metallization patterns were left behind using the photo-resist lifting techniques. Figure 1B shows the top view of a complete dual-gate FET.

A typical transconductance with various second gate biases is plotted against the first gate bias in Figure 2. It is evident that its transfer nonlinearity is readily controllable by the second gate bias. Measured at 10 GHz, the device in the common-source mode exhibited the following major results: 12.5 dB max. available gain with the second gate terminated at 50 Ω and 16 dB gain with the same gate RF-matched. Also, it was capable of delivering 13 dBm output power with 11 dB associated gain.

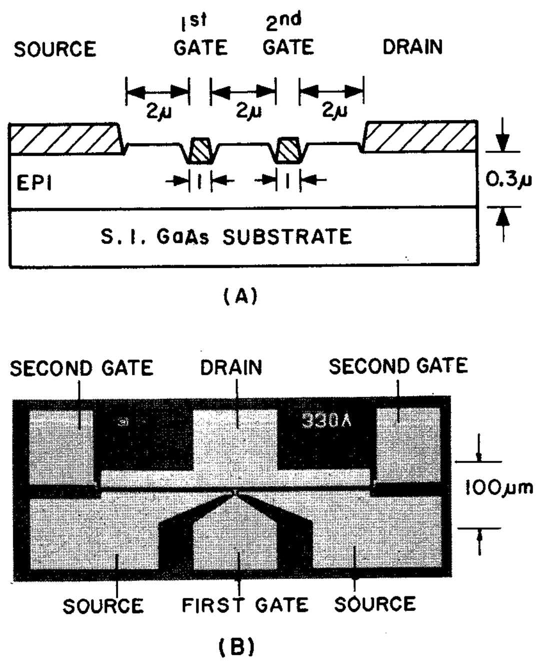

Fig. 1. A Dual-Gate GaAs FET.
(A) A Schematic Cross-Sectional View.
(B) Top View of A Complete Device.

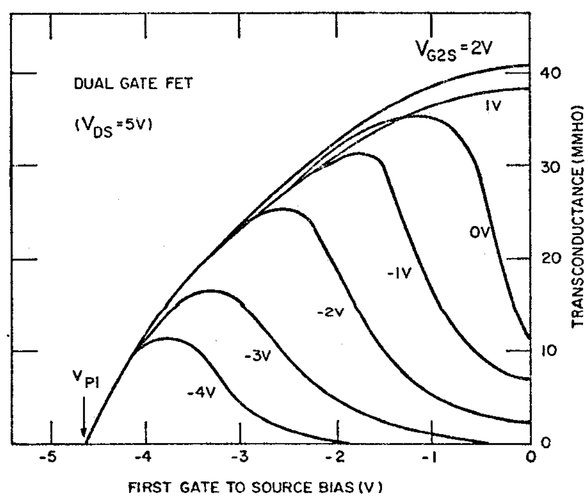

Fig. 2. The dual-gate FET transconductance versus the first gate bias with various second gate biases.

Multiplier Test Arrangement

In general, a GaAs FET has two kinds of nonlinearities: one is the I_D-V_G transfer nonlinearity and the other is the I_G-V_G input nonlinearity. The use of either one can be suitable for frequency conversion. Interestingly enough, the frequency multiplication in a dual-gate FET is arrived primarily at the combining effects from both the nonlinearities. Its basic principle of operation is briefly described as follows. The first gate transconductance is periodically modulated by an input signal and the amplified signal swing at the second gate is, in turn, modulated by its input nonlinearity, thereby generating harmonics. Then, the resultant harmonics are further amplified and extracted from the drain.

A simple test circuit arrangement for measuring frequency doubling at the Ku-band is depicted in Figure 3. An input frequency, ω_0, ranging from 6 to 9 GHz is applied to the first gate through a 9.2 GHz low pass filter, while a tuner is placed at the drain for maximizing the output frequency at $2\omega_0$. It is necessary to extract the output frequency through a high pass filter, thus suppressing the input frequency. Furthermore, the function of a sliding short at the second gate is to enhance its doubler efficiency.

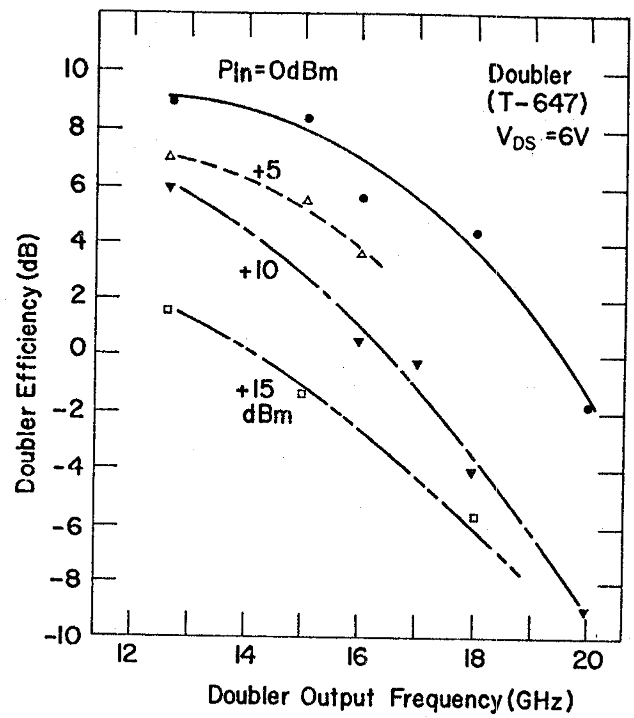

Fig. 4. Dual-gate FET doubler conversion efficiency versus output frequency. The device bias is adjusted at each data point.

Experimental Results

As illustrated, the dual-gate FET is normally operated in the common-source mode. As for frequency doubling, Figure 4 shows the measured conversion efficiency versus the output frequency from 12 to 18 GHz; the input power dependence is also given. With 6 V on the drain, both gate biases were adjusted at each data point for the maximum doubler efficiency. At 0 dBm input power, a conversion gain of 8 dB is measured at 12.6 GHz, and 4 dB gain at 18 GHz.

As an input power increases, the first gate gradually reaches the forward bias condition, thereby reducing the average drain current due to a self-bias phenomenon. Hence, this self-bias mechanism is primarily responsible for the observed efficiency decline with the increasing input power.

An attempt was also made to explore the feasibility of frequency tripling using the similar test arrangement. In Figure 5, the measured tripler conversion efficiency is plotted against the output frequency from 12 to 18 GHz, with different input powers. At 0 dBm input power, the observed conversion gain is 2.5 dB at 12 GHz and -2 dB at 18 GHz. Again, the underlying mechanism responsible for the tripler efficiency falloff with input power is identical to that previously discussed in the doubler.

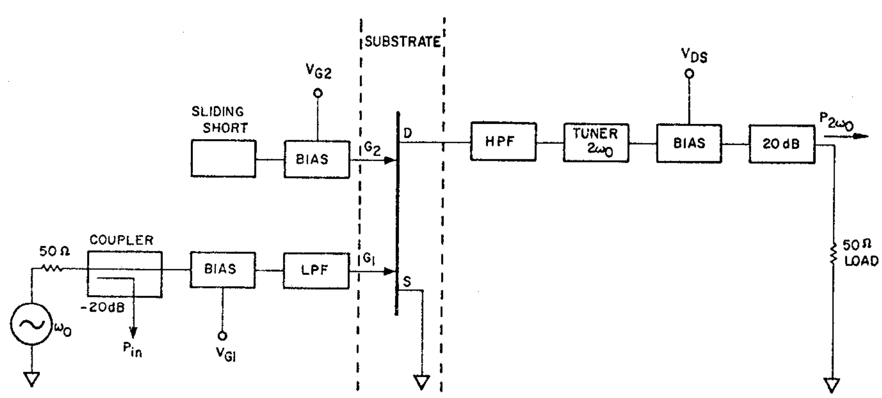

Fig. 3. A dual-gate FET doubler test circuit arrangement.

Finally, the convenient bias control by the second gate allows the dual-gate FET frequency multiplier to vary its conversion efficiency. It was proven possible to vary at least 36 dB dynamic range at 12.6 GHz.

Conclusions

Because the dual-gate FET exhibits the pronounced transfer nonlinearity controllable by a second gate bias, it has been demonstrated to be feasible in generating frequency doubling as well as tripling with a good conversion gain at the Ku-band. In addition, the experimental multiplier benefits from a built-in variable gain control. It is worth noting that the observed conversion gain can be further improved through an impedance matching at the input gate.

In short, the dual-gate FET multiplier offers the advantages of better efficiency and easier gain-control over its single-gate FET counterpart [4].

Finally, the practicality and the results presented in this paper also promise future potential for even higher frequency applications (18-26 GHz).

Acknowledgements

The authors wish to thank G. Basawapatna and R. Stancliff for their valuable discussions, P. Froess and G. Johnson for the device measurements. A special acknowledgement is also due D. Gray, the R/D Manager, for his helpful support concerning this work.

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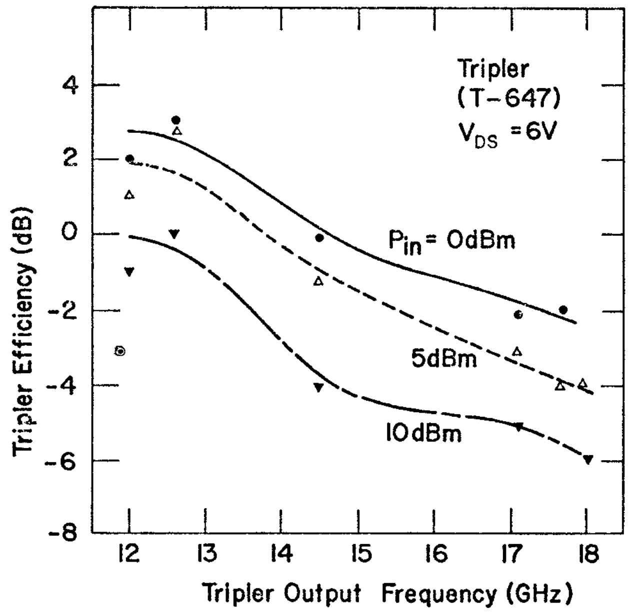

Fig. 5. Dual-gate FET tripler conversion efficiency versus output frequency. The device bias is adjusted at each data point.