A 15/60 GHz ONE-STAGE MMIC FREQUENCY QUADRUPLER

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ABSTRACT

We have developed a 15/60 GHz one-stage MMIC frequency quadrupler using a 0.25-μm AlGaAs/GaAs HEMT. The HEMT was characterized by our empirical large-signal model, in which charge conservation and dispersion are taken into consideration.

We included this model in a commercially-available harmonic balance circuit simulator, and designed the one-stage quadrupler. The fabricated MMIC quadrupler has a conversion gain of -5 dBm with -5 dBm of output power for a 0 dBm input signal.

1. INTRODUCTION

For high-speed wireless data transmissions, an RF local oscillator with low phase-noise and high frequency-stability is required. However in the millimeter-wave frequency range, it is difficult to meet such requirements.

As prototypes, pseudomorphic HEMTs or InP-based HEMTs are used for millimeter-wave oscillators [1]. However, millimeter-wave signals in practical systems are usually generated using a combination of a PLO and a chain of frequency multipliers. For example, a 60 GHz oscillator employs a 15 GHz PLO as the source signal, followed by a 15/30 GHz doubler and a 30 GHz buffer amplifier, then a 30/60 GHz doubler to generate the 60 GHz signal. Thus, a conventional configuration has three-stages [2]. We have developed a 15/60 GHz one-stage MMIC frequency quadrupler to replace conventional doubler-chains. To our knowledge, this is the first reported one-stage MMIC quadrupler using a HEMT.

We characterized an AlGaAs/GaAs HEMT with a 0.25-μm long and 100-μm wide gate by using an original empirical large-signal model. In this model, several principle intrinsic elements are represented by a set of simple functions of bias voltages, and both charge conservation and dispersion effects are taken into account [3,4].

We implemented our large-signal model in a circuit simulator, and successfully designed a MMIC quadrupler. The fabricated quadrupler has -5 dB of conversion gain for a 14.75 GHz input signal at 0 dBm.

2. HEMT MODEL

2.1 SMALL-SIGNAL CHARACTERIZATION

We used an AlGaAs/GaAs HEMT with a gate 0.25 μm long and 100 μm wide for our quadrupler. The typical Idss and gm values are 20 mA and 37 mS at Vds = 3.0 V.

To evaluate the large-signal behavior of this HEMT, we measured its S-parameters up to 62.5 GHz, and characterized them using a conventional small-signal equivalent circuit. We assumed that the extrinsic elements were independent of bias, and determined from S-parameters measured at a typical A-class amplifier's operating bias.
Then the intrinsic elements' dependence on Vgs and Vds was obtained from S-parameters measured at various bias settings [3].

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2.2 LARGE-SIGNAL CHARACTERIZATION

We used the large-signal model in Figure 1 to characterize the HEMT.

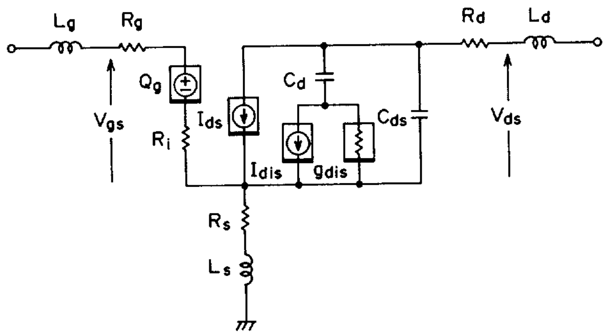

Figure 1. Large-signal model of a HEMT.

Considering both accuracy and calculation costs, we treated Cgs, Cgd, gm, and gds as bias dependent elements. The remaining intrinsic elements, Ri, tau, and Cds, are treated as constants-fixed at the values corresponding to the particular bias conditions determined by the type of application [4].

In this model, the charge source Qg corresponding to Cgs and Cgd is given by

$$Q_g(V_{gs},V_{ds}) = Q_0 \frac{\left(\frac{3}{2}+\tan^{-1}(V_j)\right)V_j - \frac{1}{2}\ln\left(1+V_j^2\right)}{1+\exp(\delta V_{ds})} + Q_c\left(1+\frac{1}{2\cosh(\mu V_{ds})}\right)\exp(\lambda V_{gs}) \quad ,(1)$$

where

$$V_j = \gamma\left(V_{gs} + \alpha\sqrt{V_{gs}^2 + V_{gg}} - V_{ds} + \beta\sqrt{V_{ds}^2 + V_{dd}}\right) \quad ,(2)$$

and Qo, δ, Qc, λ, μ, γ, α, β, Vgg and Vdd are the fitting parameters. Cgs and Cgd are defined as derivatives of Qg.

Figure 2 compares Cgs values obtained from S-parameter measurements with those calculated using Equation 1. The fitting parameters in Eqs. 1 and 2 are determined by applying simultaneous curve-fitting to obtained Cgs and Cgd values.

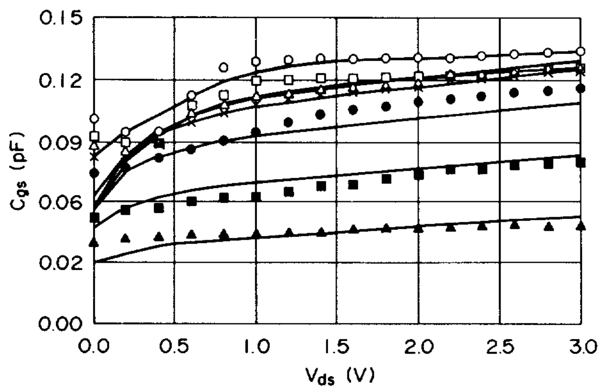

Figure 2. Large-signal characteristics of Cgs. Marks denote measured values and the solid lines show calculated values.
Vgs = +0.4 to -0.8 (0.2 V intervals).

The drain to source characteristics are essentially represented by two current sources, Ids for DC and Idis for the dispersion effect. We modeled these current sources by the same form equation as,

$$I_d(V_{gs},V_{ds}) = I_0 e^{V_g}\left[\delta(V_g + V_{g1})V_{ds} + \tanh(\lambda V_{ds})\right] \quad ,(3)$$

where

$$V_g = 1 + \alpha\tan^{-1}\beta(V_{gs} + V_{g0}), \quad (4)$$

and I0, δ, Vg1, λ, α, β, and Vg0 are the fitting parameters. gdis is added to correct small deviations, and is given by

$$g_{dis}(V_{ds}) = \frac{g_0 V_{ds}}{\left(1+\alpha V_{ds}^2\right)}, \quad (5)$$

where g0 and α are the fitting parameters. The fitting parameters in Eqs. 3 to 5 are simultaneously determined by using DC current, gm, and gds data obtained by S-parameters characterization.

Figure 3 compares DC current data with the values calculated using the model. Figure 4 shows a similar comparison for gm at RF. There is clearly a good agreement.

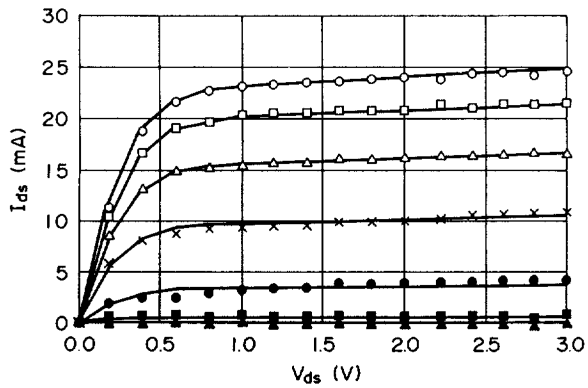

Figure 3. DC current comparison. Marks denote measured values and the solid lines show calculated values using Eq. 3.
Vgs = +0.4 to -0.8 (0.2 V intervals).

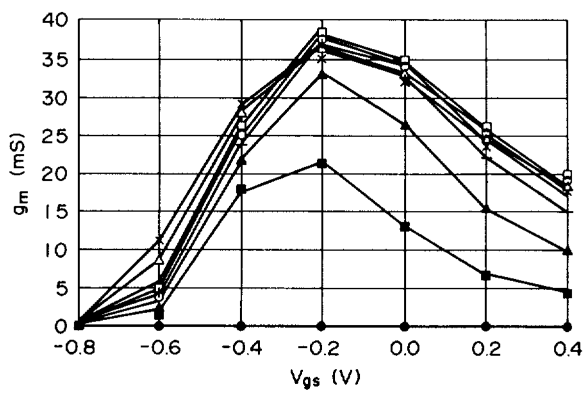

Figure 4. Large-signal characteristics of gm. Marks denote measured values and the solid lines calculated values.
Vgs = +0.4 to -0.8 (0.2 V intervals).

3. 15/60 GHz MMIC FREQUENCY QUADRUPLER

3.1. CIRCUIT DESIGN

We first obtained the operating bias (Vgs = -0.45 V, Vds = 3.0 V) to derive the maximum fourth-harmonic generation [5].

The large-signal impedances are then calculated for the gate of the HEMTs at the fundamental frequency (fo), and for its drain at the fourth-harmonic (4fo). Using nonlinear optimization, we determined the input circuit to achieve conjugate matching at fo. We also did this for the output circuit at 4fo. We represented these impedances in a linear circuit simulator, and designed circuits to eliminate undesirable frequency components.

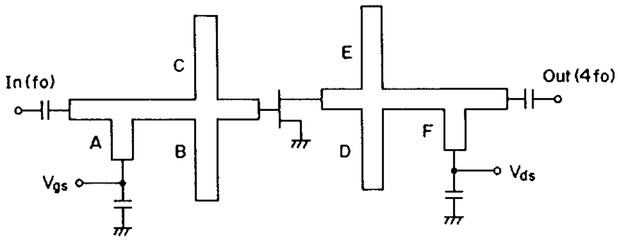

Figure 5. Circuit schematic of 15/60 GHz quadrupler.

Figure 5 shows the circuit schematic of the quadrupler. For the input side, short-stub A is used for gate biasing and signal matching at fo, and open-stubs B and C cooperate to provide short-impedances for undesirable signal components.
For the output side, open-stubs D and E provide short-impedances for undesirable signal components, while short-stub F is used for drain biasing and signal matching at 4fo.

3.2. QUADRUPLER PERFORMANCE

Figure 6 shows a photo of the fabricated quadrupler. The chip measures 1.7 by 1.4 mm.

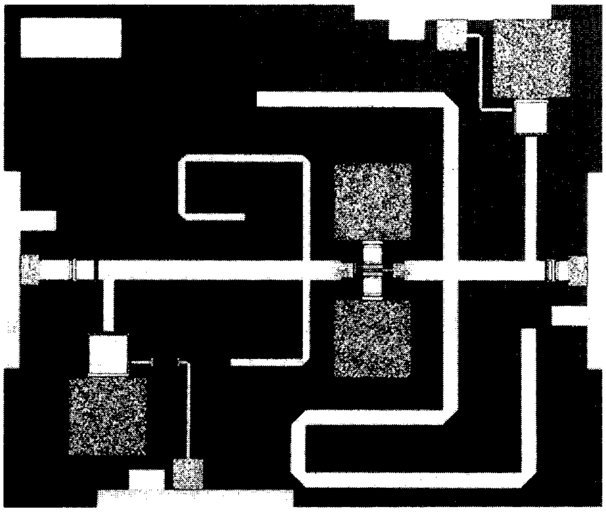

Figure 6. Photo of the fabricated quadrupler.

As shown in Figure 7, the quadrupler has a maximum frequency response for 14.75 GHz input signals.

Figure 8 shows the input-output characteristics of the quadrupler at 14.75 GHz. We obtained a conversion gain of -5 dBm for the input signal at 0 dBm. The maximum conversion gain was at an input power of about -1 dBm, and for +5 dBm of input, we can get -2 dBm of output power.

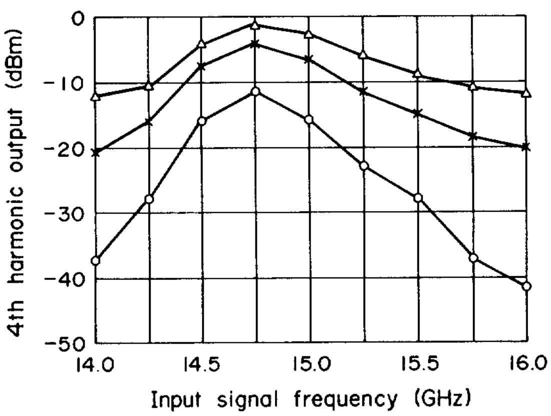

Figure 7. Frequency responce of the quadrupler. Vgs = -0.5 V and Vds = 3.0 V.
O : Pin = -5 dBm, X : Pin = 0 dBm,
Δ : Pin = +5 dBm

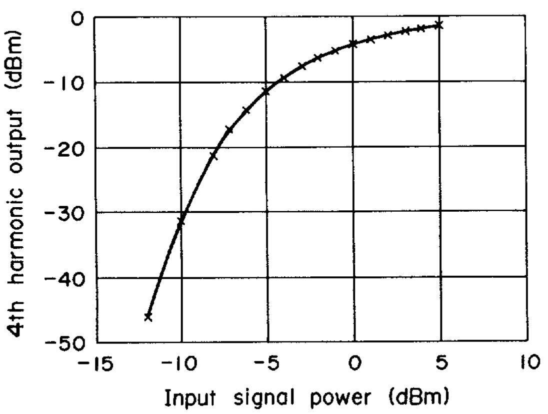

Figure 8. Input-output characteristics of the quadrupler for a 14.75 GHz input signal.
Vgs = -0.5 V and Vds = 3.0 V.

4. CONCLUSIONS

We have developed a 15/60 GHz one-stage MMIC frequency quadrupler using a AlGaAs/GaAs HEMT with a gate 0.25 μm long and 100 μm wide.

The HEMT was characterized with an original empirical large-signal model. In this model, Cgs, Cgd, gm, and gds were treated as bias dependent elements, and the charge conservation and dispersion effects were taken into consideration. The remaining intrinsic element were treated as constants-fixed at the values corresponding to the particular bias conditions determined by the application .

We implemented this model in a commercially-available circuit simulator, and successfully designed the one-stage quadrupler. The fabricated MMIC quadrupler had -5 dB of conversion gain for a 14.75 GHz input signal at 0 dBm.

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