A Novel Technique for HEMT Tripler Design

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Abstract

The effect of fundamental loading on HEMT tripler performance has been investigated. An 11.5 to 34.5 GHz HEMT tripler has been fabricated employing a novel design technique with fundamental rejection feedback. The experimental results show good agreement with the harmonic balance simulations

I. Introduction

This paper presents a novel design technique for HEMT triplers using fundamental rejection feedback. Frequency multipliers are a special category of non-linear circuits employed in communication and instrumentation systems. Frequency multipliers based on planar devices, such as MESFETs or HEMTs are more desirable than circuits realised by vertical devices, such as varactors or step recovery diodes because of MMIC process compatibility and the potential of conversion gain rather than insertion loss. The former category also has the advantages of broad bandwidth and high isolation between input and output. MESFET or HEMT frequency doublers have received considerable attention [1,2]. However, the realisation of MESFET or HEMT frequency triplers is still a challenge.

An experimental investigation of GaAs FET frequency triplers based on harmonic load pull measurements has been presented previously [3]. A theoretical study of triplers and harmonic loading effects has also been given [4]. It was found that the fundamental load of a tripler has a strong effect on its performance. Nevertheless, the second harmonic load has a much smaller effect. This paper proposes a new design technique for HEMT triplers using fundamental rejection feedback. The trade-off between the optimum conversion gain and the frequency response of the tripler has also been studied. In the present study, all the simulation work was carried out using the HP-EEsof harmonic balance simulator. A microstrip 11.5 to 34.5GHz HEMT tripler, using a commercially available packaged NE32684A pHEMT device, has been fabricated on 10mil RT/Duroid 5880 substrate. All the simulation and measurement results show that the effect of the output fundamental load on tripler performance is significant. This novel design technique can be used to enhance the conversion gain or achieve a trade-off between the optimum conversion gain and bandwidth.

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II. The Basic Mechanisms of Harmonic Generation for HEMT Multipliers

Frequency multiplers, in contrast to power amplifiers and oscillators, rely specifically on the nonlinearities of the active device rather than its linearities perturbed by nonlinear effects. From a general large signal equivalent circuit model of a MESFET or HEMT device, its major nonlinear sources causing frequency multiplication are as follows:

(1) the clipping of the drain current which occurs either near pinch-off region or near forward bias region,
(2) the nonlinear transconductance,
(3) the nonlinear output conductance, and
(4) the gate-source and gate-drain nonlinear capacitors C_{GS} and C_{GD}

The most significant mechanism with these sources is the clipping of the drain current [5]. Thus, the first issue on frequency multipliers is the choice of gate-to-source bias, V_{GS}. Multipliers operating in the forward bias region potentially have more output

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power [6]. Nevertheless, this also causes higher dc drain current, consequently lower dc-to-RF efficiencies and a higher risk of device failure due to large gate current. So, multipliers are usually constrained to operate near the pinch-off region.
The termination at unwanted harmonics have also effected the performance of multipliers [3,4,6]. Proper termination can significantly improve the output power of a multiplier. This phenomenon is due to the linear feedback effect [6].

III. A New Topology for a HEMT Tripler

A classic topology of a MESFET or HEMT tripler is shown in Fig. 1 [7]. This configuration of a class B common source FET multiplier with short circuit termination for all unwanted output harmonics only utilises the nonlinearities of the active device. Therefore, it has relatively low conversion gain. The conversion gain can be significantly improved by adding the fundamental rejection feedback. The fundamental load must be purely reactive to reduce the power loss. A new topology for a HEMT tripler is proposed as shown in Fig. 2. This configuration, using fundamental rejection feedback, allows the output fundamental load and the third harmonic load to be adjusted independently. Hence, the conversion gain can be improved or the desired trade-off between conversion gain and bandwidth can be obtained.

IV. The Tripler Simulation

The harmonic balance method was used to simulate the HEMT tripler with novel topology, shown in Fig. 2. First of all, the proper bias V_{GS} needs to be selected to generate the largest third harmonic component. To determine this optimum bias, the input and output matching networks, the output fundamental load and the second harmonic load were all optimised to obtain the highest conversion gain at different V_{GS} values with drain-to-source voltage V_{DS} = 2V. The simulated result is illustrated in Fig. 3. In order to maintain the tripler operating at a reliable and high dc to RF conversion efficiency condition, the bias point was selected near the pinch-off region. The optimum required bias V_{GS} was -0.73V which is close to pinch-off voltage of -0.7V. After deciding the bias, the output fundamental load was swept to obtain its effect on the conversion gain with all other parameters kept constant. Finally, the output fundamental load was set so that the conversion gain was relatively insensitive to its value and the frequency response of the conversion gain was calculated.
An 11.5 to 34.5 GHz HEMT tripler has been simulated. All the simulation work was carried out with the HP-EEsof harmonic balance simulator using the built-in large signal model of the packaged NE32684A HEMT. The optimisation goals were set for the optimum conversion gain and the desired bandwidth, respectively. During the simulation, the input power was fixed at 0dBm and V_{DS} fixed at 2V.

V. Results and Discussion

Based on the simulation result, a microstrip 11.5 to 34.5 GHz HEMT tripler was built. The tripler was fabricated on 10mil RT/Duroid 5880 substrate and its output was through a microstrip-to-waveguide transition. The low-pass microstrip filters used in the tripler were specifically designed to block the second and the third harmonic components. The measured results of the output fundamental loading effect and the trade-off between the optimum conversion gain and the desired bandwidth of the tripler are compared with simulations as shown in Fig. 4 and Fig. 5. The experimental results show excellent agreement with theory.
The results illustrate that the output fundamental loading effect on the conversion gain of a tripler is significant. In the positive feedback region (region 1 in Fig. 4), the conversion gain increases and reaches a maximum. In the non-sensitive region (region 2 in Fig. 4), the conversion gain remains almost constant but the bandwidth is significantly larger. Therefore, a different load at the fundamental may be chosen to meet the needs of an optimum conversion gain requirement or a desired bandwidth performance.

VI. Conclusion

The output fundamental loading effect on a HEMT tripler has been studied. A new design technique has been presented and experimentally validated for a HEMT tripler using fundamental rejection feedback.

The simulation and experimental results demonstrate that the fundamental load is a key element which influences the performance of a tripler. The circuit can be synthesised to obtain an optimum conversion gain design or an expected bandwidth design of a tripler, either of which are very useful in communication and instrumentation systems.

Acknowledgement

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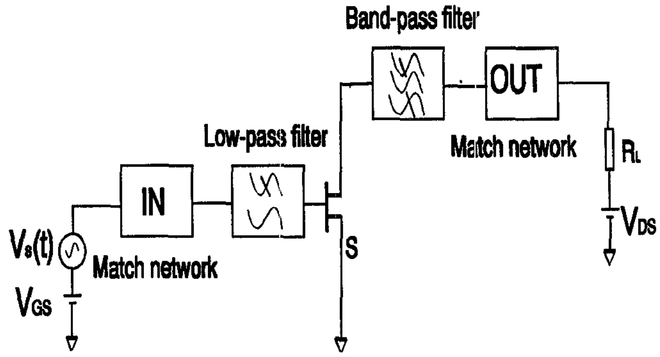

Fig.1 The general topology of a HEMT Tripler without feedback

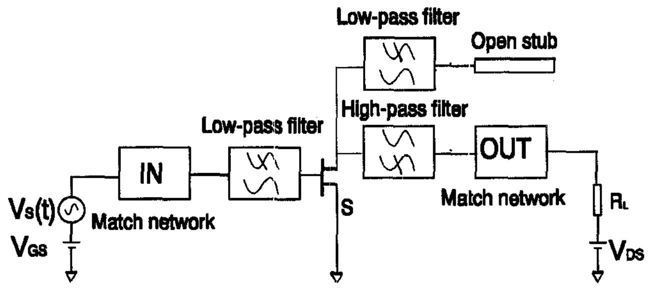

Fig.2 The novel topology of a HEMT tripler with fundamental rejection feedback

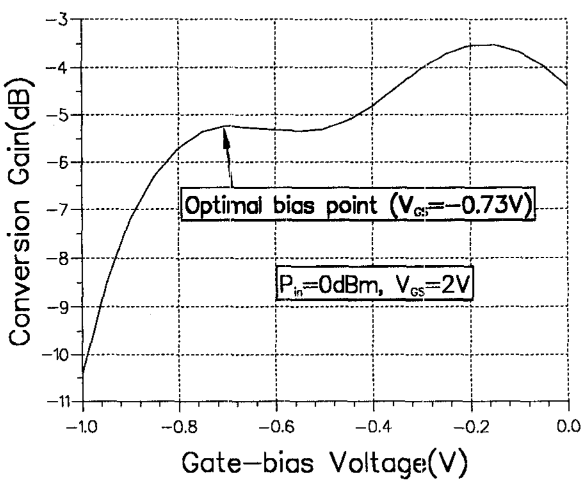

Fig. 3 Conversion gain as a function of the gate-bias voltage

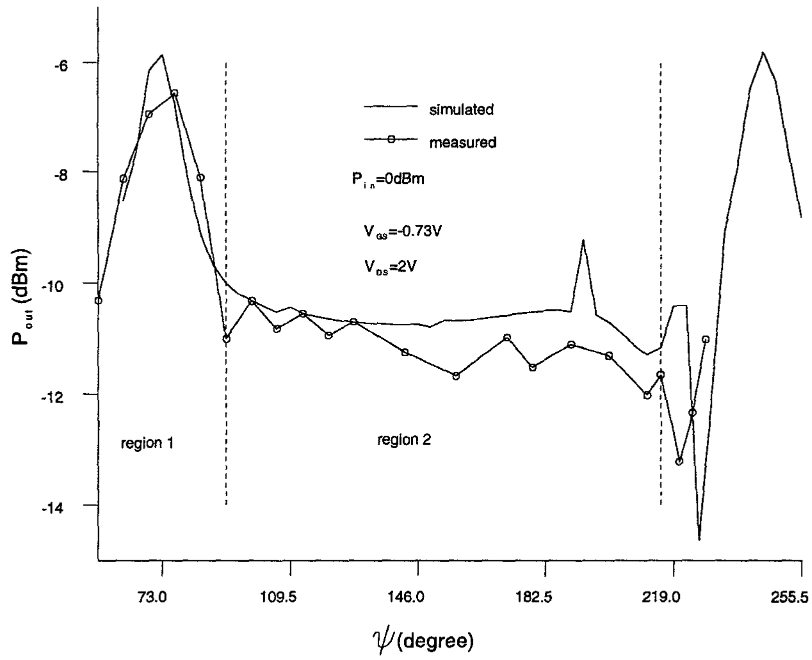

Fig. 4 The simulated and measured fundamental load effect on the conversion gain of the HEMT tripler (ψ: phase of load at fundamental frequency)

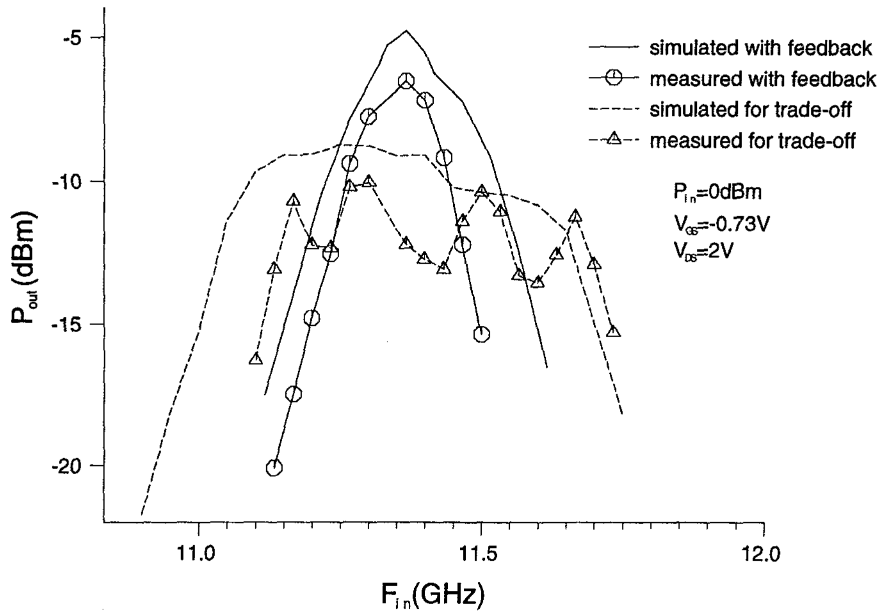

Fig. 5 The simulated and measured optimum conversion gain and the trade-off between the conversion gain and the bandwidth