A stability ensuring design approach for frequency triplers

Bernd Bunz (student member, IEEE) and Günter Kompa (member, IEEE)

University of Kassel, Fachgebiet Hochfrequenztechnik
Wilhelmshöher Allee 73, D-34121 Kassel, Germany, Tel: +49-561-804-6535, Fax: -6529
E-mail: bunz@hfm.e-technik.uni-kassel.de, http://www.uni-kassel.de/fb16/hft/bunz.html

***Abstract* – A novel design procedure for frequency triplers is presented. After first determining optimum bias conditions for frequency triplication, stable regions of operation are determined. The dependency of output power and conversion gain as functions of terminating stubs at all frequencies is examined. An experimental validation is finally carried out.**

I. INTRODUCTION

With an extraordinary boom in telecommunications during the last decade, there is a tremendous market demand towards higher system operation frequencies. Frequency multipliers are one key to the dilatation of the frequency range, because they deliver stable oscillation at acceptable phase noise levels [2],[5].

Up to now, in frequency triplers have been rarely investigated in comparison to doublers, maybe for reason of higher design complexity and less efficiency. In this paper, we focus on two key aspects: the choice of optimum bias conditions and a straight-forward, stability-ensuring design procedure, which is intended to lead to a compromise between output power at third harmonic and bandwidth.

II. BIAS CONDITIONS

Concerning publications, the optimum bias point for frequency tripler is still under discussion. Circuits with acceptable performance have been realised in class B and in class A condition [2],[3],[7],[8]. Classical theory using a Fourier series expansion has proven not to result in optimum performance [4],[6]. Therefore during design procedure, simulations for different bias settings were performed. Results validated the statement of [4]. With varying terminations for different harmonics, one is also changing bias dependency of the circuit. This dependency has been observed on output as well as on input loading. Fig. 1 gives an example for the input side.

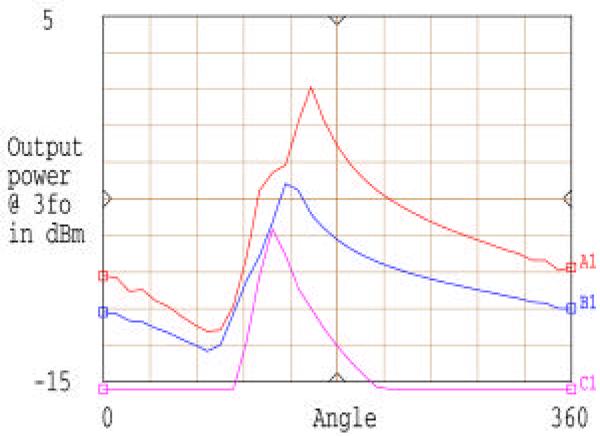

Fig. 1. Output power over phase of ($\Gamma_{IMN,3fo}$) for different bias conditions A_1= class A, B_1= class B, C_1= class C

III. NEW DESIGN APPROACH

While designing active RF-circuits, main focus is laid on offering correct terminations on all frequencies of interest. In case of a frequency tripler, that includes fundamental frequency as well as all harmonics. Due to decreasing harmonic generation efficiency with rising harmonic number, in this approach three frequencies were taken into consideration. An inhouse large signal MESFET model was taken for simulation [1].

In a first design step, an investigation in stable regions is performed. Small signal stability circles on output side for f_o and $2f_o$ as well as on input side for $2f_o$ and

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

$3f_o$ were calculated. Also stability circles after Edwards [9] were reckoned concerning load stability at f_o and source stability at $3f_o$ (Figs. 2-3). In this method, single-side matching is assumed and via matching techniques the region of terminations defined, which results in stable conditions.

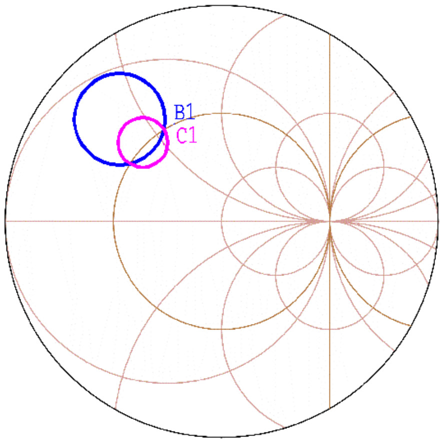

Fig. 2. Conventional stability circle (B1) and stability circle after Edwards (C1) for a load termination at f_o

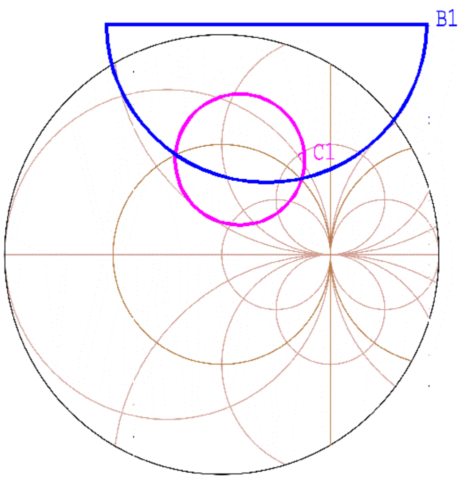

Fig. 3. Conventional stability circle (B1) and stability circle after Edwards (C1) for a source termination at $3f_o$

A second design step consists in using fictitious terminations at all harmonics for determining best performance of the transistor under condition of stability. If regions of instability of all stability circles exclude the center of the Smith chart, this approach leads to valuable results. In regions of stability, termination impedances are held as long as possible purely imaginary. Entering critical regions, terminations are varied, thus adding a resistive part to the termination (see Fig. 4).

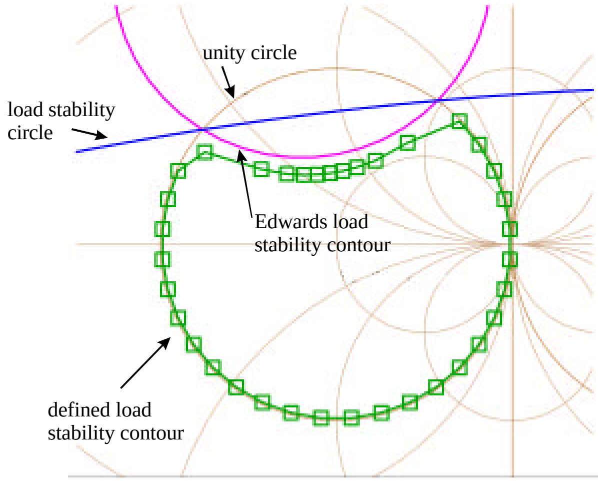

Fig. 4. Load stability contour

For input termination at f_o and output termination at $3f_o$ matching is assumed. So 4 sweep variables remain.
Curves of output power over electrical angle on input side at 3 f_o show a significant peak at 170°. The abrupt fall of output power for angles lower than 170° can be explained via the sweep, because in the region of 20° to 160°, a resistive termination must be added to the load (Fig. 5).
Regarding load termination at f_o, simulation results show a broad maximum region from 50° up to 270°, followed by a minimum at 330° (Fig. 5). The maximum at 20° was considered as too steep and was not used in further simulation.

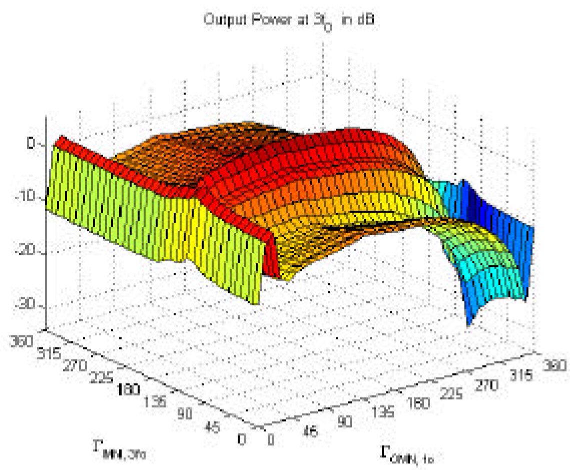

Fig. 5. Output power as function of $\Gamma_{OMN,fo}$ and $\Gamma_{IMN,3fo}$

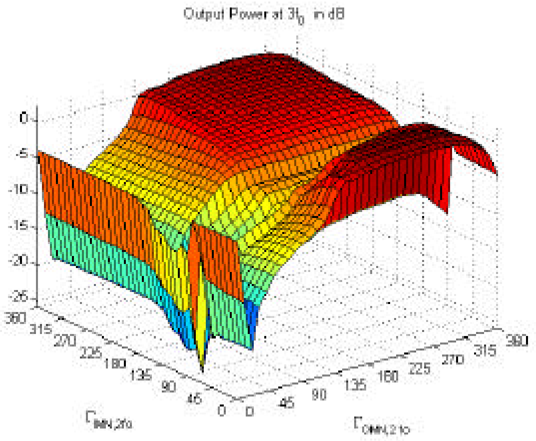

Fig. 6. Output power as function of $\Gamma_{OMN,2fo}$ and $\Gamma_{IMN,2fo}$

An often proposed method concerning terminations at $2f_o$ is to fix terminations at 180°, realizing a short circuit for this frequency. While performance is near optimum on load termination, simulation results show a worse result for input termination. Here a maximum can be stated between 20° and 80° (Fig. 6).

In this method, only specific frequency points are taken into consideration. Therefore a stability check after each design step was performed to ensure stability over the complete frequency band.

In a next design step, the fictitious terminations are replaced by input and output microstrip matching networks offering calculated terminations. On output side, as termination at 3 f_o, a combination of radial stub and cross junction was used to minimize influence at f_o. With reflection coefficients significantly different from 180°, a short circuit is not ensured at the corresponding harmonic and remarkable output power at unwanted harmonics can occur. If needed, a bandpass filter can be utilized to suppress unwanted harmonics.

The last design step consists in validation of small signal results and optimization in large signal simulation. Due to experience, optimum results are expected to lie within 10 % of variation. Depending on complexity of structures being optimized, also nested or iterative optimization methods can be chosen. Fig. 7 shows the design process in a schematic.

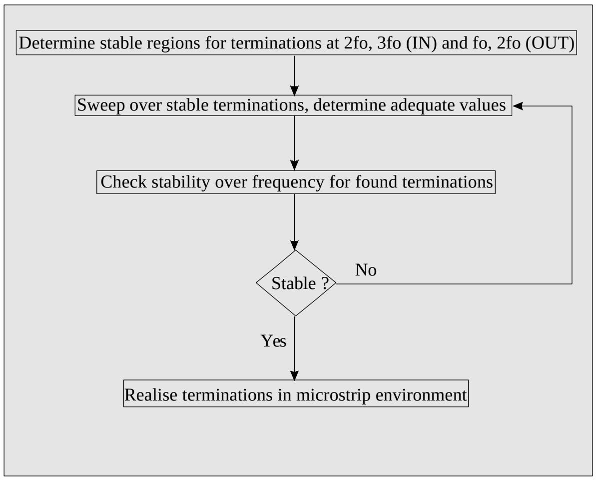

Fig. 7. Schematic of design process

IV. MEASUREMENTS

To verify results of simulation, a 6-18 GHz tripler in hybrid environment was realized. As transistor element, a GEC-Marconi 4*75 µm 0,5 µm MESFET driven in class A was used.

Measurements showed an output power of 0.34 dBm at an input power of 1 dBm, resulting in a conversion gain of –0.67 dB and a bandwidth of 2.5 per cent (Fig. 8). The value compared with simulation results differed by 1 dB, what indicates an acceptable accuracy of simulation. If less output power at f_o is needed, a bandpass on output side can be added (Fig. 9).

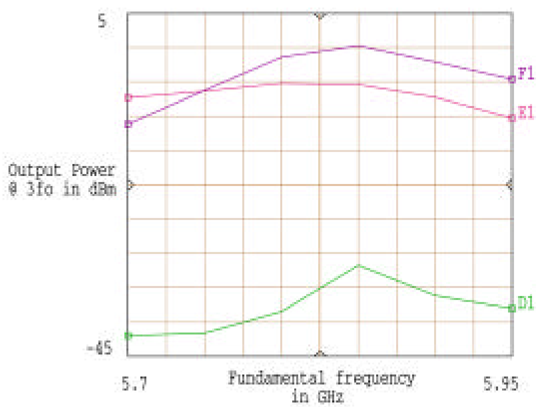

Fig.8. Measured output power at first three harmonics over frequency, curve E1=f_o, curve D1=$2f_o$, curve F1=$3f_o$

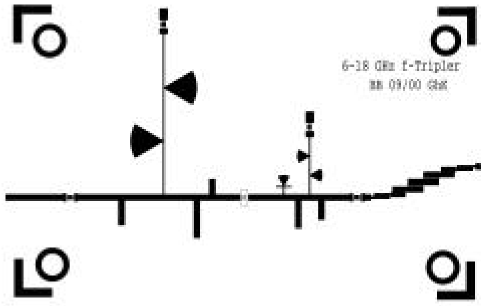

Fig.9. Final layout of the circuit, with optional bandpass

V. CONCLUSION

A novel design procedure is presented, showing for the first time the influence of all harmonic terminations on tripler behaviour while guaranteeing stable performance. Each termination is shown to influence output power of the transistor by more than 10 dB. A verification was performed by a hybrid 6-18 GHz frequency tripler showing a maximum conversion gain of –0.67 dB, which represents to our knowledge the best performance in a hybrid environment reported till now.

REFERENCES

[1] I. Schmale and G. Kompa, "A symmetric non-quasi-static large-signal FET model with a truly consistent analytic determination from DC- and S-parameter data", *IEEE MTT-S, Int. Microwave Symp. Dig.*, 1999, pp. 258-261

[2] E. Camargo, "Design of FET frequency multipliers and harmonic oscillators", Artech house, 1998

[3] H. Fudem and E.C. Niehenke, "Novel millimeter wave active MMIC triplers", *IEEE MTT-S Int. Microwave Symp. Dig.*, 1998, pp. 387-390

[4] G. Zhao, S. El-Rhabaie, and F.M. Ghannouchi, "The effects of biasing and harmonic loading on MESFET tripler performance", *MW Optical Letters,* Vol. 9, No. 4. July 1995

[5] S.A. Maas, "Nonlinear microwave circuits", Artech House, 1988

[6] Y. Campos-Roca, L. Verweyen et al., "An optimised 25.5-76.5 GHz PHEMT-based coplanar frequency tripler", *IEEE Microwave and Guided Wave Letters,* Vol. 10, No. 6, June 2000, pp. 242-244

[7] C. Beaulieu, "Millimeter wave broadband frequency tripler in GaAs/InGaP HBT Technology", *IEEE MTT-S, Int. Microwave Symp. Dig.*, 2000, pp. 1581-1584

[8] A. Boudiaf, D. Bachelet, and C. Rumelhard, "38 GHz MMIC PHEMT-based tripler with low phase noise properties", *IEEE MTT-S, Int. Microwave Symp. Dig.*, 2000, pp. 509-512

[9] M.L. Edwards, S. Cheng, and J.H. Sinsky, "A deterministic approach for designing conditionally stable amplifiers", *IEEE MTT Transactions,* vol. 43, No. 7, July 1995, pp.1567-1575