MMIC NON-LINEAR TRANSMISSION LINE FREQUENCY DOUBLER

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ABSTRACT

This paper describes the design and the predicted and measured results of a Q-band MMIC non-linear transmission line frequency doubler using a 0.7 micron GaAs MESFET MMIC process. The implemented non-linear transmission line is based on microstrip line sections loaded with Schottky diodes.

INTRODUCTION

A non-linear transmission line (NLTL) is a high-impedance line loaded periodically by reverse biased Schottky diodes serving as voltage-variable capacitors, Figures 1a and 1b. The advantage of Schottky diodes is that they can be used for signal generation and detection at frequencies well above transistor bandwidths. Therefore, a MMIC process designed for a lower frequency can be used to implement circuits at higher frequencies, which reduces the costs of the MMIC realization. For example, the FETs available in the process used (Alcatel Telettra I3P) are usable up to the X-band, whereas diodes can be used up to the Q-band.

Under reverse bias, a diode behaves as a non-linear capacitance. Strong input signals will generate harmonics and mixing products of the applied signals. Non-linear transmission lines are used as frequency multipliers, mixers, and for step-function and impulse generation.

DESIGN

The first task of the design was the lay-out and modelling of the Schottky diodes by modifying a standard FET. In the lay-out of the diode, the anode to cathode distance and the length of the anode finger were optimised within the lay-out rules aiming at minimising the diode series resistance.

The model parameters C_0 (zero bias depletion capacitance) and R_s (series resistance) were extracted from the information available for the FET. Parasitic components were calculated with the electromagnetic planar circuit simulator Momentum (Hewlett-Packard).

The basics for the design of a NLTL are set by the low-pass cut-off frequency of the periodic transmission line and by its characteristic impedance. A periodic line has a low pass filter characteristic with a cut-off frequency f_c:

$$f_c = \frac{1}{\pi\sqrt{L_1(C_1 + C_j)}} \tag{1}$$

where L_1 is the inductance of one period of the transmission line, C_1 is its capacitance, and C_j is the capacitance equivalent to the large signal capacitance of a reverse biased Schottky diode. The second harmonic frequency power generation is most effective when the third and higher harmonic frequencies are above the cut-off frequency, so the low-pass characteristics of the NLTL cancels the higher harmonic frequencies, Rodwell et al. [1].

A NLTL has an approximate impedance as follows:

$$Z = \sqrt{\frac{L_1}{C_1 + C_j}} \tag{2}$$

The capacitance C_j of the diode should be dominant compared to C_1 for an effective generation of harmonic power. It is advantageous to choose a high impedance line as a transmission line between the diodes as the diode capacitances decrease this impedance to a value close to 50 Ω.

The layout of the NLTL was required to fit into a 2 mm x 0.7 mm chip area. Therefore, the NLTL structure was optimised to maximise the conversion efficiency, while respecting these layout constraints by using harmonic balance analysis software (Libra, Hewlett Packard). The optimisation was carried out by changing parameters such as the number of sections, the length of the sections, the impedance of the connecting lines and the diode size.

The designed NLTL is based on microstrip line sections. For this structure a diode with W = 40 μm x L = 1.0 μm was chosen. Diodes are connected to the ground by vias. The final optimisation was done by iterating the numbers of the sections and their lengths. Nine sections gave the best result in this case.

SIMULATION RESULTS

The simulation results are presented in Figure 3. The minimum conversion loss is 8.5 dB from the fundamental frequency 18 GHz to the second harmonic frequency 36 GHz. The bandwidth of about 20 % is achieved for a conversion loss of 10 dB. By tuning the diode bias voltages, the frequency band can be tuned within a few GHz's.

In Figure 4 simulation results are presented where the length of a section has been chosen for the sweep parameter and frequencies are presented with different curves. The maximum realisable length of the section, L = 382 μm, with nine diodes has been highlighted in the figure.

MEASUREMENT RESULTS

The on-wafer measurement results of the NLTL are shown in Figures 5 to 7. In Figure 5a and 5b the second harmonic output power of the NLTL multiplier are shown for an input power of 13 dBm and various bias voltages. For a bias voltage of -2 V a minimum conversion loss of 8.7 dB is obtained for an input frequency range between 22.5 and 25 GHz, compared to a minimum simulated value of 8.5 dB. The optimum conversion efficiency is obtained with a different biasing voltage compared to the simulation. This is attributable to variation in the diode DC characteristics from the nominal values given in the foundry manual and to imperfections in the Schottky diode model.

In Figures 6a and 6b, the on-wafer measured second harmonic output power for an input power of 15 dBm is shown for various bias voltages. In this case the minimum conversion loss is approximately 7.5 dB over the frequency range 22.5 to 25 GHz.

In Figure 7 the input return loss (small signal s-parameter measurement) is shown. The return loss is better than 15 dB between 10 to 35 GHz for various biasing voltages. The output return loss is similar to the input return loss, because of the symmetry of the structure.

CONCLUSIONS

A wide-band non-linear transmission line frequency doubler has been realised using a 0.7 micron GaAs MESFET MMIC process. An excellent conversion loss of 7.5 dB was achieved for Q-band output frequencies with very low input and output return loss.

The measurement results confirm the design approach, where the signal generation capabilities of a low cost, low frequency MMIC process can be extended to Q-band by using the NLTL concept.

ACKNOWLEDGEMENT

The authors would like to thank Mr Dirk Hannes for performing the measurements.

REFERENCES

[1] Rodwell et al.: "Active and non-linear wave propagation devices in ultrafast electronics and optoelectronics", Proceedings of the IEEE, Vol. 82, No. 7, July 1994.

[2] ETM Technical Note, <http://www.estec.esa.nl/xrmwww/pubs/xrmtn.htm>, Vol. 6, no. 6, 10 June 1997.

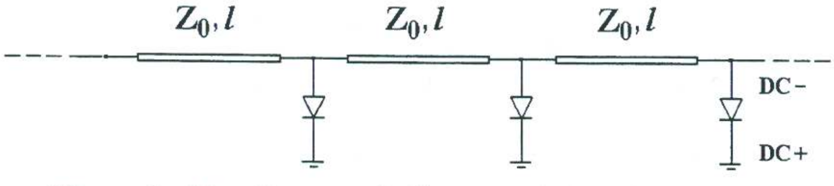

Figure 1a. Non-linear periodic transmission line (NLTL).

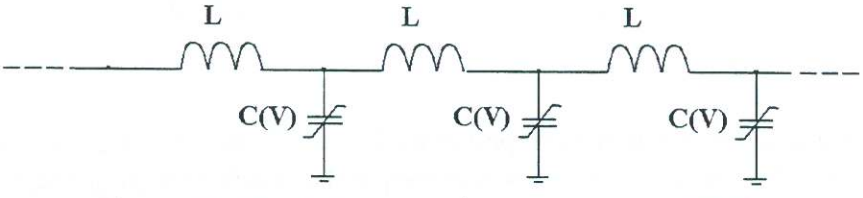

Figure 1b. Simplified equivalent circuit for a NLTL.

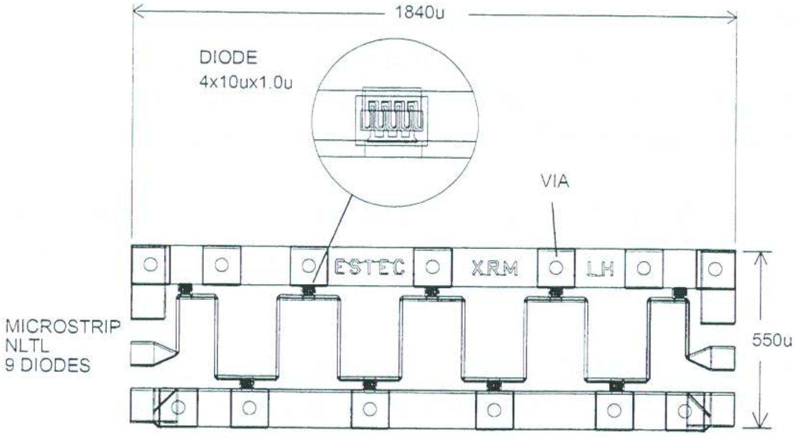

Figure 2. Layout of the designed microstrip line NLTL.

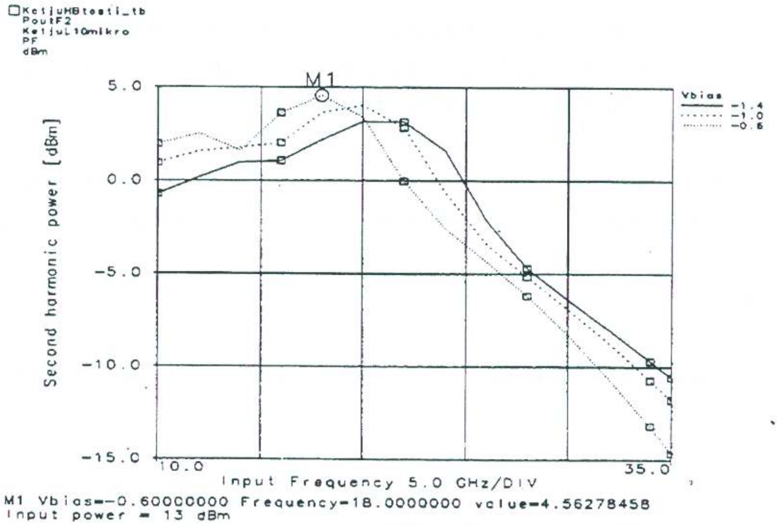

Figure 3. Simulated second harmonic power of the NLTL. Diode W = 40 μm x L = 1.0 μm; length of a microstrip line section L = 382 μm; nine diodes.

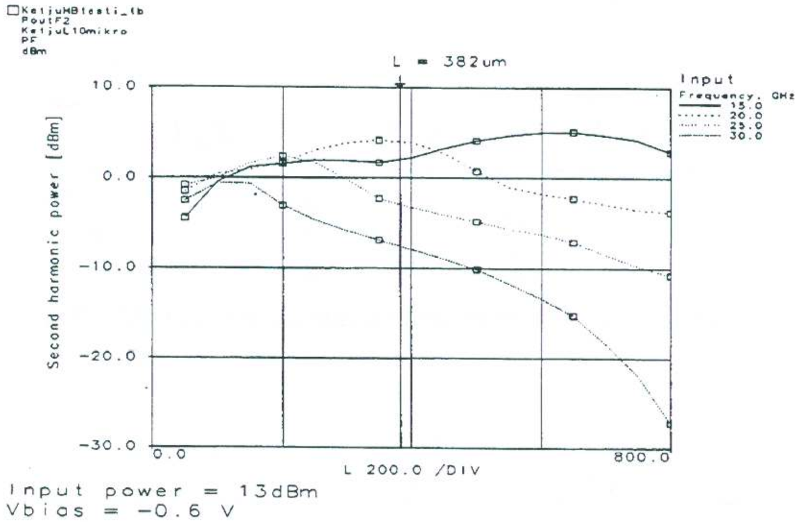

Figure 4. Simulated second harmonic power of the NLTL as a function of the microstrip line section length. Different curves correspond the different frequencies. The maximum realisable length of the section, L = 382 μm, with nine diodes is highlighted in the figure.

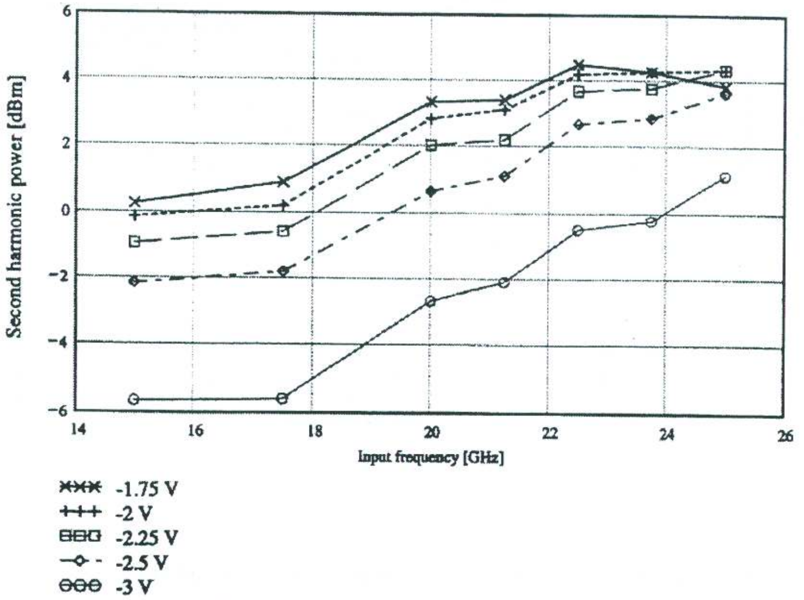

Figure 5a. Measured second harmonic power, Pin = 13 dBm, V_{bias} = -1.75 V … -3V.

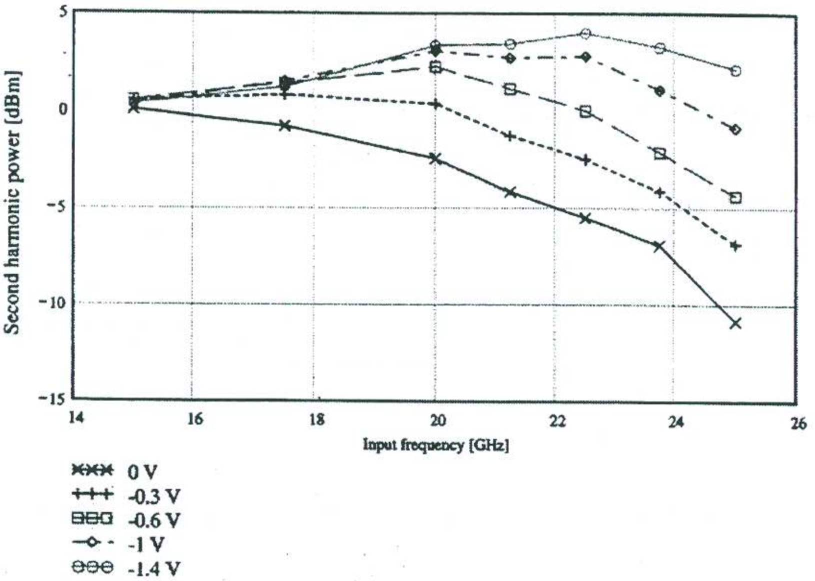

Figure 5b. Measured second harmonic power, Pin = 13 dBm, V_{bias} = -0 V … -1.4 V.

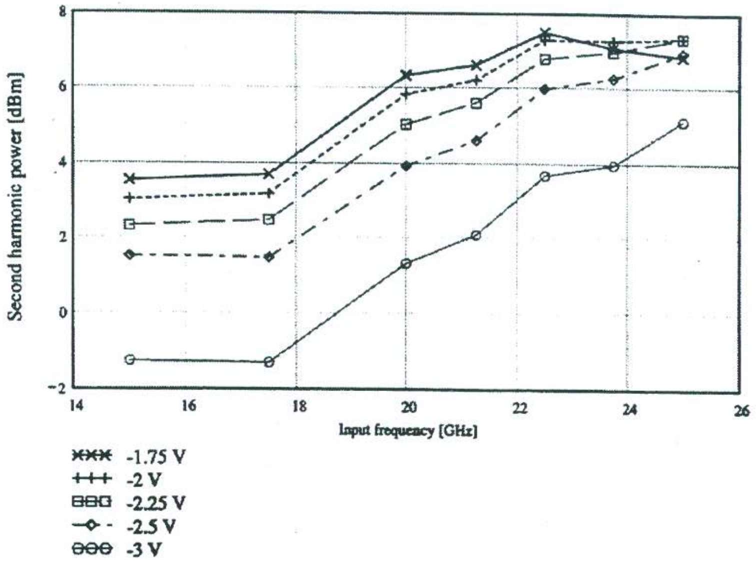

Figure 6a. Measured second harmonic power, Pin = 15 dBm, V_{bias} = -1.75 V … -3V.

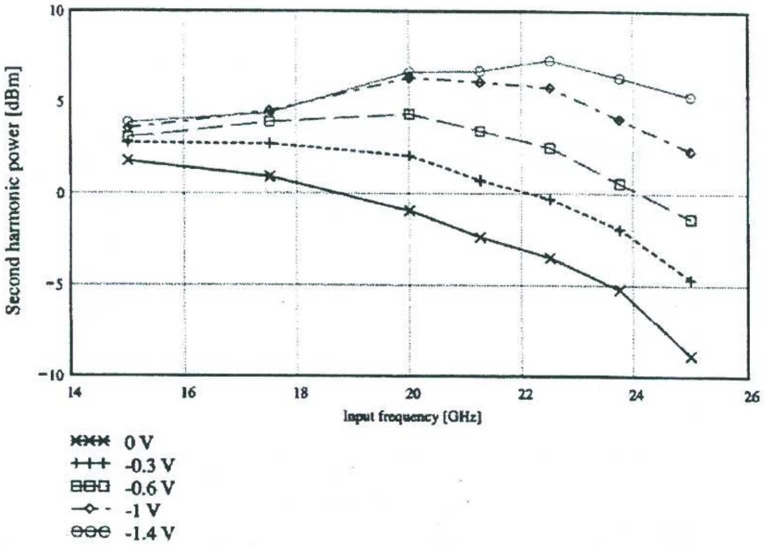

Figure 6b. Measured second harmonic power, Pin = 15 dBm, V_{bias} = -0 V … -1.4 V.

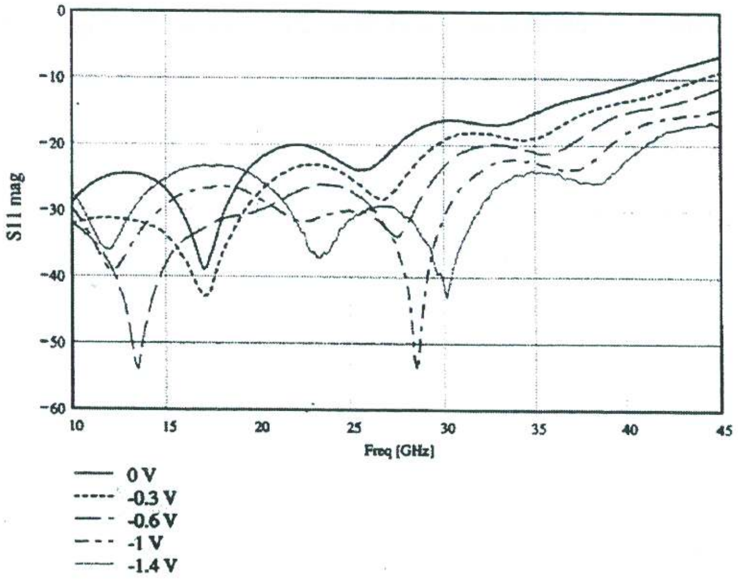

Figure 7. Input return loss.