A Low Cost Fixed Tuned F-band HBV Frequency Tripler

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***Abstract*— We present a novel fixed tuned heterostructure barrier varactor diode (HBV) tripler. This new multiplier consists of a microstrip section, which provides the critical impedance matching, and the diode, connected to microstrip to waveguide transitions at each end. The circuit is inserted in the E-plane of a waveguide mount, and both the input (Q-band) and the output (F-band) waveguide to microstrip transitions are realized using antipodal finlines. A peak efficiency of 4.2% with a 3% 3-dB bandwidth at 3×42.6 GHz for an input power of 13 dBm has been measured.**

I. Introduction

Millimeter wavelengths have an increasing number of applications, but a limitation is the lack of low cost fundamental frequency sources. Traditionally, crossed waveguide Schottky multipliers are used to generate power at these frequencies. The waveguide blocks used are expensive and require manual tuning with back-shorts. With the introduction of the heterostructure barrier varactor (HBV) [1], higher order multipliers such as triplers are easier to design due to the symmetry of the device. The HBV generates only odd harmonics, requires no bias and the power handling can be increased by stacking several barriers in the diode.

In this paper we report on a new fixed tuned HBV tripler topology designed for an input frequency in the *Q*-band (33-50 GHz), hence providing an output in the *F*-band (90-140 GHz). The embedding circuitry for the varactor diode is realized in a microstrip environment, connected with microstrip to waveguide transitions at each end. This new circuit is simple to fabricate, suitable for monolithic integration [2], and scalable to higher frequency ranges. This makes the topology highly suitable for high power harmonic sources for millimeter and sub-millimeter wave applications.

II. Design

The tripler uses a four-barrier planar $Al_{0.7}GaAs/GaAs$ HBV diode (UVA-NRL-1174) [3] with a 57 μm^2 device area, which is flip-chip mounted in the tripler. The measured current and capacitance characteristics for this varactor are shown in Fig. 1.

The optimum embedding impedances for 20 mW input power at ≈43 GHz for this diode were estimated to

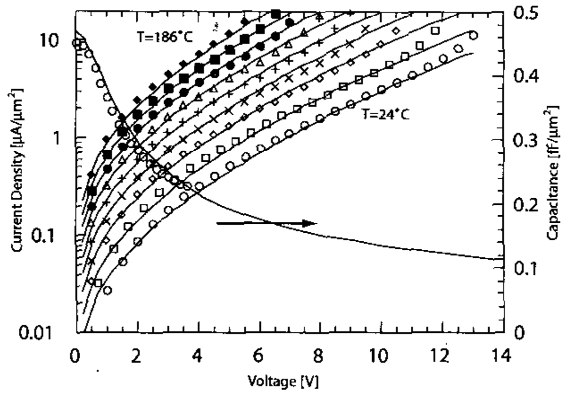

Fig. 1. Measured current versus voltage and capacitance versus voltage characteristics for the UVA-NRL-1174 HBVs.

Z1≈33+j261 and Z3≈47+j105, respectively, which yields a maximum theoretical conversion efficiency of 30% [4]. The available HBV diodes were originally designed for an input frequency of 90 GHz, resulting in the high impedance levels at this frequency.

A block diagram overview of the complete tripler is given in Fig. 2, and a close-up of the microstrip matching section is shown in Fig. 3.

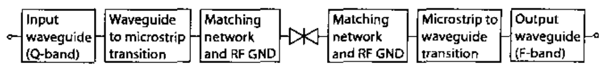

Fig. 2. Block diagram of the complete tripler.

The input port section for the fundamental frequency consists of a quarter-wave impedance transformer (Z_{f1}), a short inductive line (L_{f1}) and an RF-ground in the form of a bandpass filter. For the output port (third harmonic), the bandpass filter provides the real part of the impedance. Further, a short inductive line (L_{f3}) matches the imaginary impedance part and two shunt connected hammer head stubs provide RF-ground for the third harmonic. Similar microstrip arrangements for Schottky doublers have been exploited [5], but unlike doublers, RF-grounds for both

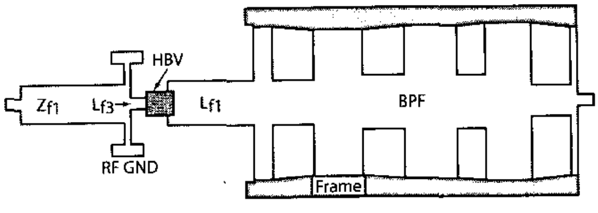

Fig. 3. The microstrip RF matching section.

the fundamental frequency and the harmonic realized with open quarter-wave stubs cannot be used for triplers. Hence a bandpass filter consisting, of a ladder network of shorted interconnected quarter-wave stubs at the third harmonic, was used [6]. The shunt connected stubs are connected together in a metal frame (Fig. 3), which was then shorted to the waveguide block.

The complete circuit with the waveguide to microstrip transitions is shown in Fig. 4, and a close-up picture of the diode and the hammer head stubs is given in Fig. 5.

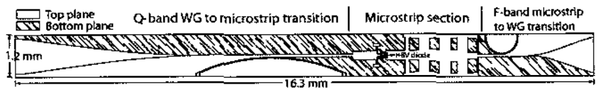

Fig. 4. Complete quartz circuit with waveguide to microstrip transitions and RF matching section.

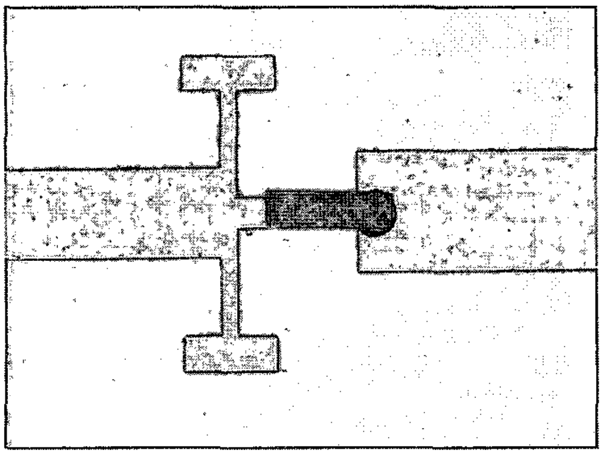

Fig. 5. A close-up picture of the flip-chip mounted HBV diode and the hammer head stubs.

Both transitions were realized with an antipodal finline taper in connection with a mode transducer in form of a semi-circle. Finline tapers have been studied by a number of researchers [7]–[10]. For these antipodal finline tapers the "optimum" TEM-taper synthesis method [11] was modified to account for non-TEM modes [8], and the required synthesis data was obtained from simulations by Ansoft HFSS [12]. The mode transducer acts as a parallel slot resonator [13], and the size and position of these were set to avoid resonances in the required frequency band.

The circuit was fabricated on 100 μm thick quartz (ε_r=3.78), and inserted in the E-plane of a custom made waveguide block as shown in Fig. 6.

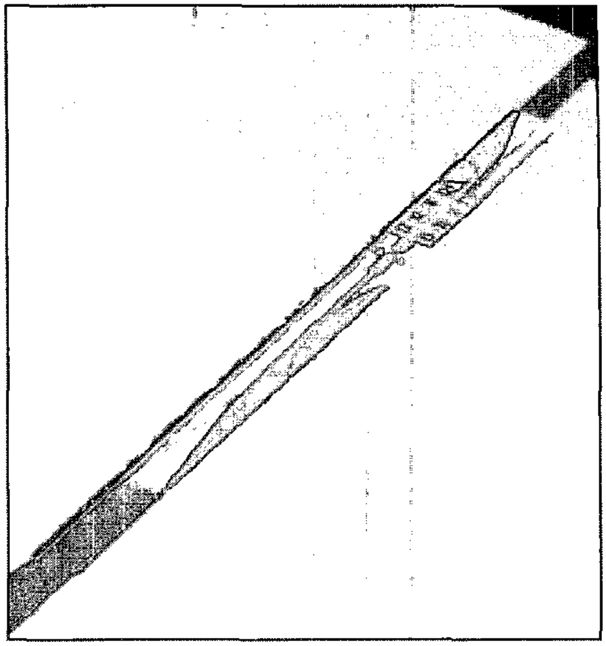

Fig. 6. The HBV tripler circuit inserted into the E-plane of the waveguide block.

The height of the WR-22 input waveguide is tapered down to match the height of the WR-9 output waveguide. Excessive large mounting grooves in the output transition, which degrade the performance, were avoided by using a reduced height waveguide section where the circuit is inserted.

The microstrip circuitry was designed by means of Agilent ADS, where the Chalmers HBV model was used [3]. Finally, the complete circuit was verified together with extraction of S-parameters, using Ansoft HFSS. The S-parameters for the fundamental frequency and the third harmonic where used in harmonic balance simulations for estimation of the tripler response. In these simulations, higher harmonics were assumed to be short circuited.

III. Results

To characterize the tripler, an Anritsu Power meter (ML 4803A) was connected to the output waveguide of the tripler block to measure output power. Input power was provided by two different klystrons to cover the frequency band (OKI 40V12 and 47V12). The simulations were carried out using Ansoft HFSS and Microwave Office.

The maximum power level that can be handled by the small area HBV diode in this frequency range is estimated to approximately 40 mW, which therefore has been the upper limit of the input power sweeps.

Fig. 7 shows a frequency sweep, where a maximum output power of -0.8 dBm with a 3% 3-dB bandwidth for an input power of 13 dBm is observed at 42.6 GHz. The general behavior shows a good agreement except for deviations in frequency, which can be related to to the modeling of the air-bridge fingers of the HBV. These fingers act as high impedance microstrip lines and whose effective length and position depends on how accurately the diode has been mounted.

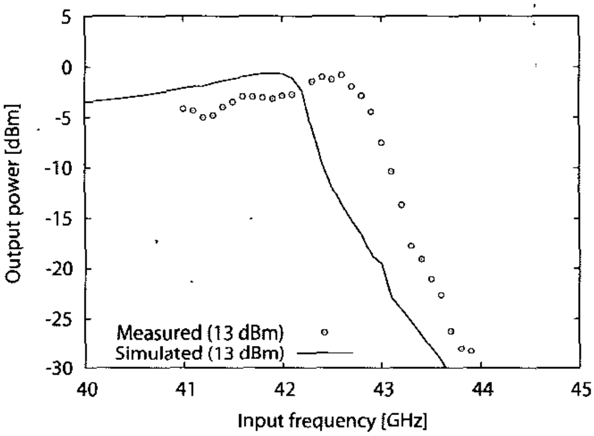

Fig. 7. Measured and simulated output power versus input frequency for an input power level of 13 dBm.

In Fig. 8 two additional frequency sweeps are presented. One with an input power of 10 dBm and the other with an input power of 16 dBm.

In Fig. 9 the conversion efficiency and output power versus input power for an input frequency of 42.6 GHz are presented. A peak flange-to-flange conversion efficiency of 4.2% is observed at an input power level of 13 dBm.

The circuit provides a good match at the fundamental frequency as shown in Fig. 10. However, the matching for the third harmonic can be improved.

IV. Conclusion

A new HBV frequency tripler design with a measured peak efficiency of 4.2% at 42.6 GHz and a 3-dB bandwidth of 3% has been presented. This is the first demonstration of a fixed tuned, single diode E-plane HBV multiplier. The proposed topology is highly suitable for low cost, compact circuits.

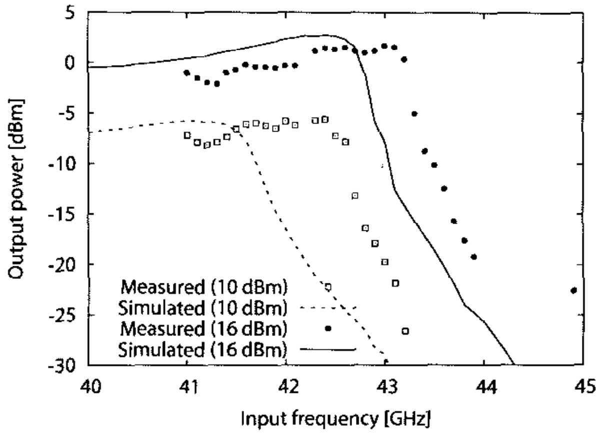

Fig. 8. Measured and simulated output power versus input frequency for input power levels of 10 dBm and 16 dBm.

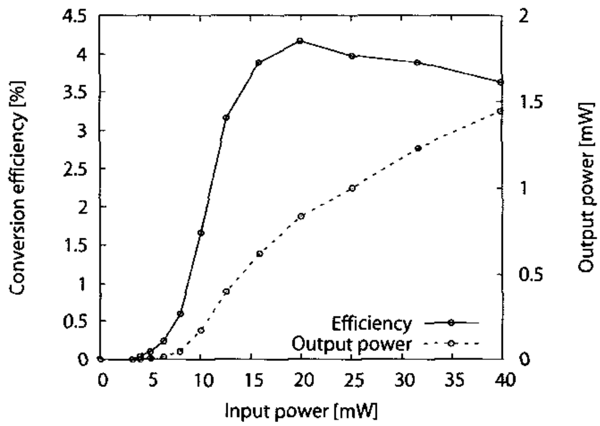

Fig. 9. Measured conversion efficiency and output power versus input power at an input frequency of 42.6 GHz.

The HBV diode used was not designed for the frequency range employed. By using a diode with a larger area or improving the impedance match at the third harmonic, Fig. 10, the conversion efficiency and the power handling capability can be increased significantly.

HBV diodes and this circuit topology have a high Q-value, which complicates the simulations. However, the good agreement between the measured results and the simulations justifies the design methods used.

With this microstrip topology, the finline transitions can be replaced by e. g. a coaxial transmission line or a conventional waveguide probe.

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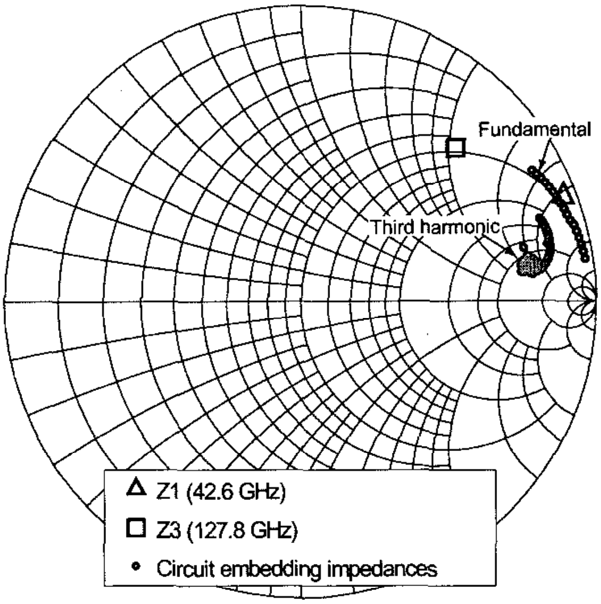

Fig. 10. The optimum impedances along with the circuit embedding impedances.

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