HBV Frequency Quintuplers

Arne Øistein Olsen, Tomas Bryllert, Josip Vukusic, Tahereh Arezoo Emadi, Peter Sobis, and Jan Stake

***Abstract*— A 500 GHz heterostructure-barrier-varactor quintupler has been designed and fabricated. The design consists of a mixture of waveguide and microstrip components for impedance matching. A InP based HBV diode is flip-chip mounted onto the quartz circuit, where beam-leads are used for ground connections to the waveguide block. Extensive back-side processing has been carried out in order to create these beam-leads. The multiplier is a frequency scaled version of a successful 100 GHz quintupler with a conversion efficiency of 11.4%.**

***Index Terms*— Harmonic generation, heterostructure barrier varactor (HBV), sub-millimeter wave, multiplier, quintupler.**

I. Introduction

Frequency multipliers are commonly used in sub-millimetre wave frequency region, due to lack of fundamental frequency sources. The heterostructure-barrier-varactor (HBV) diode [1], which only generates odd harmonics, is particularly suitable for frequency multipliers. So far the HBV has mostly been used in frequency triplers ($\times$ 3) [2]. However, recent work has been targeted onto quintupler circuits ($\times$ 5) [3], [4], that enables higher output frequency without cascading a number of multipliers.

The 500 GHz quintupler circuit is based on a previously built 100 GHz quintupler. This frequency scaled multiplier was tested with both a GaAs based [4] and a InP based 4-barrier HBV diode [5]. Measured frequency sweeps for these diodes are shown in Fig. 1.

The multiplier is tuned for optimum performance at each measurement point, and the input power is 15 dBm. A conversion efficiency of 4.7% was obtained at an output frequency of 102.5 GHz using a GaAs HBV. The quintupler performance was later improved by using a InP HBV to 11.4%, at an output frequency of 98.5 GHz with the same input power.

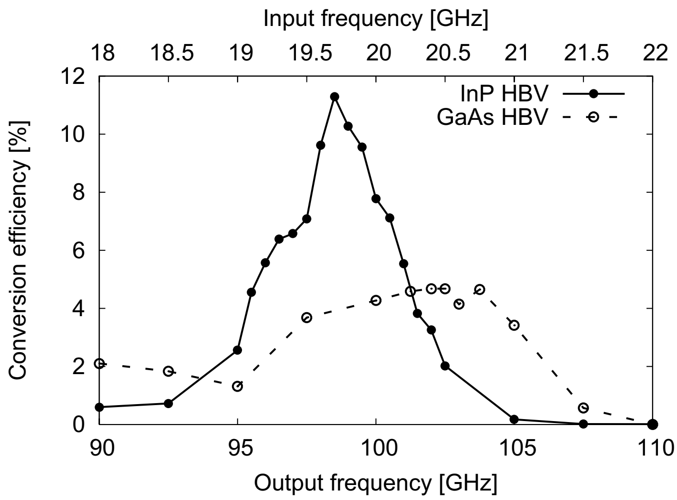

Fig. 1. 100 GHz quintupler measurement where the circuit is tuned for optimum performance at each measurement point. The input power is 15 dBm and measurements for GaAs and InP based HBV are shown.

II. Circuit operation

A mixture of waveguide and microstrip elements is used to provide the optimum diode embedding impedance. Two input waveguide tuners are used to match the impedance for the fundamental frequency. The required embedding impedances for the third harmonic (idler) and the output frequency are provided on the quartz substrate with circuit elements. However, a output waveguide back-short is added for flexibility. A picture of the waveguide block is shown in Fig. 2.

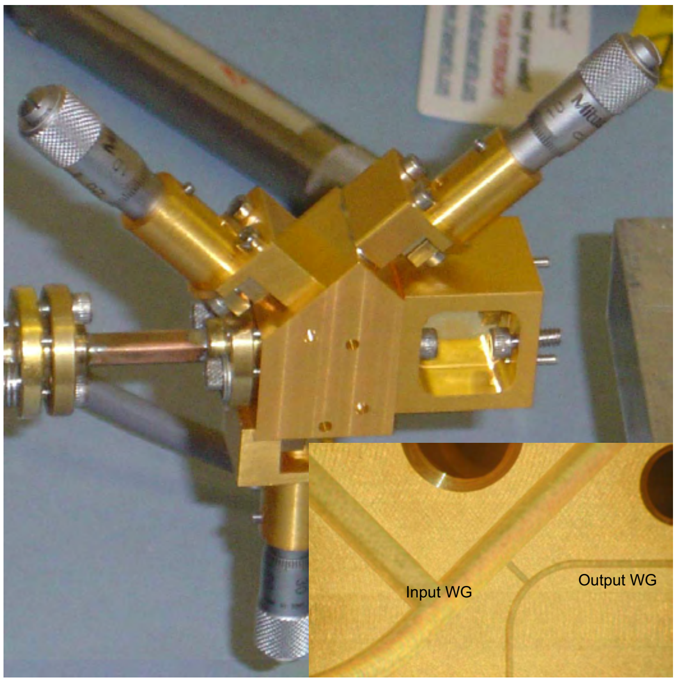

Fig. 2. Waveguide block used for the 500 GHz quintupler, and an internal view over the waveguide channels.

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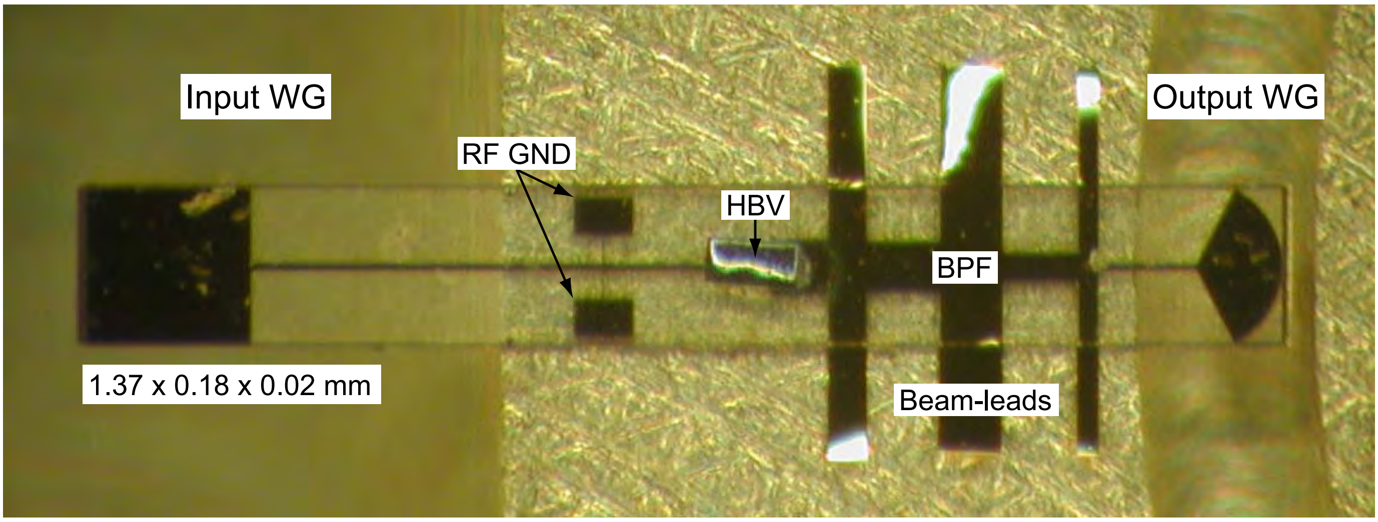

Fig. 3. Quartz circuit with the HBV, microstrip probes and microstrip circuit components.

A short rectangular waveguide section connected to the WR-8 input waveguide, and a transition block from the output WR-1.6 to WR-10 waveguide mounted at the output are also shown in the picture. The multiplier block can be spilt into two halves and an internal view of the waveguide channels is shown at the bottom of Fig. 2. Both the input and the output waveguide are bended to accommodate the waveguide tuners. A narrow channel where the circuit is placed connects the input and the output waveguides. A close-up picture of quartz circuit placed in the circuit waveguide channel is shown in Fig. 3.

The circuit substrate is 1.4 mm long, 180 μm wide and 20 μm thick. It consists of among input and output waveguide to microstrip probes. Two shunt connected hammerhead stubs and a band-pass filter provide the RF ground for the fundamental and the fifth harmonic respectively. This band-pass filter [6], which consists of a ladder-network of quarterwave shorted stubs at the fifth harmonic, also provides the real part of the embedding impedance for the output frequency. Beam-leads are used to ground the quarterwave stubs to the multiplier block, and a small amount of super-glue is used to keep the circuit in position. The HBV diode is flip-chip soldered onto the circuit, and the short inductive impedance lines connecting the diode completes the matching. Both the embedding impedances for the output frequency and the inductive idler impedance are accounted for by use of microstrip components.

III. Circuit fabrication and initial testing

Conventional photo-lithography is used to create the circuit pattern. A thin seed-layer consisting of a 70 Å thick chrome layer and gold is patterned with photoresist. The circuit pattern is plated up to an overall thickness of 1 μm. Chrome was used for the adhesive layer because of its resistance towards HF acid which is used later for the back-side processing. The 100 μm thick quartz substrate is attached upside-down onto a Si-carrier-wafer after the patterning process. A dicing saw is then used to produce the beam-leads. First is the quartz substrate lapped down to an overall thickness of 25 μm as shown in Fig. 4.

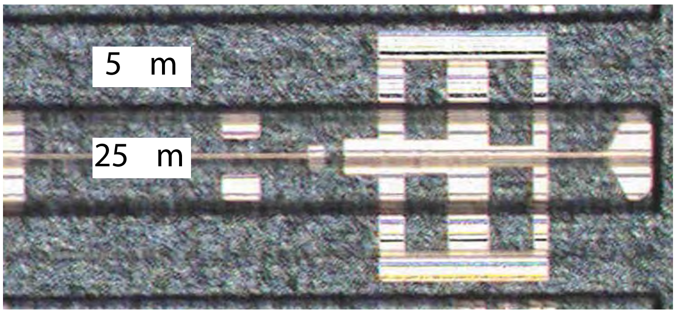

Fig. 4. Backside lapping of the quartz wafer to produce the beam-leads.

5 μm thick streets are then cut across the area above the beam-leads. The wafer is after dicing wet-etched, where 5 μm quartz is removed and the beam-leads emerge. The Cr layer is removed from the beam-leads and the circuits are separated from the carrier wafer.

An initial test has been carried out using a Gunn at 85 GHz. A couple of nano-watts was measured and the test set-up is shown in Fig. 5.

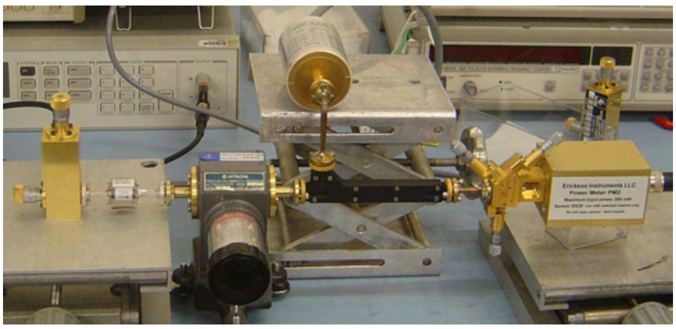

Fig. 5. Measurement set-up for the initial test consisting of a gunn oscillator, isolator, attenuator, coupler, waveguide transition and power meters.

The gunn oscillator provides 40 mW and it is connected to the multiplier through an isolator, attenuator and a coupler. The directional coupler is used to measure the reflected power.

The reflected power is used to set an initial tuning position for the input tuners. A Neil Ericksoon power meter coupled to a waveguide transition is used to measure the output frequency.

IV. Conclusion

A 500 GHz quintupler has been fabricated. It consists of backshort tuners for matching at the fundamental frequency, and conventional microstrip elements for matching at the idler and the output frequency. This quintupler is a frequency scaled version of a very successful 100 GHz quintupler. The 100 GHz quintupler obtained a conversion efficiency of 11.4% with use of a InP HBV. Extensive backside fabrication processing has been performed to create the beam-leads. Initial testing has been carried out at 85 GHz with a gunn oscillator, and an encouraging result was obtained. However, proper testing at 100 GHz input frequency with sufficient input power has to be performed to measure at the proper operation conditions.

V. Acknowledgement

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References

[1] E. Kollberg and A. Rydberg, “Quantum-barrier-varactor diodes for high-efficiency millimetre-wave multipliers,” *Electron. Lett.*, vol. 25, no. 25, pp. 1696–1698, Dec. 1989.

[2] T. David, S. Arscott, J. M. Munier, T. Akalin, P. Mounaix, G. Beaudin, and D. Lippens, “Monolithic integrated circuits incorporating InP-based heterostructure barrier varactors,” *IEEE Microwave Wireless Compon. Lett.*, vol. 12, no. 8, pp. 281–283, Aug. 2002.

[3] Q. Xiao, Y. Duan, J. L. Hesler, T. Crowe, and R. M. Weikle, “A 5-mW and 5% efficiency 210 GHz InP-based heterostructure barrier varactor quintupler,” *IEEE Microwave Wireless Compon. Lett.*, vol. 14, no. 4, pp. 159–61, Apr. 2004.

[4] A. Ø. Olsen, M. Ingvarson, B. Alderman, and J. Stake, “A 100-GHz HBV frequency quintupler using microstrip elements,” *IEEE Microwave Wireless Compon. Lett.*, vol. 14, no. 10, pp. 493–495, Oct. 2004.

[5] T. Bryllert, A. Ø. Olsen, J. Vukusic, T. A. Emadi, M. Ingvarson, J. Stake, and D. Lippens, “11% efficiency 100 GHz InP-based heterostructure barrier varactor quintupler,” *Electron. Lett.*, vol. 41, no. 3, pp. 30–31, Feb. 2005.

[6] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave filters, impedance-matching networks, and coupling structures*. McGraw-Hill, 1964.