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A NOVEL FREQUENCY TRIPLIER HYBRID COMPONENT FOR APPLICATIONS IN HIGH FREQUENCY INTEGRATED SUBSYSTEMS

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1. Introduction

A novel integrated hybrid package which consists of a frequency tripler and a micromachined waveguide for broadband harmonic generation has been designed and fabricated and has demonstrated a broad range of frequencies up to 600 GHz. The essence of this approach is that the entire circuit is produced monolithically and incorporates novel HBV devices electrically and mechanically interconnected by a low loss thin membrane. The frequency tripler is then accommodated at the E-plane of a novel micromachined waveguide to form a compact and cost effective subcomponent with high commercial potential for applications in high frequency integrated systems.

The frequency tripler utilizes the nonlinear wave propagation along the nonlinear transmission lines (NLTLs) for higher harmonic generation. NLTLs typically consist of active nonlinear semiconductor devices periodically loaded along a high impedance transmission line and the nonlinear wave propagation is generated through the interaction between nonlinearity from the active devices and dispersion from the transmission line [1]. The power in the fundamental frequency is converted to the power in the higher frequencies after the signal is propagated through the NLTL sections and the conversion efficiency is mainly determined by the nonlinearity of the NLTLs. In the design, Heterostructure Barrier Varactor (HBV) diodes were used as the nonlinear active devices due to their symmetrical capacitance-voltage characteristic which is ideally suited for frequency tripler design where only odd harmonic is generated at the output frequency [2]-[3]. This ensures most of the input power is converted into the third harmonic which helps improving the conversion efficiency. Novel HBV devices with undercut mesa were used in the design which has been shown to have higher nonlinearity [4]. The HBV devices were fully integrated with the transmission line to help minimizes the device resistances and parasitics for high frequency operation. Substrate transfer technique was used to replace the original substrate with thin membrane which acts as the new substrate for the circuit to minimize dielectric losses at high operating frequency. The frequency tripler was then integrated into a micromachined waveguide to form a hybrid component with particular attention has been paid to the electrical performance, connectivity and cost effectiveness during the design.

2. Frequency Tripler Design and Realization

The frequency tripler was designed with the input frequency from 150 to 200 GHz and input power of 20 mW. The main aim of the design is to archive broadband performance rather than maximum output power at particular frequency. The structure of the frequency tripler is shown in Fig. 1. The fundamental frequency is coupled via the WR-5 input waveguide to the NLTL sections by a broadband finline transition. Smooth impedance variation was achieved along the transition to minimize the reflection loss over the desired input frequency. A notch at the front of the transition also minimizes the discontinuity between substrate and the unobstructed waveguide and further improves the matching. The performance of the frequency tripler is determined by the nonlinearity of the NLTL sections. HBV diodes consisting of only two barriers were used because simulations showed that they exhibited a higher capacitance-voltage variation which provides a higher nonlinearity for the NLTL sections [4]. HBV diodes featuring an undercut mesa are also able to provide a higher nonlinearity by introducing a higher rate of depletion for the charge stored in the diode [4]. These HBV diodes also have a top ohmic contact which is significantly larger than the vertically etched alternatives with a

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similar junction capacitance, which significantly reduces the device series resistance. Ideally, there exits an optimum number of NLTL sections for maximum power conversion, but practical losses such as device series resistance and distributed section parasitics lower the optimum number of NLTL sections. The undercut HBV diodes help to reduce the optimum number of NLTL sections whilst maintaining good conversion efficiencies due to their higher nonlinearity. The reduced number of devices and interlinking sections and associated resistances simplifies the design of the frequency tripler and improves the fabrication yield. Six NLTL sections were used for the final frequency tripler design for optimum conversion efficiency. The Bragg's cutoff frequency of the NLTL sections was set at 650 GHz. Thus the fifth harmonic is rejected from appearing at the output via the band-pass characteristic of the NLTL sections [1]. This ensures majority of the input power is converted to the third harmonic, helping to improve the conversion efficiency. After generation and propagation through the NLTL sections, the third harmonic is coupled into the output waveguide using another finline transition, which acts as a broadband antenna and radiates the power to the output waveguide.

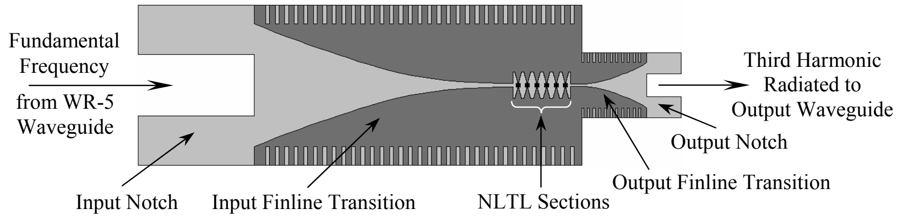

Fig. 1. Layout design of the fully integrated membrane supported frequency tripler.

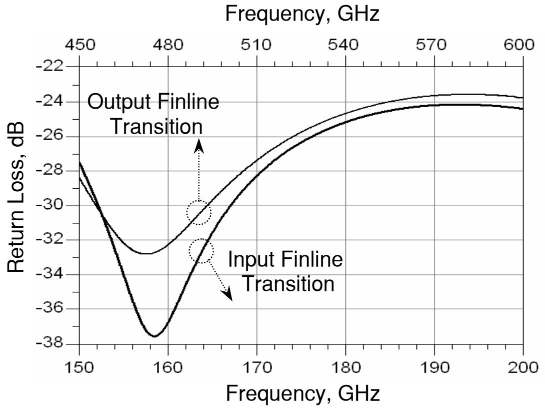

Fig. 2. Simulated return loss of the input and output finline transitions by using Agilent High Frequency Structural Simulator (HFSS).

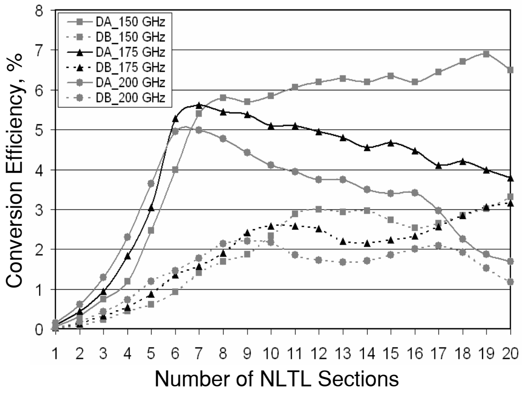

Fig. 3. Simulated conversion efficiency with different number of NLTL sections and input frequencies.

The HBV layers were grown on an InP substrate and were first etched by wet chemical process to form an undercut mesa body as shown in Fig. 4. A larger mesa was then formed which acts to separate the active devices from one another as shown in Fig. 5. Gold and silver overlays were used as the low resistance interconnect between the HBV diodes and then form the NLTL sections as shown in Fig. 6. Silver was used to pattern the finline and the input and output transitions as shown in Fig. 7. The entire circuit was then coated with SU-8 resist, which forms the membrane substrate and includes the patterning for the input and output notches. The entire circuit was then lifted-off from the InP substrate, via mechanical polishing followed by HCl etching. The circuit is now mechanically supported by the SU-8 membrane which acts as the low loss new substrate for the entire circuit. SU-8 was used due to its properties of having both low dispersion and a low relative dielectric constant, which are critical where dielectric losses become dominant factors for high frequency propagation.

3. Waveguide Machining and Integration

The frequency tripler was accommodated by a micromachined rectangular waveguide featured with stepped impedance to control the generation of higher order mode. The waveguide blocks were fabricated using a novel high precision micromachining technique [5] which have high dimensional accuracy and excellent surface quality and favours precise integration of E-plane circuit such as the frequency tripler. The precise alignment of the frequency tripler to the waveguide blocks is facilitated by the photolithography itself. The waveguide blocks were then mounted by a specially designed metal block for measurement. Both the metal blocks where aligned to each other using alignment pins and then clamped together firmly and precisely. This formed a hybrid component which has accurately controlled features and predictable parasitics which is suited for high frequency wave propagation.

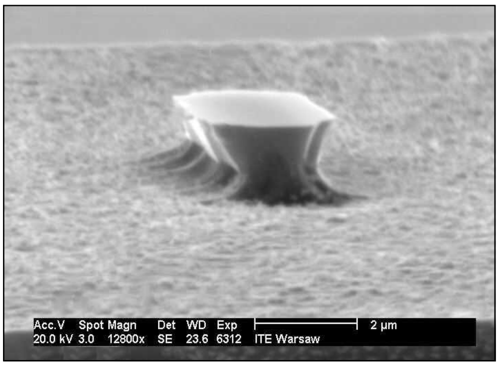

Fig. 4. HBV mesa with an undercut to provide higher nonlinearity for the NLTL sections.

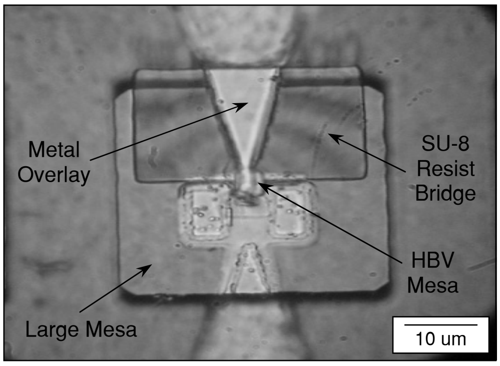

Fig. 5. Optimized HBV and interconnection layout to minimize device resistance and section parasitics.

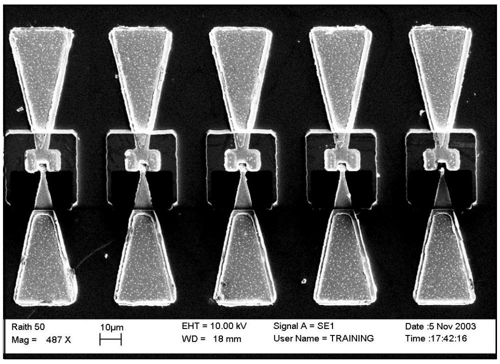

Fig. 6. NLTL sections before the deposition of low resistance metal finline transmission line.

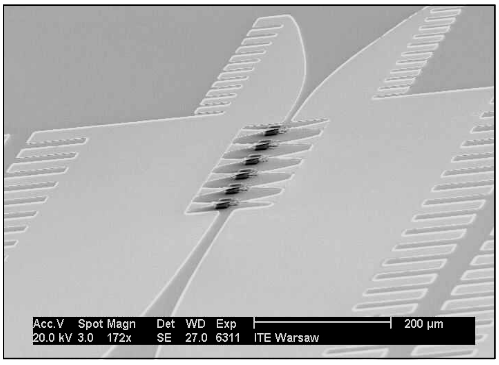

Fig. 7. NLTL sections integrated with the finline together with the input and output transitions.

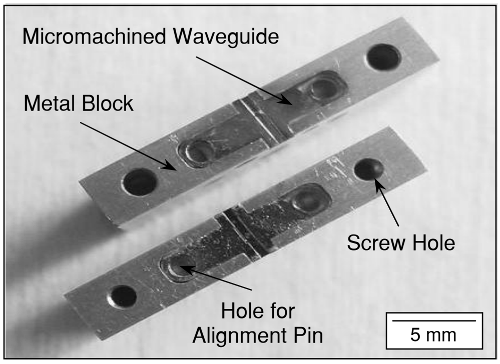

Fig. 8. Micromachined waveguide blocks mounted by the metal text fixture for measurement.

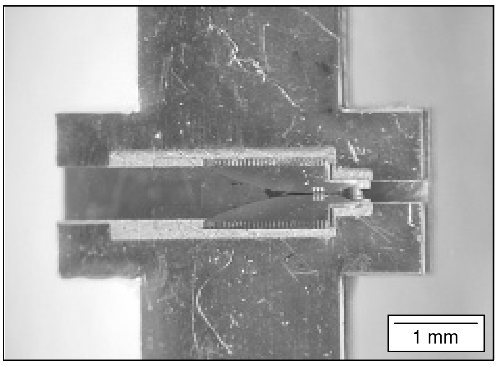

Fig. 9. Membrane supported frequency tripler accommodated by the micromachined waveguide.

4. Measurement and Discussions

A 115 to 190 GHz Backward-wave oscillator (BWO-06S) with an output power up to 17 dBm was used to excite the frequency tripler. A variable attenuator was connected between the BWO and the frequency tripler block to enable the power level to be optimized before input to the frequency tripler block. A conical horn was connected to the output of the frequency tripler block and radiated the output power via free space to an interferometer. The configuration used to detect and measure the generated signals, is shown in Fig. 10. The generated harmonics were detected by a calibrated Golay cell and frequency domain signals extracted using LABVIEW and a lock-in amplifier, chopper and controller. Absorbing material was placed around the measurement setup to prevent unwanted signals from entering the Golay detector, and the measured results are shown in Fig. 11. The generated power was lower than expected and our suspicions for the cause for this lie with the integrity of the HBV diodes where the resistivity of the ohmic contact was known to be much higher than desired which subsequently increases the contact losses. A significant portion of the generated power also probably lost during the free space propagation before entering the Golay detector. Higher order modes may also be generated inside the frequency tripler block (but not pass to the output) which would also reduce the output power level at the third harmonic. Although the generated and detected power was very low, the frequency tripler did nevertheless exhibit tripling over a broad frequency range as intended by the design. The frequency tripler "package" also very successfully demonstrates the strength of this integration approach, featuring micromachined cavities and low loss membranes, and which is simple and straightforward to produce for millimeter and submillimeter wave operations.

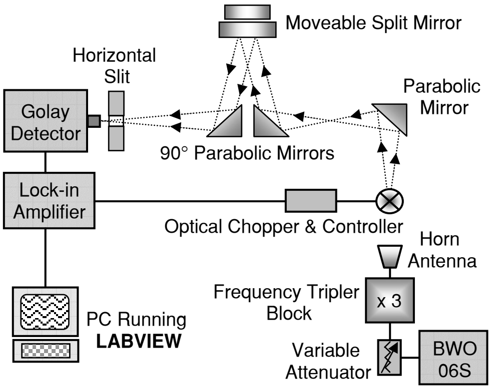

Fig. 10. Setup of the interferometer for the measurement of the generated harmonics.

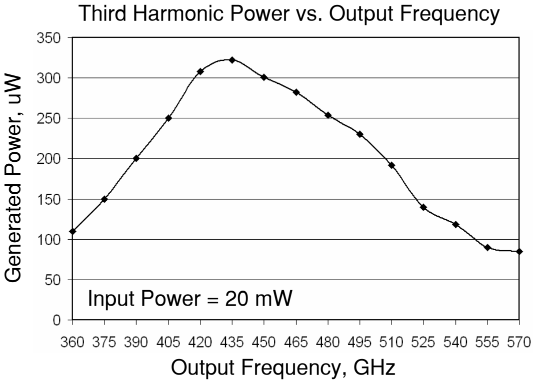

Fig. 11. Measurement of the generated output frequency and power with 3 dB bandwidth of 55%.

5. Conclusion

An integrated frequency tripler package for broadband harmonic generation has been presented, by employing a novel HBV structure and fully integrated circuit on low loss membrane. This helps greatly to reduce the device parasitics and enables the devices and associated circuit to operate at higher frequencies and with higher conversion efficiencies. The micromachined waveguide also allows compact hybrid subcomponents to be formed with accurately controlled features and predictable parasitics for high frequency operation.

6. References

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