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# A Wideband H-Band Image Detector Based on SiGe HBT Technology

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## Abstract

A wideband H-band detector operating near 300 GHz has been developed based on SiGe HBT technology. The detector consists of an on-chip antenna and a HBT differential pair for square-law detection. It showed responsivity of more than 1,700 V/W and noise equivalent power (NEP) smaller than 180 pW/Hz$^{0.5}$ for the measured frequency range of 250–350 GHz. The maximum responsivity and the minimum NEP were 5,155 V/W and 57 pW/Hz$^{0.5}$, respectively; both were obtained at 330 GHz with DC power dissipation at 9.1 W.

**Key Words**: Detector, Imaging, SiGe HBT, Terahertz, Wideband.

## I. INTRODUCTION

The continuous scaling and material innovations in the semiconductor technologies in recent decades have led to transistors with $f_{max}$ up to 500 GHz [1] and beyond 1 THz [2, 3] based on Si and III−V semiconductors, respectively. This improved speed has triggered device application at increasingly high frequency bands, penetrating into the THz band (300 GHz to 3 THz). The THz band has lots of unique properties, such as high absorption in water, high transparency over paper, plastic, and clothes, and it has no harmful ionization effects on biological tissues. However, the band has been traditionally less developed compared to its neighboring microwave and optical bands due to the lack of properly operating devices in this band and its strong attenuation in the earth's atmosphere. Now with the advent of high speed semiconductor devices, there is a growing opportunity to exploit the useful properties of the THz band. One of the applications based on this band is imaging, which benefits from its wavelength being smaller than the microwave and its small chip size when implemented on-chip. This work presents a wideband THz detector operating near 300 GHz, developed in SiGe HBT technology.

## II. CIRCUIT DESIGN

There are two types of image detection schemes widely adopted for THz imaging: direct detection and heterodyne detection. Heterodyne detection tends to show lower noise level [4], while direct detection can be implemented with a compact size and small power dissipation [5]. Hence, they are attractive for single-pixel and array imaging applications, respectively. The detector developed in this work is for direct detection.

Fig. 1 shows the schematic of the detector, which is composed of a detector core and an on-chip integrated antenna. The detector core consists of a common-base (CB) differential pair ($Q_1$ and $Q_2$) [6] and an impedance matching network ($T_1$–$T_4$). Due to the nonlinearity of the transistors, the collector current of each transistor bears a square term of the input signal. At the

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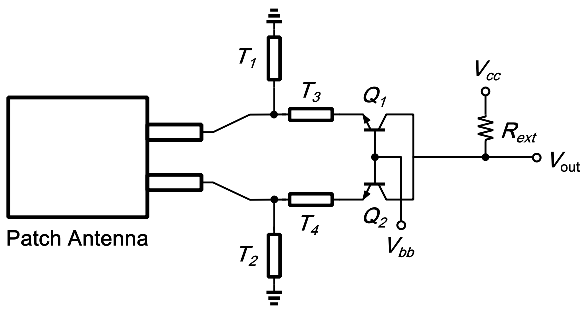



Fig. 1. Schematic of the H-band detector.

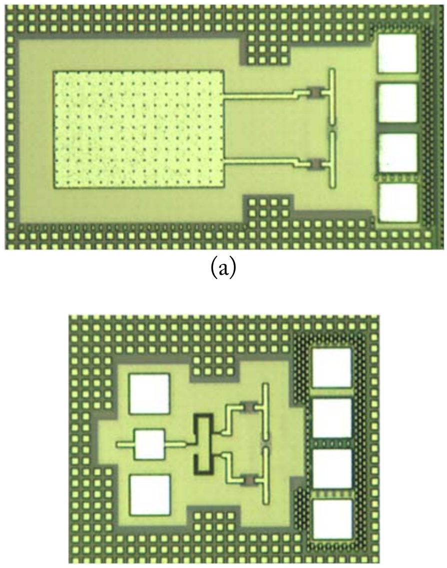
common node at the collector, the square terms (and other even-order term) survive with superposition, while the fundamental terms (and other odd-order terms) are cancelled out due to the differential operation. From the square term at the common node, a DC component can be extracted that is proportional to the input power. Hence, the circuit operates as a square-law detector. Compared to the common-emitter (CE) configuration which is also popular for detectors, CB configuration benefits from the emitter-to-collector capacitance being much smaller, leading to negligibly small RF input signal leakage to output. This also obviates the need for the collector RF choke that is typically included for detectors based on CE configuration. Collector bias is supplied through an external resistor, which provides flexibility in circuit operation.

For the on-chip antenna, the differential patch type is employed, so that differential input signal can be applied to the detector core without need for an input balun. Simulated gain and efficiency of the antenna is 3.86 dB and 53.5% at 300 GHz, respectively.

## III. Measurement Results

The circuit was fabricated in IHP 130-nm SiGe HBT technology [1]. A chip photo of the fabricated detector is shown in Fig. 2(a). The chip size is 820 × 400 μm², including the antenna and bonding pads. A version without an antenna was also fabricated, as shown in Fig. 2(b). This was intended for on-wafer probing that will facilitate the electrical characterization.

Firstly, electrical characterization was carried out with the circuit shown in Fig. 2(b). To allow for a single-ended measurement, a balun was added in the circuit at the input. The input signal was generated with an H-band ×24 frequency multiplier connected to a signal generator. The power of the injected input signal was monitored through a directional coupler and an attached Erikson PM4 power meter. An H-band atenuator was inserted before the coupler so that the input power level could be adjusted. It is noted that the input signal was electrically modulated at 20 kHz to suppress the low frequency noise at the detector. Hence, the output of the detector is in fact a modulated signal, which was acquired with an audio signal



(a)

(b)

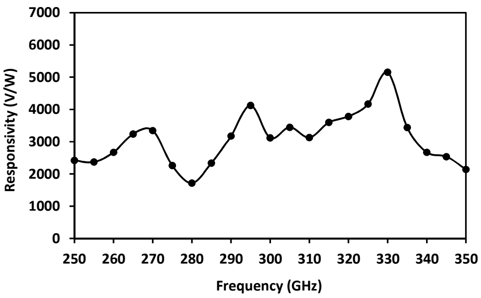
Fig. 2. Chip photos of the fabricated detector with on-chip antenna (a), and with on-wafer probing pads (b).

analyzer to test the magnitude and noise level. Fig. 3 shows the measured responsivity and noise equivalent power (NEP). A peak responsivity of 5,155 V/W was obtained at 330 GHz, while maintaining values higher than 1,700 V/W for the entire measured frequency range of 250–350 GHz. Measured NEP ranges roughly 60–180 pW/Hz$^{0.5}$ for the same frequency span. The minimum value was 57 pW/Hz$^{0.5}$, observed also at 330 GHz. This value is favorably compared with other results reported [6]. The measured large bandwidth of the detector can be attributed to the short microstrip lines employed in this work, which lead to a decreased Q-factor of the matching network. In addition, the large bandwidth of the employed CB configuration for the detector helped [6]. The measurement was made with a bias condition of $V_{bb}$ = 0.7 V and $V_{cc}$ = 2 V, leading to a DC power dissipation of 9.1 W.

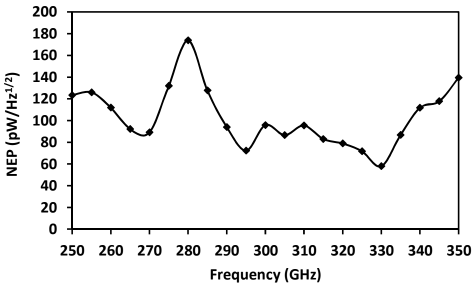
Secondly, THz images were acquired with the fabricated detector. The imaging setup is illustrated in Fig. 4. The signal from a signal generator is converted up to the H-band through a ×24 frequency multiplier and then radiated from a horn antenna. The radiated THz beam is focused on a target object through a couple of lenses and then re-focused on the detector with another set of lenses. The object is 2D scanned by a computer-controlled moving stage. The output signal from the detector is processed to reconstruct the THz 2D image of the object. Fig. 5 shows an example image obtained from the setup at 300 GHz, which reveals the internal structure of a floppy disk, well representing the characteristics of THz imaging.

## IV. Conclusion

In this work, a wideband H-band detector operating near a




(a)




(b)

Fig. 3. Measured performance: (a) responsivity, (b) noise equivalent power (NEP).

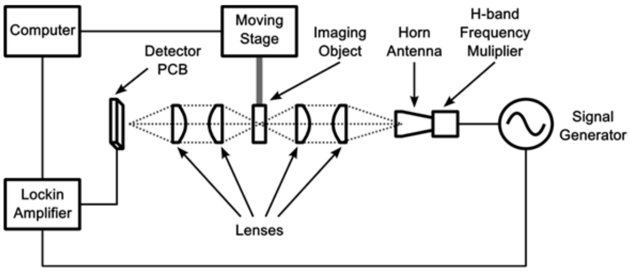



Fig. 4. Setup for image acquisition.

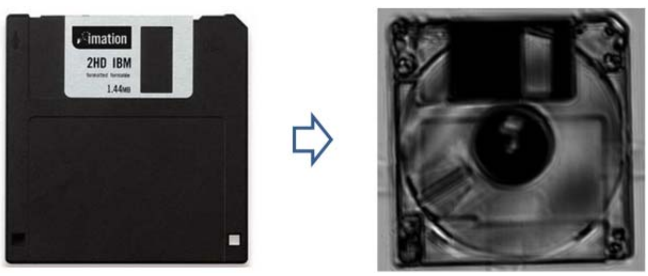



Fig. 5. Acquired image of a floppy disk obtained with the fabricated detector.

300 GHz band was developed based on SiGe HBT technology. It showed a peak responsivity of 5,155 V/W and a minimum NEP of 57 pW/Hz$^{0.5}$; both were obtained at 330 GHz. The results show that the developed detector is a promising candidate for high resolution THz imaging with a wide frequency range.

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