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300-GHz Dual-Beam Frequency-Selective On-Chip Antenna for High-T_c Superconducting Receivers

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***Abstract* – This paper presents a novel terahertz (THz) on-chip antenna design for high-T_c superconducting (HTS) heterodyne receiver frontends. The antenna includes a two-element ring-slot array in conjunction with a hemispherical lens, which generates highly-directional dual radiation beams with stable angular separation, thus significantly facilitating the quasi-optics design for coupling radio-frequency (RF) and local oscillator (LO) THz signals. Besides, a double-layered band-pass frequency selective surface (FSS) is designed, and integrated in the THz on-chip antenna to filter out external interferences other than 300-GHz band for maximizing the HTS receiver frontend's noise performance. Numerical simulation shows that the antenna achieves a coupling efficiency of -3.5 dB and a realized gain of 13.5 dB at 300 GHz, and exhibits very stable radiation performance over the whole operating bandwidth of 283 to 316 GHz.**

***Index Terms* — THz On-chip antenna, dual beam, frequency selective surface, high-T_c superconducting receiver.**

1. Introduction

HTS Josephson-junction mixers are promising heterodyne receiver frontends for THz communication and sensing systems. These devices have numerous attractive features, such as low noise, low LO pumping power, wide intermediate-frequency (IF) bandwidth, and in particular capable of operating at higher temperatures (thus requiring smaller and cheaper cooling systems) compared to those low-T_c superconducting counterparts. Recent research progress in HTS THz mixers has been reported in the open literature [1]-[4].

To guarantee the noise and conversion performance of the HTS THz receiver frontend, a superior quasi-optics design is always desired for effectively coupling the THz signals whereas rejecting other unwanted electromagnetic interferences. Currently reported HTS THz fundamental mixers generally adopt a quasi-optical configuration [see Fig. 1(a)]: a beam splitter is applied to combine the RF and LO THz signals coupled into the HTS mixer module through the cryocooler window; a THz filter used to suppress external electromagnetic interferences for receiver noise minimization. Obviously, such a quasi-optical configuration not only makes the receiver frontend system so cumbersome but increases the efforts in alignment adjustment, thus bringing much inconvenience when applied in THz communication or sensing systems. As shown in Fig. 1(b), this paper presents an improved quasi-optics design based on a novel THz on-chip antenna, which features highly-directional dual beams for coupling RF and LO signals, respectively, and integrates a double-layered FSS for interference rejection. This new antenna greatly simplifies the quasi-optics configuration enabling the whole receiver frontend architecture to be much compact and thus more suitable for practical THz wireless applications. The specific design details and simulation results of the presented THz on-chip antenna are discussed in this work.

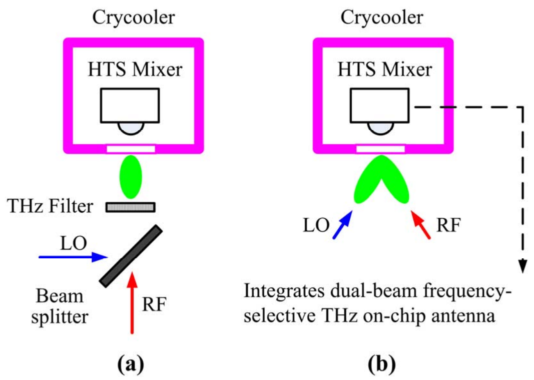

Fig. 1. Quasi-optics design for the HTS THz receiver frontend: (a) Conventional configuration; (b) improved configuration with the presented THz on-chip antenna.

2. Antenna Design and Simulation

Fig. 2 shows the geometry of the presented 300-GHz dual-beam frequency-selective on-chip antenna, which has a multi-layered feature including the gold thin-film radiator network, MgO (relative permittivity ε_r = 9.63) and High-resistivity silicon (HRSi; ε_r = 11.68) substrates, double-layered FSS, followed by a HRSi hemispherical lens with an anti-reflective (AR) Parylene (ε_r = 2.62) coating. The main radiator is a two-element ring-slot array fed through the coplanar waveguide (CPW) transmission line by a HTS Josephson junction integrated at its port. The CPW line also behaves as an impedance transformer that reduces the mismatch between the high-resistance ring-slot antenna and the low-resistance Josephson junction. On left side of the ring-slot array is a CPW isolation network for preventing the leakage of THz current onto the microwave IF port. Taking advantage of the offset center effect of the ring-slots relative to the HRSi lens, a highly-directional dual-beam radiation can therefore be produced by the presented on-chip antenna. On the other hand, although the ring-slot antenna exhibits narrowband operation characteristics around its resonant frequency, it would also couple those unwanted interference signals in the neighboring parasitic bands owing to the presence of the CPW matching and isolation networks. Hence, a double-layered band-pass FSS made up of Jerusalem-cross slots is designed and embedded between the HRSi substrate and the hemispherical lens to suppress the parasitic interferences.

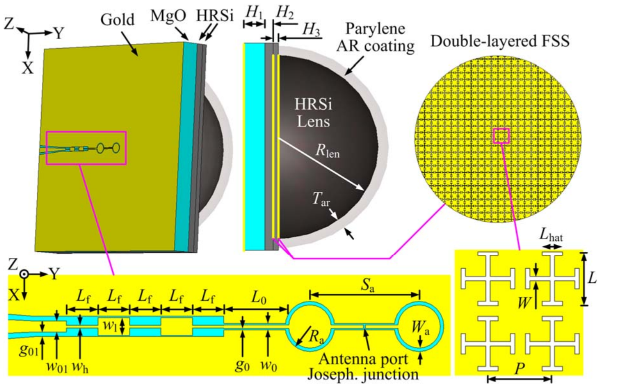

Fig. 2. Geometry of the 300-GHz dual-beam frequency-selective on-chip antenna. The final structural parameters after optimizations are: R_{len} = 1.5 mm, H_1 = 300 μm, H_2 = 120 μm, H_3 = 80 μm, T_{ar} = 154 μm, w_{01} = 36 μm, g_{01} = 16 μm, w_h = 8 μm, w_l = 60 μm, w_0 = 12 μm, g_0 = 5 μm, L_f = 108 μm, L_0 = 216 μm, R_a = 85 μm, W_a =12 μm, S_a = 374 μm, P = 120 μm, L = 100 μm, W = 8 μm, L_{hat} = 38 μm.

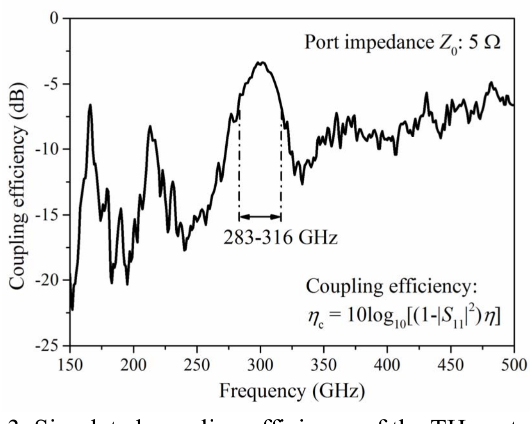

Fig. 3. Simulated coupling efficiency of the THz antenna.

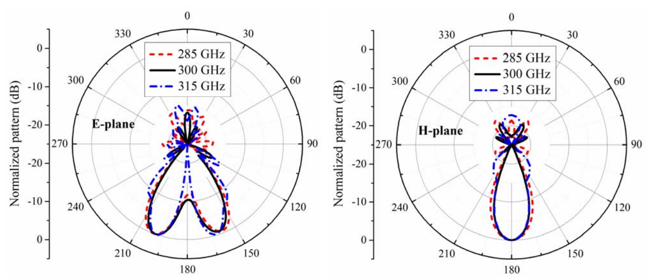

Fig. 4. Simulated radiation patterns on the E- and H-planes.

The THz on-chip antenna is analyzed and optimized using the software Computer Simulation Technology (CST) Microwave Studio. Fig. 3 shows the simulated coupling efficiency of the antenna, which is defined as

$$\eta_c = 10\log_{10}\left[\left(1-|S_{11}|^2\right)\eta\right] \quad (\text{dB}) \qquad (1)$$

where S_{11} is the reflection coefficient, and η is the radiation efficiency. Here, the port impedance is assumed as 5 Ω, a typical value of the junction normal resistance. Clearly, the antenna exhibits a coupling efficiency of around -3.5 dB at 300 GHz and a 3-dB operating bandwidth from 283 to 316 GHz. Fig.4 shows the simulated radiation patterns on the E-plane (YZ plane) and H-plane (rotating the XZ plane around the X−axis by 20°). The antenna has very stable radiation patterns over the whole band of interest, producing highly-directional dual beams towards the directions of (160°, 90°) and (200, 90°), respectively. Fig. 5 shows the simulated realized gain in the main-beam direction, achieving 13.5 dB at the frequency of 300 GHz. Compared to the same design but removing the FSS, the parasitic-band radiations are effectively suppressed.

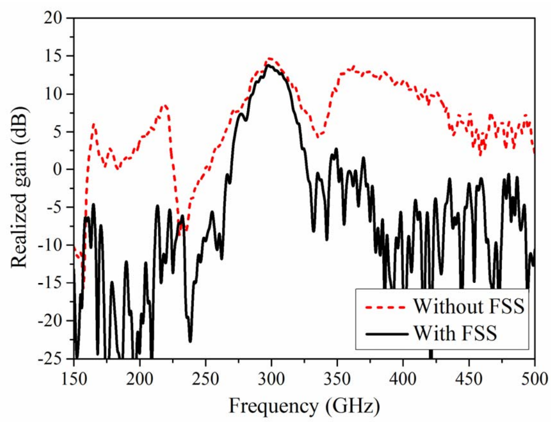

Fig. 5. Simulated realized gain in the main-beam direction.

3. Conclusion

This paper presents a novel dual-beam frequency-selective THz on-chip antenna. Detailed design and simulation results were provided, which showed a very good performance of the antenna and its great potential of application in THz communication and sensing systems.

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