A Superconducting Phase Shifter and On-Chip Fourier Transform Spectrometer for W-Band Astronomy

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Overview

W-Band (75-110 GHz) contains a plethora of information about star formation, galaxy evolution, and the cosmic microwave background. We designed and fabricated a dual-purpose superconducting circuit to facilitate the next generation of observations in this regime. In phase shifter mode, our device provides circuit parameters to design and optimize kinetic inductance parametric amplifiers (KIPs) that offer substantial bandwidth, dynamic range, and noise performance improvements over state-of-the-art transistor-based amplifiers. Our device can also operate as an on-chip Fourier transform spectrometer (FTS) which is much smaller than a mechanical FTS and has no moving parts. In order to characterize this circuit and other W-Band devices, we have developed a cryogenic waveguide feedthrough to deliver W-Band signals to our DUTs.

Predicted Results

Figure 3: FPM over 1 m of w = 3 μm NbTiN line at 90 GHz under l = 0.12 mA DC bias (Gordon et al. 2015) (left). Predicted phase shift and quadratic gain for same parameters (right). True KIP gain is exponential function of Δφ(T), but simulation excludes dispersion features, which also explains relatively small gain.

Device Fabrication & Packaging

Step 1: Deposit NbTiN on SOI
Step 2: Pattern Device Side
Step 3: Etch NbTiN
Step 4: Pattern Handle Side
Step 5: Handle Si DRIE

Figure 4: Phase shifter/On-chip FTS fabrication process. NbTiN is deposited via reactive sputtering. Central hole shown in Step 5 is etched completely through handle Si and mates with raised section of package backplate (shown in Figure 6). DRIE also separates die from wafer along scribe lines.

Waveguide Feedthrough

Figure 7: W-Band waveguide feedthrough design (left) with enlarged views of vacuum window (based on Edids et al. 2005 design) and thermal break (modified Melhuish et al. 2016 design). Gap between warm and cold horns is 0.256 μm. Model of our pulse tube cryostat with feedthrough installed (right).

• Delivers W-Band signals to DUT mounted on 4K stage while minimizing heat load on cooling system
• Avoids stray light issues that complicate solutions employing mirrors and lenses
• Within 50 dB electromagnetic loss budget for phase shifter testing
• Provides in-house capability to test future W-Band devices
• Potentially scalable to higher frequencies

Summary & Future Work

• Designed NbTiN phase shifter/on-chip FTS for applications in W-Band astronomy
• Fabricated Nb prototype and designed package
• Developed feedthrough for W-Band testing

Next Steps

• Integrate feedthrough into cryogenic testbed
• Nb prototype continuity test
• Fabricate NbTiN device and measure Δφ(T)

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