1.5 THz Low Noise Schottky-Diode Mixers

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Abstract

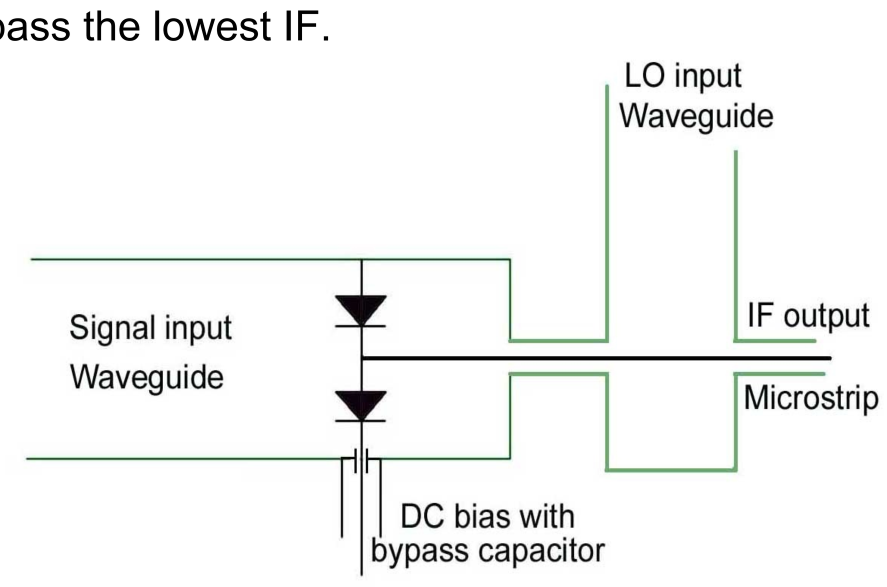
Schottky diode mixers are competitive in noise as ultra-wideband mixers in the THz range. We have built a balanced mixer at 1.5 THz with a noise temperature that should be close to that of HEB mixers but with much better stability and an IF bandwidth >100 GHz, limited only by the IF amplifier. LO power is within the range that may be produced by a quantum cascade laser. This mixer is also useful as a harmonic mixer using a ~100 GHz LO to measure the laser frequency.

The same mixer can also be used as an upconverter to generate tunable sidebands on a fixed laser at ~23µW power level that could pump an HEB mixer.

Low Noise Mixer with Wide IF Bandwidth

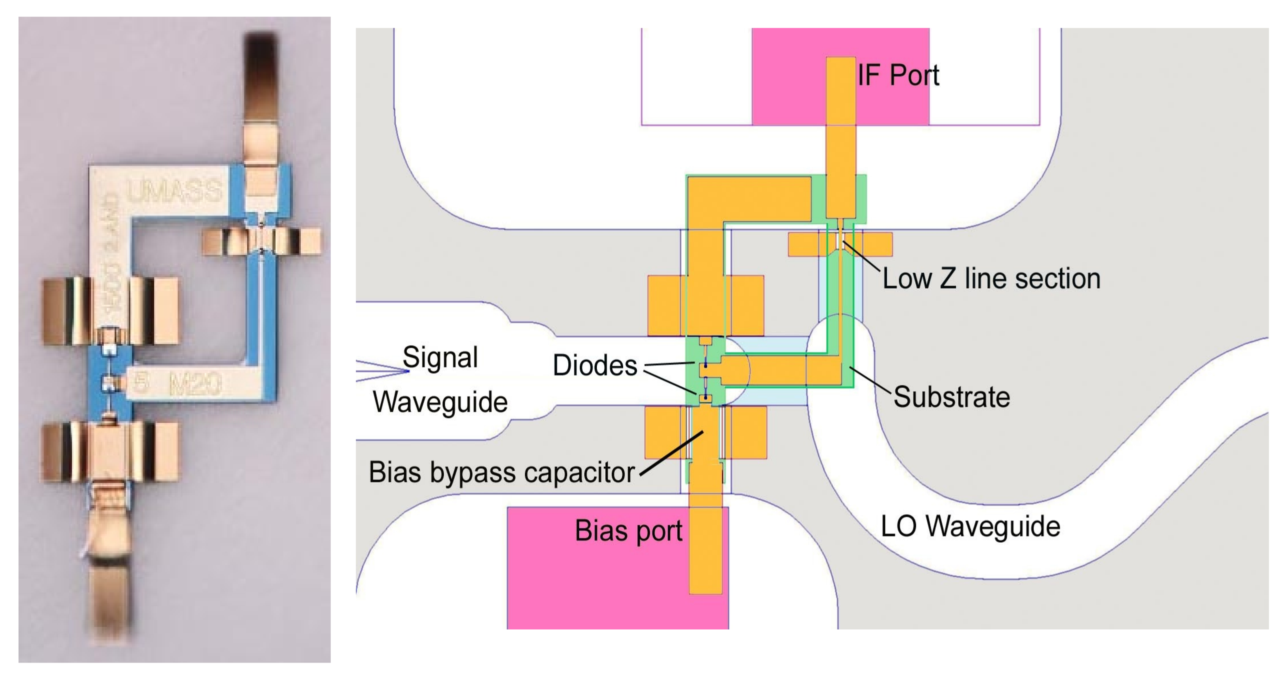
Mixer and MMIC Design

The mixer is based on crossbar waveguide balanced mixers. Separate waveguides are used for the LO and signal and symmetry ensures high isolation between them. The LO port and IF output are common to the diode center point requiring a simple diplexer. The bias port must have sufficient capacitance to bypass the lowest IF.



Schematic diagram of a balanced crossbar mixer.

The MMIC wafers were fabricated at JPL, and the chip includes most of the circuit function. The diode substrate is 3 µm thick GaAs with beam lead contacts for ground, IF and bias. A SiN layer with thickness 0.1 um is used to produce a 1.0 pF capacitor to bypass the bias port. The beam leads completely suspend the fragile substrate. The mixer block is split along the E plane centerline, which is the mounting plane of the diode. At the end of the LO waveguide probe, a high impedance line continues along the axis of the waveguide through the backshort, forming the IF port. A low impedance section of line in the IF port improves the LO rejection. The block was machined in brass as an E-plane split-block.



Photograph of the diode and installation in the mixer. The GaAs substrate appears blue in the photo. Signal and LO waveguides transition to identical diagonal horns on opposite sides of the block.

IF Bandwidth

The two diodes are in parallel to the IF port, halving the IF impedance, which eliminates the need for an IF matching circuit. The off-chip IF circuit is simply a 50 ohm line, which enables a nearly unlimited IF bandwidth

Predictions from HFSS show that the IF band should extend beyond 120 GHz, increasing with the operating frequency. At the low end of the band the limitation is the on-chip bypass capacitor in the IF port. Good IF performance occurs down to ~3 GHz. The IF return loss has been measured to 50 GHz with DC bias only and is >12 dB over this band.

Mixer tests at room temperature

LO 1561 GHz, IF 3 GHz, T_{IF} ~150 K.

LO power ~1 mW, DC bias current of 1 mA.

Y factor = 1.050 with 297K / 77K loads, Tr = 4500K DSB.

Assuming T_{diode} ~300 K ⇒ T_{mix} ~3000 K DSB, L_c ~10 dB.

DC bias and LO power not optimized, and much better IF amps are available. This noise is substantially lower than any other Schottky mixer results at a similar frequency.

Design band of 1250-1650 GHz, verified with a similar prototype design.

Cold operation

The noise from THz Schottky mixers drops by only a factor of ~2 when cooled. **The best cold receiver noise with this mixer might be ~1600 K DSB, but since the diode noise dominates, similar noise may be achieved up through a very high IF.** HEB mixers in this range have receiver noise temperatures ~1200-1500 K, but IF bandwidth ~3 GHz, so this Schottky mixer should be very competitive in applications requiring wide bandwidth. Experience with Schottky diode mixers at lower frequencies has shown them to have the best dynamic range and stability of any type of mixer.

Noise should rise ~linearly with frequency up to 3 THz using scaled devices from this wafer, leading to a simple all solid state receiver with wide frequency coverage through use of the >120 GHz wide IF.

High Harmonic (N = 16) Mixing

A challenge with THz lasers is a means of locking their frequency. Comparison to a microwave reference via harmonic mixing has not been practical in the THz range due very high conversion loss. Conversion loss rises ~ 3 dB per harmonic. A very high LO is needed to reduce the harmonic number N to below 20 and the conversion loss to ~60 dB.

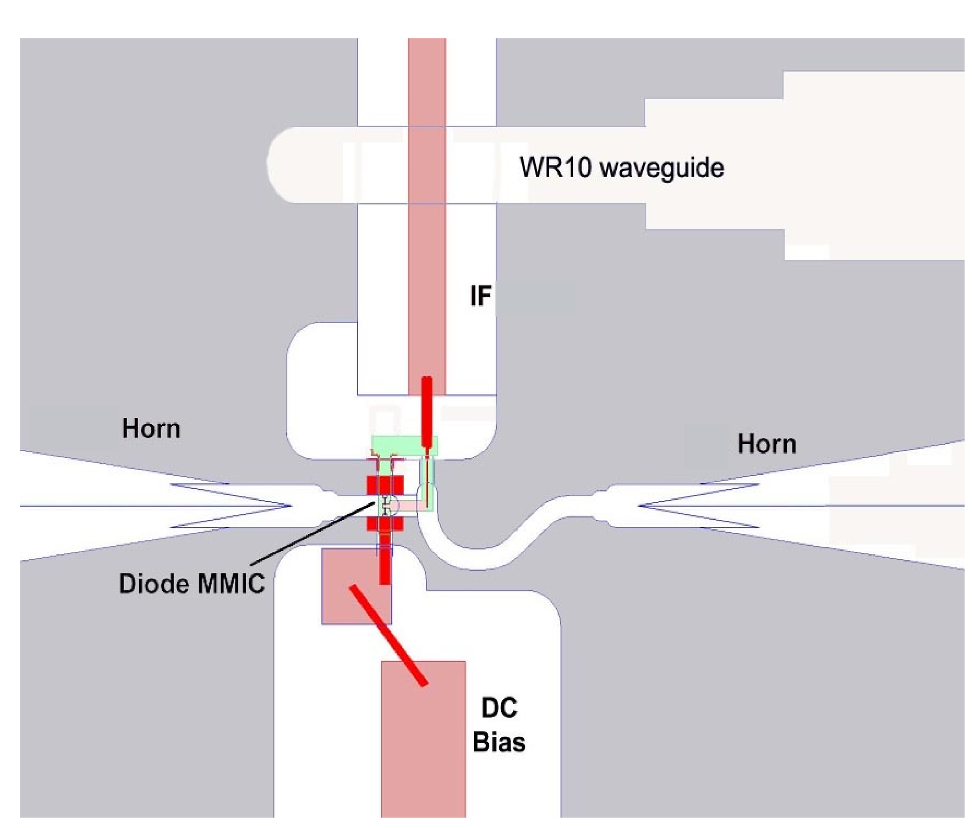
A WR 10 waveguide was added to one mixer, coupling to the IF microstrip line, but leaving the coaxial IF port functional for low frequencies, as shown at right.

1561 GHz laser mixed with LO at 97.4 GHz (N = 16)

LO from synthesizer followed by x8 active multiplier chain.

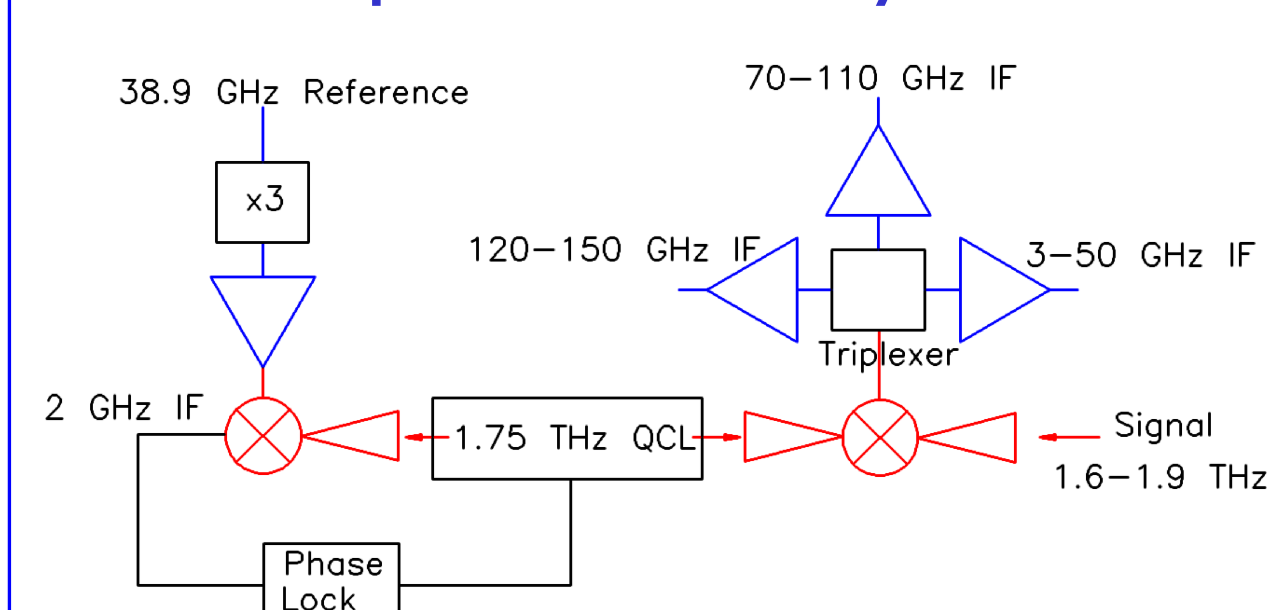
Conversion loss ~55 dB; S/N on a spectrum analyser ~40 dB 10 kHz resolution BW, 300 Hz video BW

With an LO in the 150-200 GHz range, harmonic mixing up to ~3 THz should be practical. ~1 mW of laser power is required but this can come from the unused back facet of a QCL.



Layout of the mixer block showing the added WR10 waveguide which allows low frequencies to couple from the mixer to the coaxial IF port at the top of the block. This waveguide bends away to offset it from the LO feedhorn.

Complete Receiver System



With DSB coverage, multiple lines can be covered over 300 GHz BW. This is over half of Herschel band 6 with a fixed LO.

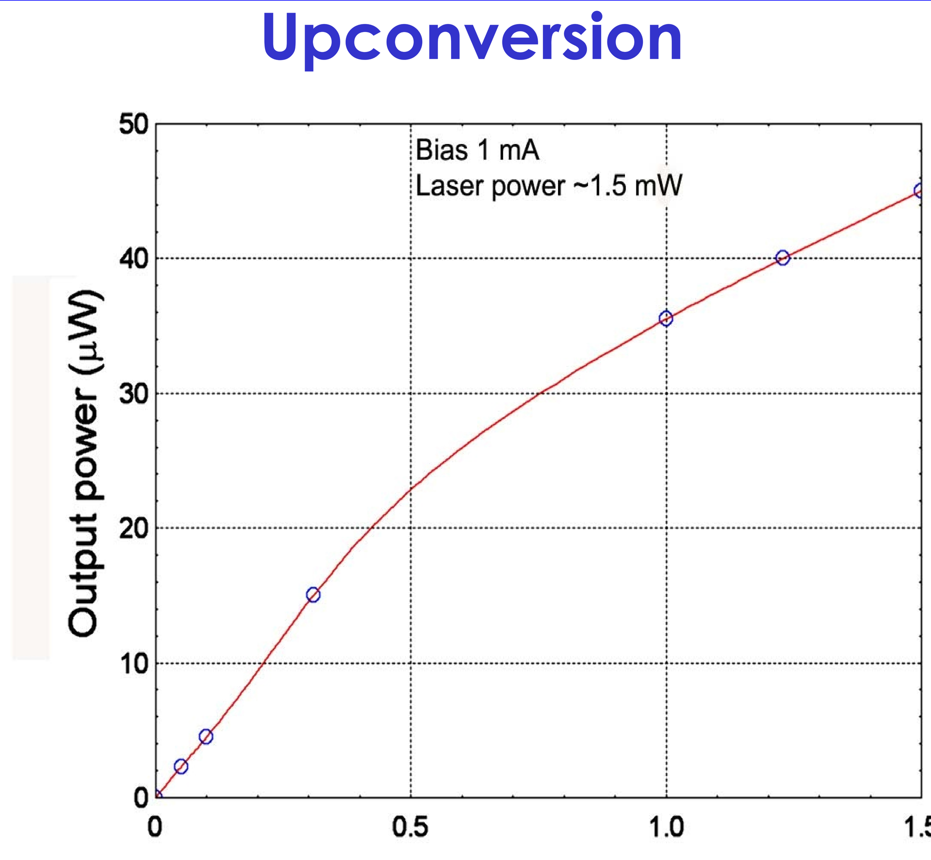
One QCL could pump 2 mixers. The IF can be multiplexed into 2 or 3 channels, with little compromise in performance. This entire receiver would operate at 20-30 K for optimum performance but QCL may operate to ~80 K. MMIC chips fabricated on same wafer for 1.5-2.0 THz band, but not tested.

Upconversion

Upconversion tests were done using an optically pumped laser at 1561 GHz, with an available power level of >10 mW attenuated to 1.5 mW at the mixer input. The IF was 10 GHz from a synthesizer. Four mixers were tested. Diodes were forward biased in operation, with the conversion efficiency rising with bias up to 1 mA (the maximum used).

With an IF power of 1.5 mW, the output power from the best device in the two sidebands is 45 µW with only 5 µW of LO feedthrough (~25 dB LO-RF isolation).

The feedthrough power was measured with the IF signal off. In tests with a similar mixer, a very narrow band FPI etalon was used to separate the LO from the sideband signals showing that there was no change in LO feedthrough with the IF applied. For two other devices taken from very nearby on the wafer, output power was within 10%, while the fourth device from another region produced only 18 µW.



Output power vs 10 GHz IF drive with laser power of 1.5 mW. Output power is compressed by ~1dB at 1 mW Diode failure is likely within a factor of 1.5 higher input.

Diodes may be added in series and using two anodes in series increases the maximum input power by a factor of four, assuming that the failure mechanism is related to power density within the device. This scaling comes about because for the same impedance level, each device can have twice the area if two devices are in series. Four-anode devices were fabricated but the anode size was only 1.5 times larger so the maximum power in this case should only increase a factor of three.

No good 4-anode devices have been found in the best wafer. A second wafer with lower doping showed significantly poorer performance in general but has some working 4-anode devices.. These 4-anode devices only produced 37 µW, but this is 3 times the power of 2-anode devices from the same wafer.

LO-RF isolation with 4-anodes is ~30 dB (2 µW feedthrough with 2 mW input). 4-anode mixers from a good wafer might produce an output power ~70 µW SSB and with a high IF, filtering to SSB should be simple.