N90-13466

Advances in SIS Receiver Technology

M. A. Frerking
Jet Propulsion Laboratory
Pasadena, CA 91109

Significant advances in SIS receiver technology since the last Asilomar meeting include: superconductor materials, integrated inductive tuning elements, and planar mounting structures. The effect of these advances is to push the upper frequency operating limit from about 600 GHz to 1500 GHz, and to enhance the feasibility of focal plane arrays of heterodyne receivers.

A fundamental high frequency operating limit of SIS mixers is set by the superconducting energy gap. The high frequency cutoff associated with the energy gap occurs when the photon-assisted reverse tunneling current is a significant fraction of the total photon assisted tunneling current. Nearly all operational SIS mixers are currently fabricated using lead alloy technology. The energy gap for these superconductors is about 2.7 meV, resulting in a cutoff frequency of about 600 GHz. Recently, fabrication techniques for SIS junctions using higher energy gap materials have been developed [1]. Niobium nitride has an energy gap of about 6 meV, corresponding to cutoff frequencies of about 1500 GHz. NbN-MgO-NbN junctions with low subgap leakage currents have been fabricated but not yet tested as a mixer. The discovery of high T_C superconductors may push this frequency limit yet higher.

A practical limitation for high frequency operation of SIS junctions is their parasitic capacitance and resistance. The performance of the mixer will be degraded by the RC roll-off. Considerable effort has been put into reducing the RC product by optimizing device geometry. The normal state tunneling resistance decreases exponentially with barrier thickness while the capacitance varies inversely so that the smallest RC product occurs for the thinnest barrier. The figure of merit typically used to describe the speed of the SIS material is the Josephson critical current density, which varies inversely as the normal tunneling resistance. High quality NbN-MgO-NbN tri-layers have been fabricated with J_C of 14 kA/cm^2 corresponding to an ωRC product of 1 at about 150 GHz [1]. This implies an ωRC of 3 at 500 GHz and 10 at 1500 GHz.

Recently, several designs have been reported for inductive elements integrated on the same substrate as the SIS junctions to tune out the bulk junction capacitance [2]. This allows high frequency operation of lower speed devices over an instantaneous bandwidth determined by the ωRC product. The integration of the tuning element onto the substrates has several significant advantages over external tuners. They can be placed close to the junction increasing bandwidth and decreasing loss. Their primary disadvantage is that they are not tuneable. With a factor 2, ωRC can be regarded as the Q-factor of the junction. Mixers with an ωRC product of 5 have about a 20% 1 dB bandwidth for a matched mixer which should be adequate for most applications.

Most millimeter SIS-based heterodyne receivers have used waveguide coupling structures. Since waveguide elements have dimensions on the order of a wavelength, they are extremely difficult to fabricate for use at submillimeter wavelengths. Further, they are hard to replicate in arrays. Several forms of planar antennas, both on thick and thin substrates, have been developed which can be fabricated using photolitho-graphic techniques, thus making them integral with the SIS junction [3]. In addition, they become readily fabricated in arrays. A SIS mixer mounted on a planar antenna has been demonstrated in the laboratory to 1000 GHz [4].

In summary, technology has advanced to the state where programs that have a high probability of success can be defined to produce arrays of SIS receivers for frequencies as high as 1500 GHz. This is in contrast to the situation three years ago, when the SIS receivers were proposed for frequencies to 600 GHz, and the heterodyne array was described as "only a hope, rather than a firm expectation."

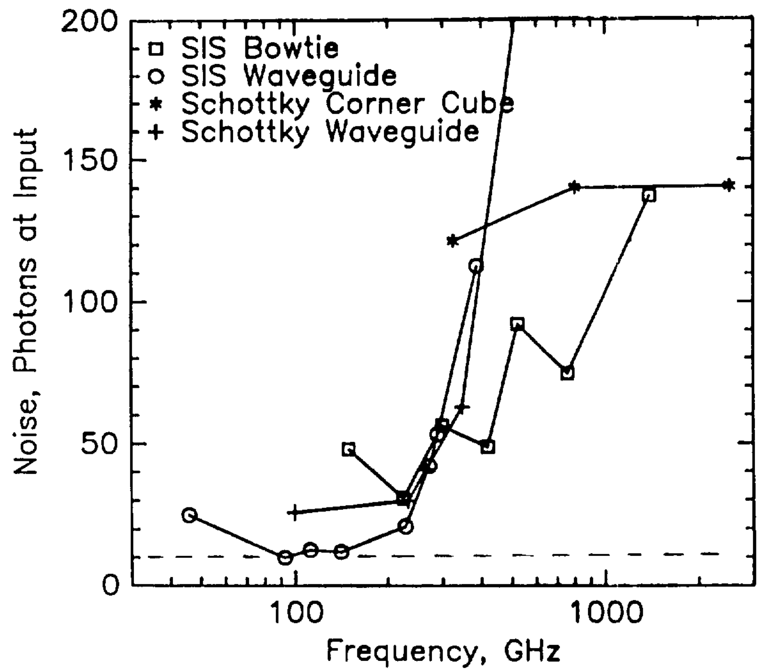

FIGURE 1. Photon Noise at Input vs. Frequency

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