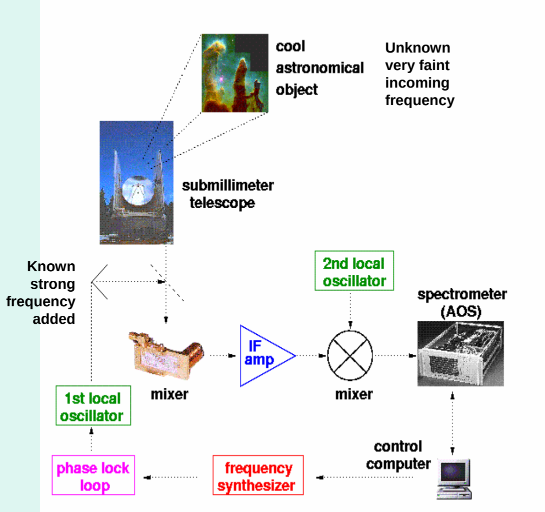
4th Floor Receiver Room

More Info Than You'd Ever Want To Know About Submillimeter Receivers

Heterodyne receivers constitute the other major type of light detector at submillimeter wavelengths. This technology stems from longer-wavelength radio observatories, where such receivers are used to the exclusion of all other techniques. Such receivers work on the same principles as your stereo AM/FM tuner, but at *much* higher frequencies and many *orders of magnitudes* higher sensitivity. In short, these receivers mix the electromagnetic field of the astronomical photons with a locally-generated electromagnetic field (called the *local oscillator*). The result is a signal at the difference, or beat, frequency. Radio astronomers call this the *intermediate frequency, or IF*. The original astronomical signal is therefore downconverted to a much lower frequency (from say, 490 GHz to 4-6 GHz), where more conventional low-noise electronics can amplify and process the signal.

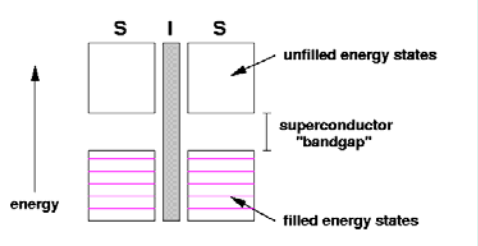
The signal at the *intermediate frequency carries both phase and spectral information* about the original astronomical signal. This means that it is fairly *straightforward to extract the* ***spectrum*** *of the astronomical source*, and the phase of the incoming light waves. The latter is especially useful for combining the phase information from several receivers on separate telescopes to create an interferometric signal. In this way, ultra-high angular resolution (and more light-gathering ability) can be obtained. This is commonplace at lower-frequency radio observatories like the Very Large Array (VLA) and has in recent years become possible at millimeter wavelengths such as at the Owens Valley Radio Observatory or IRAM's Plateau de Bure Interferometer or the BIMA array. A tantalizing prospect would be to interferometrically combine the signal from the Heinrich Hertz Telescope (HHT) of the Submillimeter Telescope Observatory (SMTO) atop Mt. Graham, Arizona with submillimeter array receivers on the dual-8.4-meter Large Binocular Telescope (LBT) to produce a good submillimeter interferometer. Long term efforts to do this on a very large scale include the SMA and the MMA. (Taken from US SORAL website: http://soral.as.arizona.edu/overview.html)



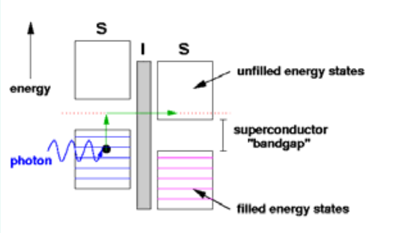
The light collected by the radio telescope is directed into a *feed horn* that deposits the energy into a "light-pipe" called a *waveguide*. The waveguide can be optimized by *tuning*, i.e. altering the electrical length of the waveguide by tuning stubs called *backshorts*. An optimized waveguide can deposit the fundamental signal mode to the *mixer* with low losses. The *mixer* couples the incoming astronomical signal with the local oscillator signal. The result is a signal at the difference frequency, which can be amplified to yield a signal that can be post-processed by spectrometers or other analysis electronics. Mixers used in SORAL receivers use the properties of superconductors (lossless conduction of electric currents) to produce the desired electrical response to incoming submillimeter light (i.e. detection of the astronomical signal). These are called **SIS** mixers, standing for *Superconductor-Insulator-Superconductor*, relating to the "sandwiching" of these elements in such a mixer.

Here's a simplistic idea of how it works: When two superconductors are separated by a thin insulator, superconducting pairs of electrons (called *Cooper* pairs) can travel readily from one superconductor to the other, since the energy levels of both superconductors are the same.

With judicious choice of this biasing voltage, an incoming submillimeter photon can induce a single superconducting electron to "tunnel" across the insulating barrier to an unfilled energy level on the other superconductor. This is perfect -- we can convert an incoming stream of photons to an electrical current across the junction. We've got an electrical signal to work with now! Life is suddenly looking good...



An unbiased SIS junction allows superconducting electron pairs to travel unimpeded across the insulating layer. Energy states are identical for both superconducting layers.



The optimal biasing level will allow a submillimeter photon of the desired frequency or energy to boost the superconducting electron to the other side of the insulative potential barrier by filling in an empty energy level in the other superconducting layer. This yields a large current flow for a photon "impact", the desired effect.

Unfortunately, the SIS junction will only work if you have those two "S's". Superconducting material with the appropriately small energy bandgaps need to be kept at "very cryogenic" temperatures; typically 4 Kelvin (!!) for niobium junctions often used in SIS mixers at submillimeter wavelengths. That's 4 degrees above Absolute Zero (-459°F), where atomic and molecular motion ceases! Higher temperatures increase thermal noise and shrink the bandgaps until, at the threshold superconducting temperature, the bandgap is zero and the junction is no longer useful. Here's a zoomed-in image of an 810 GHz mixer block:

SIS345 Receiver
made by MPIFR (Germany)

SIS460 Receiver
made by SORAL(UA)

JT Receiver
The next generation of receivers made by ARO (UA)