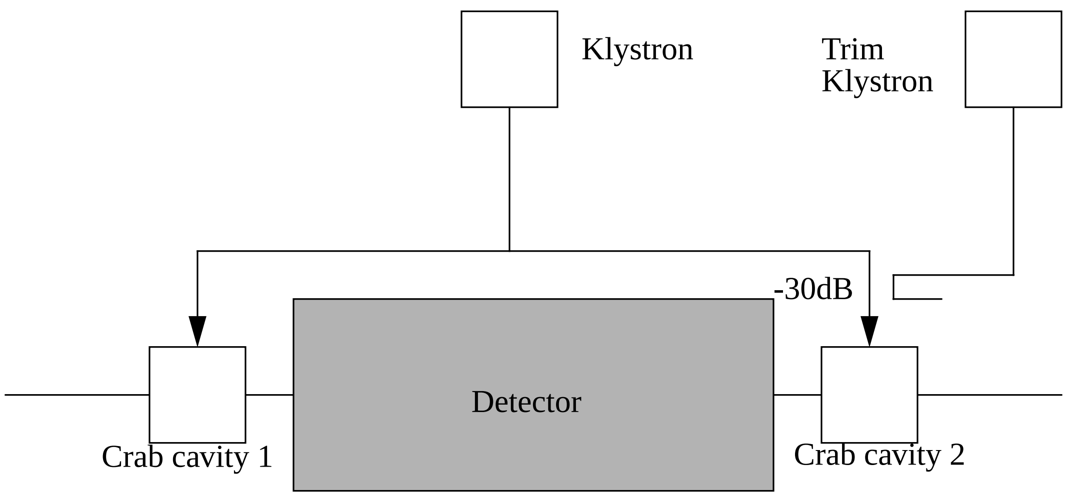
Crab Cavity Phase Noise Calculations

The NLC is considering using a pair of “Crab Cavities” to rotate the bunches at the IP and allow a larger crossing angle. These cavities must be phased relative to each other with very high stability. Slow drifts can be measured with the electron beam, and corrected with feedback. Pulse to pulse jitter in measurement, and in the cavity drive are a potential problem. We try to estimate the size of these effects.

The crab cavities can be designed for either S-band or X-band. Use of S-band will reduce the problems caused by wake fields in the small irises of an X-band cavity. We will assume S-band here as the phase tolerances are more difficult to meet for this case.

Drive System: We are considering a drive system where the two cavities are driven from a single klystron. The power is split and transported using waveguide. Relative phase adjustments between the cavities are made with a second RF source, (probably also a klystron) a small fraction of whose power is sent to one of the cavities. This power is used to make small changes to the relative phases and amplitudes.



Jitter Requirements: Note that all jitter requirements are from the NLC ZDR. The amplitude jitter requirements are ~6%, and should be easy to obtain. The common mode phase jitter tolerance is 0.5 degree. The differential mode phase tolerance is the most difficult specification at 0.05 degrees S-band. It is this tolerance that we will consider.

Drive Jitter: In the absence of an arcing, with the two cavities driven by the same Klystron, any phase jitters are presumed to be due to path length changes in the drive waveguide.

0.05 degrees S-band corresponds to a waveguide length change of about 15 microns. This is much larger than the stability tolerance for the magnets in the final focus, and should not be a problem.

Changes in the shape of the S-band waveguide can change the propagation velocity, and therefore the output phase. The length of waveguide from the klystron to each crab cavity is estimated to be about 40M. This means that a change in propagation speed in the waveguide of $3x10^{-7}$ corresponds to the allowable phase shift. This is roughly equivalent to a change in the dimension of the waveguide of 30 nanometers.

Measurements on standard SLAC waveguide (performed before SLAC was constructed) showed approximately a 2 degree S-band per Meter-Atmosphere shift with atmospheric pressure. This would indicate that an atmospheric pressure change of 1/2000 atmosphere would cause an unacceptable phase shift. Static pressure shifts would be corrected by slow feedbacks, so acoustic noise provides the primary source. This pressure change corresponds to an acoustic noise level of approximately 130dB, much higher than expected. The range of frequencies of interest is probably from a few Hz to about 100Hz. Frequencies higher than this will have several wavelengths within the length of the waveguide, and lower frequencies will tend to not provide differential effects, and will be attenuated by feedback. Note that thicker wall waveguide can be used if these effects become significant.

The phase trim klystron is coupled with a -30dB coupler. This allows a maximum fast phase control of about +/-2 degrees. Noise on this klystron will have only a small effect on the output phase due to the attenuation.

Phase Measurement Jitter: In order for the feedbacks to operate, it is desirable to be able to measure phase jitter between the cavities on a pulse to pulse basis. We now consider the problems associated with measuring a S-band phase difference to 0.05 degrees.

We assume the use of a mixer to measure the phase difference between the two cavities. The cables / waveguide from the cavities to the mixer will be subject to the same noise limitations as the power waveguide.

Typical mixers operate with input levels of approximately 0dBm, with a conversion loss of about 6dB. The required detection bandwidth is approximately 10MHz. In that bandwidth, thermal noise in a 10MHz bandwidth is -98dBm. If we allow an amplifier noise figure of 6dB, we are left with a signal to noise of 86dB. This is sufficient to detect phase shifts of 0.003 degrees.

Prototype: Although the drive and detection problems seem practical, it may still be interesting to construct a prototype system. Effects from either high power, or possibly vibrations due to water cooling could be an issue. In addition a prototype would allow checking for unforeseen problems. A prototype using high power components, but operated at low power could be constructed first. This system could be connected to high power klystrons as a second stage test.