THz Sensitivity Characterization of a $LiTaO_3$ Pyroelectric Detector

Write-Up Questions for Laboratory Project
(due by 5:00 PM local time, 10 December 2008)

A **Water Grey Bodies in NEΔT Set-Up**

1. In class we discussed the Debye Model for the dielectric function of water and mentioned that the "double Debye" is significantly more accurate than the "single Debye" at frequencies approaching 1 THz and above. Write a short script using Excel, MATLAB, or the numerical tool of your choice to compute the real and imaginary parts of the dielectric function of pure water between 100 GHz and 10.0 THz. Plot these together and include in your write-up.
2. Use the results of 1 to estimate the reflection coefficient and emissivity of our grey bodies consisting of pure water in a low-density polyethylene (LDPE) wash bottle. Assume the dielectric function of LDPE is 2.3 + 0.0j, and apply Kirchoff's radiation law on the two interfaces: air-to-LDPE, and LDPE-to-water. Assume the radiation is always at normal incidence to simplify the calculation.
3. Find the average emissivity between 0.1 and 3.0 THz, which is roughly the range of transmission of the black-polyethylene filter used to block the background infrared.

B. **Calculation of NEΔT**

4. Use the results of 2 above to calculate the apparent brightness temperature of the two grey bodies used between 0.1 and 3.0 THz.
5. You made measurements of the magnitude of the signals from chopped grey bodies (water in LDPE wash bottles) at two temperatures. What is the relationship between the LIA magnitude and the peak-to-peak value you would see feeding the same signal into an oscilloscope (assuming the chopper induces a sinusoidal modulation of the grey-body emitted power) ?
6. You also measured the the in-phase (x_I) and quadrature (x_Q) components of electrical noise with the detector blocked. Use these values to calculate a value that can be compared to the signal value from 5 (assume that the electrical noise is Gaussian).
7. From 4, 5, 6 and the definitions given in class, convert your data to an estimation of NEΔT'.

C. **Coherent THz Source in NEP Set-Up**

8. The NEP set-up uses a frequency extension module (FEM) with 600 GHz output frequency radiating through a pyramidal feedhorn known to have a nearly symmetrical beam with a directivity of 26 dB. Find the beamwidth β (FWHM) using the "ice-cream-cone" approximation.
9. Derive an expression for the equivalent TEM_{00} Gaussian beam using the diagram in Fig. 1 and requiring that the half-intensity points coincide.
10. Use the equivalent Gaussian beam to calculate what fraction of the incident power is intercepted by the pyroelectric detector of diameter D (assume the pyroelectric detector has a diameter of 5.0 mm)..

D. **Calculating the Optical NEP**

11. From the calculations in C above, calculate the optical (i.e., external) responsivity at 600 GHz assuming the beam from at the mouth of the FEM feedhorn is much smaller than the chopper-blade opening, so that the modulated FEM power can be assumed to be a square wave, and assuming a peak FEM power of 1.0 mW.

12. From the I and Q noise measurements using the LIA in the NEP set-up, estimate the NEP' using the definition NEP' = $X'_N / \Re_X$, where X'_N is the rms electrical noise per $Hz^{1/2}$ and $\Re_X$ is the optical responsivity, both measured right after the transimpedance amplifier.

E. **Comparison of NEΔT and NEP**

13. In class we stated that in the RJ limit NEΔT ≈ NEP/($Mk_B\Delta\nu$), where M is the number of spatial modes accepted by the detector and $\Delta\nu$ is the spectral (THz) bandwidth centered about the frequency ν_0. From the packaging diagram displayed in Fig. 2 for the pyroelectric detector in the TO-5 can, estimate the angular field-of-view, $2\theta_M$, and the associated beam solid angle Ω_B.

14. From 13 write an approximate expression for the number of spatial modes as a function of frequency, and calculate the number of spatial modes M accepted by the pyroelectric detector in its TO-5 can at 600 GHz.

15. Use M to estimate the NEΔT' from the NEP' measured experimentally. How does this derived value compare to the experimental value from Part B ? If significantly different, comment on possible reasons for the discrepancy (e.g., systematic errors the experiments, etc).

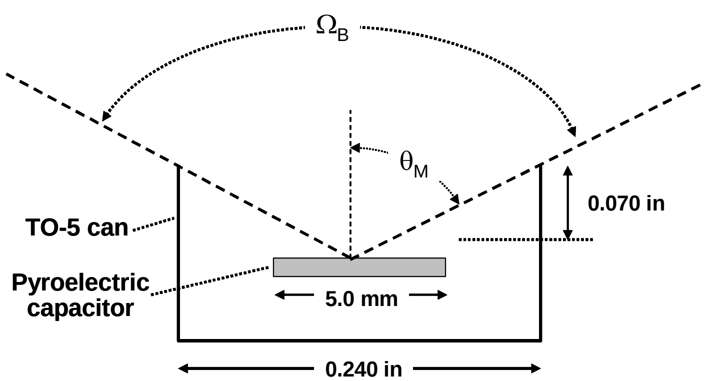

Fig. 1

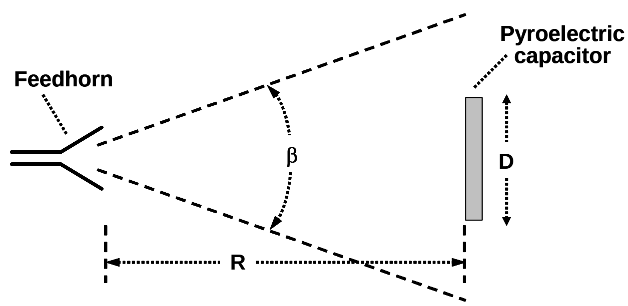

Fig. 2