CMB Pre-Lab

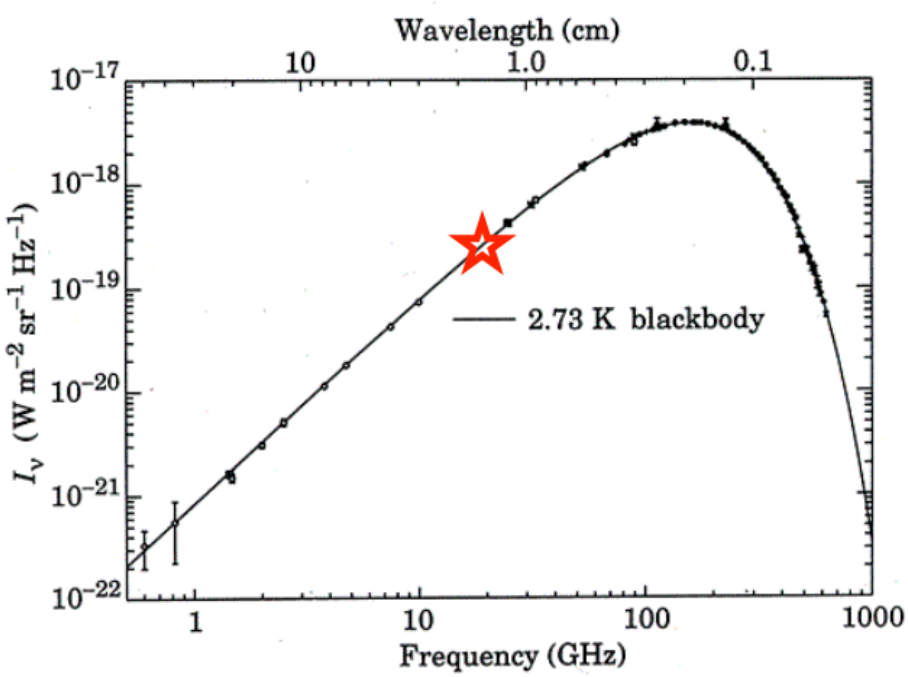
Show your calculations. Hand in your work on part 2 at the beginning of class. Part 3 may be done in-class on the first day of your class.

Part 1: Preparation

Read the CMB Guide through page 8.

Part 2: Estimating CMB power in a bandwidth

Imagine you are in space so that there is no interference from other signals nor from the microwave emission from the atmosphere. You want to measure the CMB blackbody at some frequency in some bandwidth. The first step is to estimate how much power (in watts) you must measure. This will depend on frequency, your antenna, and the bandwidth over which you integrate the CMB noise power. The figure below shows the CMB blackbody spectrum in suitable power density units: watts per square meter per steradian per Hz. Assume your measurement will sum the noise power over some band centered on 19 GHz (the red star).



The intensity spectrum of the CMB.

Assume that the total bandwidth at 19 GHz that you can use is 500 MHz wide. The amount of the CMB that you can intercept depends also on the effective aperture of your antenna and the amount of sky its directional beam "sees.". Assume that your antenna has an effective capture area of 400 square cm, and a beam covering 100 square degrees of the sky.

Using these parameters for your microwave receiver, estimate the power in watts that you must measure on its output. For simplicity assume all the CMB power captured by your antenna in that bandwidth appears on the output of your receiver.

Show your reasoning and show your calculations. Discuss your estimated power level and how you might measure it. Suppose you send the microwave output of your receiver through a diode (which squares the radio frequency signal creating a DC signal). Imagine hooking the diode output to a 50 Ohm resistor and then measuring the voltage across it due to the CMB power from your receiver. Roughly what is that voltage and can you measure it with the test equipment you have been using in the lab? Discuss.

Do this calculation over for the same setup but now with one change: assume that you amplify the microwave power in your receiver by a factor of 200,000. What is the power level you must measure now?

Part 3: Two-horn beam pattern measurement

In this CMB experiment you will be using a special microwave horn which is very directional: very little response to signals arriving off-axis. In order to get some familiarity with this, we have a small microwave dual horn lab setup you may use in this prelab.

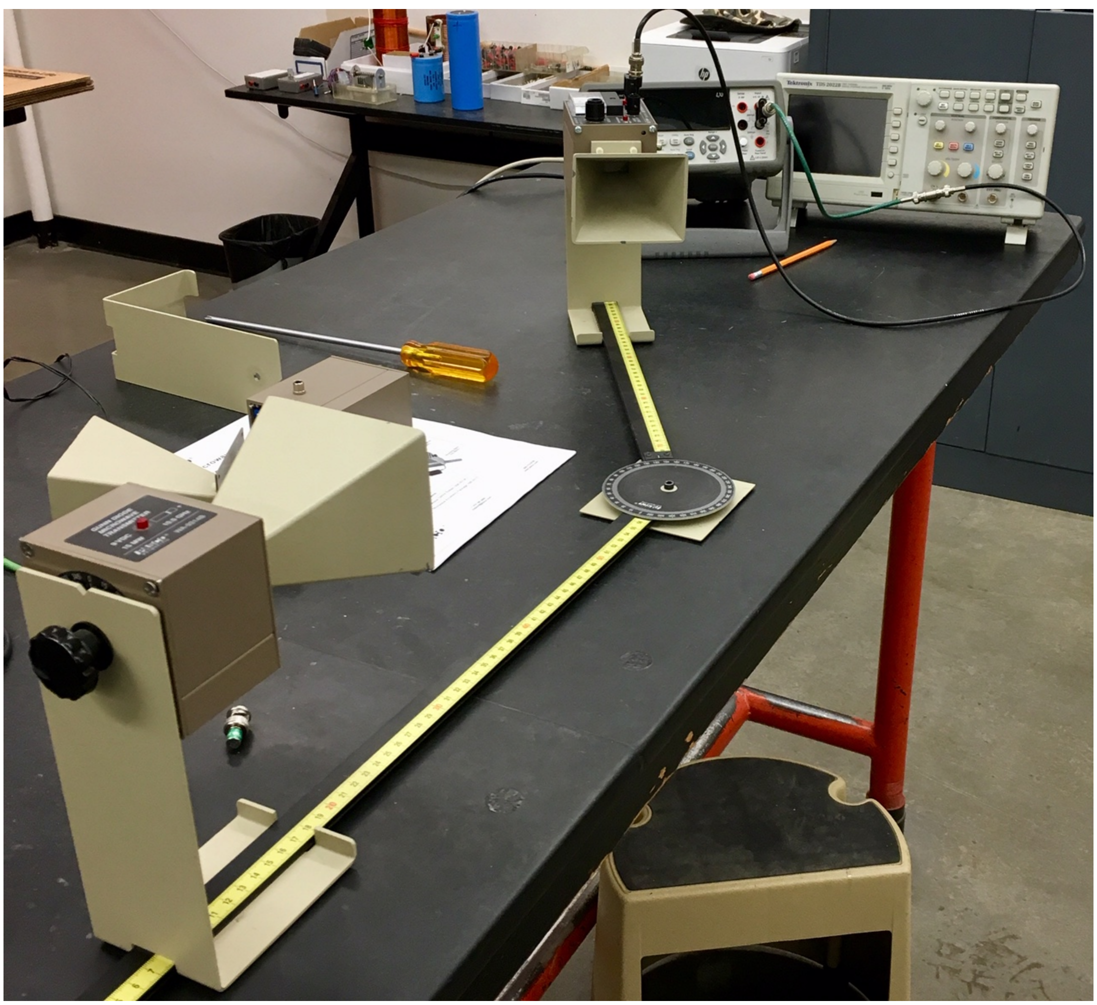
The two small horns, shown on the next page are identical but the electronics attached differs: one horn has a 10.5 GHz transmitter attached, and the other horn has a 10.5 GHz diode receiver and amplifier attached. The horns are mounted on a goniometer with degree scale which allows you to change their relative angle, as shown in the photo.

Plug the power connector into the bottom of the transmitter. The receiver is battery operated: its power is turned on via the rotary switch on the top. Note that switch has several gain settings for the internal amplifier. The highest gain is fully clockwise. The labels are a bit confusing: Highest gain G=30 is fully clockwise (to the right), marked "Mult 1". Lowest gain (lease sensitive) is counter-clockwise G=1 "Mult 30." You will start in this lowest gain setting, with the horns pointing directly at each other [goniometer angle 0 deg]. Play around with goniometer angles and gain settings.

You actually cannot rely on the meter on the top of the receiver for the low level measurements you need. The receiver has a plug on top which is the voltage output of the amplified diode signal. Plug this DC receiver output into an oscilloscope and an integrating voltmeter [Agilent 34410A]. Note the erratic signal on the scope. Sync the scope to the AC line to see if it is AC pickup. Experiment with schemes to reduce this interference pickup. What if you turn off the fluorescent lights? You will need to measure one millivolt at the highest gain and largest angle.

So you need to average the noisy DC voltage. Pushing the right button on the 34410A increases the averaging time and the number of significant figures. In order to measure the beam profile of the receiver horn, you will have to take readings of the receiver output voltage which is proportional to the microwave power in the receiver. Start at 0 deg and gain 1, because the signal is very strong. Make sure there is nothing nearby which can reflect the off-axis beam power from the transmitter into the receiver horn! Try sheets of Eccosorb microwave absorber. As you move to larger angles you will find you must increase the gain. Take data from 0 deg to 40 deg in 5 deg increments. Make a table of gain times your voltmeter reading and the angle.

Plot ten times log_10 of the diode DC voltage (your voltmeter measurement times the gain) vs the angle in degrees. This is the beam response in decibels (dB) vs angle.



The 2-horn microwave setup using your test equipment.