Exam Basic Detection Techniques 2021

Thursday, Nov 4, 15-18h KB 161

Books, lecture notes, other written material, a laptop or other electronic device in "flight mode" (no internet access)and a calculator can be used. There are questions on the 4 subjects that have been discussed in class. The number of points per subject is 2,5. The final mark will be the total number of points.

Please give the answers of the 4 questions on 4 (or more) separate pages, so that we can distribute them easily to the lecturers for grading. Do not forget to put you name on each sheet of paper.

Question 1: Submm technology.

Full Body Video Scanner


(reproduced from Wikipedia)

A PhD student was asked to evaluate if a single pixel mechanical scanner can be used for concealed weapon detection using 5 Hz frame rate imaging. The system uses a 1 m diameter mirror at a stand-off distance of 5 m, installed behind Goretex membrane, that is transparent for submm radiation. People are slowly coming through a door 2m high and 1m wide.

A heterodyne radiometer working at 1 mm wavelength with system noise temperature of 150 K and 10 GHz IF bandwidth is used for detection.

System needs to have S/N=50 for an automatic detection. Assume that a typical human has a brightness temperature of 36 C on top of 18 C room temperature background. The weapon has 18C brightness temperature, because it reflects the background.

1) Using telescope angular resolution λ/D multiplied to the distance to target, estimate spatial resolution of the system and amount of pixels per image frame.
2) Using scanning rate and amount of pixels per frame calculate required integration time per pixel. Calculate achievable integration time per pixel for heterodyne system for required S/N. Compare the required and achievable integration times. Make conclusion on feasibility.
3) Compare system noise temperature of the system with quantum limit. What is the theoretical limit of integration time for this system in this application?

Question 2: Particle detection.

A cylindrical proportional tube has an anode wire radius of 0.003 cm and a cathode radius of 2.0 cm. It is operated with an applied voltage of 2000 V.

- If a minimum electric field of 1 MV/m is required to initialize gas multiplication, what fraction of the internal volume of the tube corresponds to the multiplication region?
- Assuming the given geometry of the detector, and that the multiplication is 1000, how large signal (in terms of collected charge) will be induced by a minimum ionizing particle (e.g. electron) which is crossing the detector perpendicularly to the cylinder and along the diameter. Consider that the detector is filled with air at the pressure of 1 bar (W_{air} = 33.8eV/ion pair, density 1.225 kg/m^3).

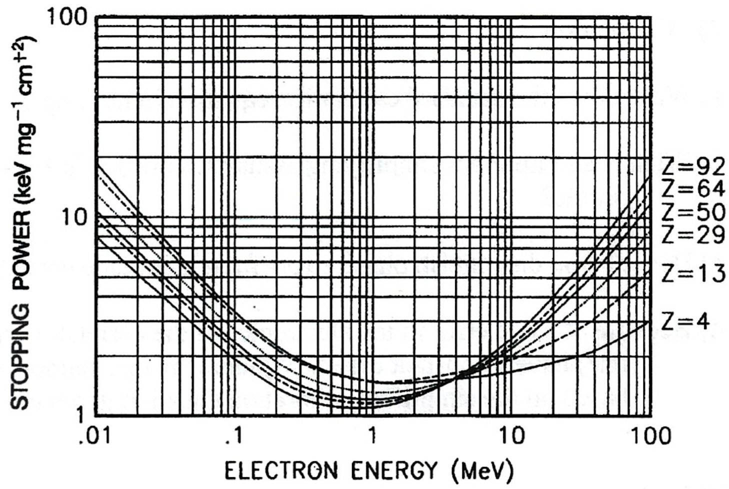

Figure 7-10 Stopping power of electrons in the energy range from 0.01 MeV to 100 MeV for a number of elements. For low-Z substances, dE/dx is almost constant between about 0.5 MeV and several MeV. The rise of the curves at high energies is due to increasing bremsstrahlung probability.

Question 3: Radio Astronomy and Interferometry

1) Geometry

Because of the low transparency of the atmosphere at high frequencies, astronomers are designing a sub-mm telescope to be launched into space. It will operate at 1 THz (1000 GHz).

a) What should the dimensions of the dishes be in order to be able to image fields 1 arcminute in size?

b) How long should the longest baselines be to get to 1 arcsec resolution?

c) Like all interferometers, fringe stopping (also known as delay tracking) must be done. Explain why this is not the case if the telescopes would all fly in the same plane perpendicular to the line of sight to the source.

2) Calibration

a) Write down the standard calibration equation in its simplest form

b) What is an important simplifying assumption which is always made to make this equation more usable?

c) How do you distinguish phase errors from amplitude errors?

d) Because of some error in the electronics of the correlator, the visibilities on one baseline (and only one) have a constant offset. Explain why one cannot correct the data using selfcalibration based on the simplified calibration equation given in b).

3) Basic interferometry

a) Make a drawing of how the signals of two dishes are combined in a monochromatic interferometer.

b) Explain what is the geometrical delay between two dishes. Indicate in the drawing you made for a) what causes this delay. Write down the formula to calculate the geometrical delay.

c) During an observation, because the source moves along the sky due to the rotation of the earth, the geometrical delay changes with time. How do you compensate for this changing geometric delay in the interferometer? Indicate in the drawing of a) where this happens.

d) In principle, for a monochromatic interferometer, if you would not compensate for the changing delay, you would still get a useful signal. However, for interferometers observing over a non-zero bandwidth, this delay compensation is necessary otherwise the signal would be affected. Explain why.

e) The output, averaged over a single sampling time of, e.g., 10 seconds, of the interferometer you have drawn in a) is a single number. However, visibilities are complex quantities, i.e. they have amplitude and phase (i.e. two numbers). What do you have to do to be able to derive the amplitude and the phase from an observation?

Question 4: Optical and infrared detection.

a) What is the purpose of the slit, the collimator lens (or mirror) and the imaging lens (or mirror) in a standard reflecting grating design.

b) Explain in a few words what the advantages are of a reflective blazed grating as compared to a transmission grating.

c) What is the purpose of cooling semi-conductor detectors and why is it difficult to make very long wavelength (>100 μm) semi-conductor photo-diodes.

d) Explain in words why semiconductors photo-detectors are elements from group IV of the periodic table, or combinations of group III,V or II,VI.

e) Show (with some simple math) that the antenna theorem, that relates wavelength, beam solid angle and aperture size follows (approximately) from the FWHM beam size that follows from diffraction theory of a circular aperture (and the beam solid angle you can calculate from that).

f) The PSF at wavelength λ in the focal plane of a of a diffraction limited telescope with diameter D and Focal Length F is highly oversampled with N pixels sampling the central part of the Airy disk. The angular resolution of this system is R (arcsec), and the plate scale is P (arcsec/mm). How many pixels are needed to sample the central area of the airy disk, what is the plate scale (compared to P) and what is the angular resolution (compared to R) if I:

- increase the diameter of the dish to $D\times\sqrt{2}$, without changing the focal length
- increase the diameter of the dish to $D\times\sqrt{2}$, and also change the focal length to $F\times\sqrt{2}$
- with the original D and F, increase the wavelength to 1000 nm.

g) With beam shaping one can make the field coupling on a telescope aperture to be gaussian. This results in low sidelobes, since the far-field of a gaussian distribution is also gaussian. What would be the disadvantage of doing this, as compared to a full plane wave illumination that results in the Airy disk with rings and sidelobes.

h) Compute the S / N obtained for an astronomical source in a CCD image with an exposure time t = 3600 sec. The CCD has a gain of 3 -e /ADU, a read-noise of 10 -*e* ,and a dark rate of 20 -e /pix/hr. The sky background level is measured to be 800 ADU, by averaging the pixel values in an annulus of blank sky around the object of interest with an inner radius of 20 pixels and outer radius of 40 pixels. The signal due to the source, measured in an aperture of radius 5 pixels, is found to be 7000 ADU (by subtracting background from source+background). How does the S/N change if the exposure time was increased to 7200 sec.