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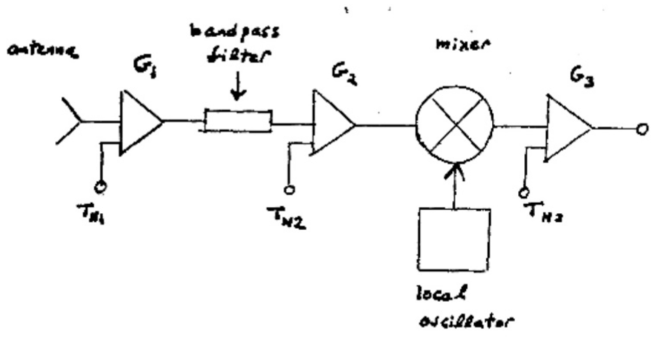
AA674N – Assignment 6

May 30, 2020

1. Electromagnetic radiation is emitted from a distant object with a frequency of 1.4 GHz.
   a) What is the corresponding wavelength?
   b) Which band of the EM spectrum this belongs to?
   c) Suppose a radio telescope of diameter 25 m is constructed to detect this signal. What will be the resolution of such a telescope?
   d) What is the effective area of the telescope?
   e) The telescope is located at latitude of 34° N and the source emitting the signal is at declination of 30°N. Will the source pass through the zenith?
   f) Should the observers be looking towards the south or north from their position in order to watch the source transit? What will be the value of the Hour Angle of the source during transit?
   g) The size of the radio source emitting the signal is found to be elliptical with a major axis of 0.3° and a minor axis of 0.1°. What is the solid angle of the source?
2. A radio observation at a wavelength of 6 cm yields the determination that a particular radio source has a solid angle of 7.18×10^{-6} sr and has a flux density of 350 Jy.
   a) What is the temperature of the radio source?
   b) What is the intensity of this source at 2.7 cm?
3. Two radio telescopes, A and B, with perfect reflectors are identical in every regard except for their diameters and observing wavelengths. Telescope A has a diameter of 5 m and detects radiation at wavelength of 2 cm, while Telescope B has a diameter of 10 m and detects radiation at wavelength of 6 cm. If these telescopes are used to observe radio sources that are both known to have flux densities of 1 Jy at the observed wavelengths, and the telescopes use the same bandwidth, compare a) the power collected and b) the resolution angles in these observations.
4. Below is a block diagram of a simple radio receiver.



Courtesy: G. B. Taylor

The antenna temperature is 10K. The characteristics of the receiver are as follows:
G1 = 25 dB, T_n1 = 50 K
G2 = 25 dB, T_n2 = 250 K
G3 = 80 dB, T_n3 = 250 K
Bandpass filter frequency range 4990-5000 MHz
LO frequency 4950 MHz.
Assume (incorrectly!) that the mixer and bandpass are lossless components.
(a) What is the receiver temperature? (b) What are the contribution of the second, and

third stage amplifiers to the net receiver noise temperature?
(c) Draw the spectrum (accurately) of the signal that would be measured at the output of amplifier 3. This drawing should have properly labeled axes and the right numerical values should be provided (power in W/Hz vs frequency in MHz).

5. A Haystack Small Radio Telescope has a diameter of 2 m and can observe at a wavelength of 21 cm with a maximum bandwidth of 1.5 MHz. Assuming that it has the optimum edge taper, calculate the following:
   a) The angular resolution,
   b) The maximum collecting area,
   c) The maximum detected power from a 1 Jy source located at the peak of a sidelobe.
6. Two radio antennas located along the Earth's equator are separated by 30.0 meters and observe at a wavelength of 6.00 cm a source on the celestial equator and at an hour angle of 1 h.
   a) What is the time delay of a wave front's arrival at the more distant antenna relative to the closer antenna?
   b) What is the phase difference between the parts of the same wave entering the two antennas?
7. If the calibrated response of the two element multiplicative interferometer (discussed in problem 5) is given by : $R = F_\nu \cos\left(2\pi \frac{b}{\lambda} sin(\omega_E t_{HA})\right)$, where flux density of the source F_ν = 3 Jy, $\omega_E = 7.29 \times 10^{-5}$ radians/s = angular rotation rate of the Earth,
   a) What calibrated value is measured by the two antennas acting as a multiplicative interferometer?
   b) What are the amplitude and phase of the detected fringe?
   c) How long must we wait to measure one full oscillation of the fringes?

8. In continuation with the interferometer discussed in the last problem, imagine that the phase centre was chosen to be the sky position currently located 14.98° to the west of the zenith.
   a) What is the phase of the fringe function in this measurement? What are the visibility amplitude and phase?
   b) The phase centre is adjusted to be the location of the point source. How does the visibility change from what it was in (a)? If the visibility contains information about the source, why can our visibilities in (a) and (b) differ when observing the same source?
   c) If the same observation as in part (b) is made on two more baselines, of lengths 10.0 m and 40.0 m, calculate the visibility amplitudes and phases in each of these two measurements.
9. The radio galaxy Cygnus A contains two especially bright points of radio emission separated by about 0.71 arcmin. Imagine you set out to build your own interferometer to observe at a wavelength of 6.00 cm and decided to use this bright radio galaxy to test it out. Over what range of baselines should you make observations of Cygnus A to be able to measure the angular separation between these two points?

10. The rate of change of the fringe phase angle is commonly called the fringe frequency and is defined (in radians/s) by $\frac{d\Phi}{dt} = \omega_F$. It is given by $\omega_F = \pm\omega_E \frac{b}{\lambda}(cos\gamma\ cos\delta \cos \omega_E t_{HA})$
    Where $\omega_E = 7.3 \times 10^{-5}$radians/s is the angular rotation frequency of the Earth, γ is the north-south tilt of the baseline ($\gamma = 0\ means\ purely\ E - W\ baseline$), δ is the declination of the source and t_{HA} is the hour angle in seconds.

    A pair of antennas are aligned in the east–west direction to be used as an interferometer with a fixed baseline, b.

a) The antennas are pointed at OJ287, a well-known, bright, point source whose equatorial coordinates are α = 08 h 54 min 48.86 s and $\delta = +20^\circ\ 06'\ 30''.6$ (J2000).* At the time of the observation, OJ287 is at an hour angle of +2 h. Observing at a wavelength of 1.35 cm, we obtain a cross-correlation, and find the rate of change of the phase to be −0.432 radians/s. We can use these data to measure the baseline length; what length do we infer?

b) After the baseline is measured, we use this interferometer to observe a new source, with coordinates α = 13 h 24 min 12.09 s, $\delta = +40^\circ\ 48'\ 11''.8$ (J2000). The measured fringe frequency is +0.288 radians/s. What was the hour angle when we observed this new source?

11. The Sub-Millimeter Array (SMA) in Hawaii is composed of eight 6-m dishes, while the Very Large Array(VLA) in New Mexico has twenty-seven 25-m dishes. Which array would benefit more from the addition of another dish? (Hint: Calculate percentage increase in baselines.)

12. We learn of a new radio source reported to have an angular size of approximately 3 arcmin with a brighter central core component of about 5 arcsec. To obtain a reasonable map of this source at 1.35-cm wavelength, what baseline lengths should we use?